ABSTRACT BOOK

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1. Mines, Mining and Mining heritage

O89 - Mining, metallurgy and urbanisation

1. Mines, Mining and Mining heritage

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Abstract text: The High Middle Ages, from the end of the 12th century, was a period of advances in metal extraction techniques. But a change was also taking place in many other areas of society. One such change was evident in medieval urbanisation. Central places had indeed existed before, but now central places were created that acquired special privileges and which laid the foundation for modern urban institutions and governance. The towns or cities were active participants in this societal development. The kingdom’s governance, moreover, acquired new forms.

As the economy changed so the central power grew correspondingly dominant and influential. The development of mining and metallurgy and the demand for metals in many different areas of life were part of this tendency. That the links between mining and metallurgy and the urban centres were important appears, not least, from the geography where this occurred.

Methods: In the historical literature, the emergence and development of the towns in central Sweden during the Middle Ages is linked to the growth of mining and metalworking. This may also apply to certain towns outside central Sweden. The inventory of the remnants of iron and copper extraction provides additional important material for discussing the role these factors have played in the development of urban centres.

Results: For the urbanisation process in medieval Sweden, the 13th and early part of the 14th century play a key role. Central places of different types have – it is true – existed prior to this period but what happens is that certain of these centres now acquire a formal status and defined rights in relation to their hinterland. This occurs at the same time as the governance of the kingdom assumes new structures that offer new scope for controlling and directing – in some sense – what happens in the kingdom of Sweden. The oldest town privileges preserved, down to our own time, date from 1284 and 1288. There was a strong German influence, primarily from Lübeck. Merchant families from there were indeed actively involved in the Swedish copper mining operations.

Conclusions: When the urbanisation process in Sweden is viewed as a whole, it is indeed striking to see how far this process and the development of mining operations are tied to one another.

O100 - Early mining in the Bergslagen region – or Garpenberg, the exception that breaks the rule

1. Mines, Mining and Mining heritage

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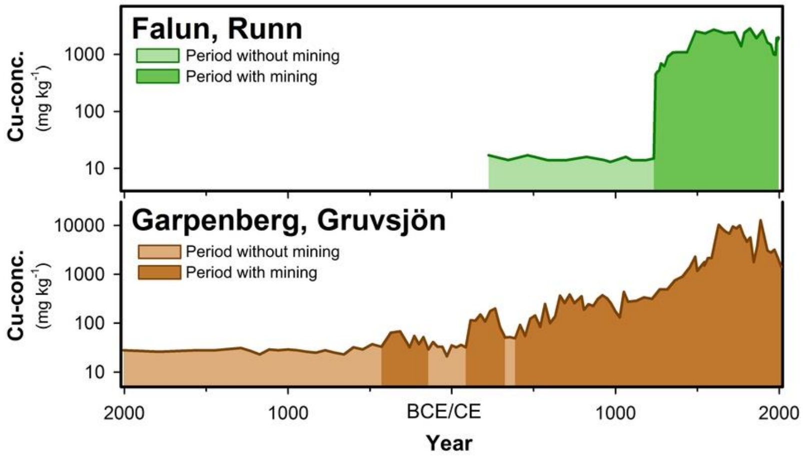
Abstract text: During historic times, Bergslagen stood out as one of Sweden's foremost mining regions, and it is nearly impossible to overstate the significance of the mines in Falun and Sala for the development of the Swedish nation. Based on written documents and archeological evidence, it is well established that mining in Bergslagen was thriving by the late 1200s, but determining when the mining actually started is challenging. The nature of mining, i.e., the gradual expansion of a cavity, means that traces of the earliest activities often are destroyed by later activities.

A complementary approach to study early mining involves utilizing lake sediments or peat records. These natural archives preserve a continuous record of all activities that have occurred in their vicinity, including traces of early mining and metallurgy. Over the last two decades, we have collected sediment profiles from lakes across the Bergslagen region. In nearly all sites, e.g., Norberg and Falun, the earliest traces of mining can be dated to the 1100s-1200s, aligning with existing evidence from archeological investigations (e.g., the blast furnace at Lapphyttan). However, there is one exception to this general "rule" – Garpenberg.

In a sediment record from Gruvsjön – the lake adjacent to the historic mine in Garpenberg –Cu, Zn and Pb concentrations begin to increase already during the Pre-Roman Iron Age, around 400 BCE. The levels of mining-related metals experience another increase around 115 CE, and again from 400 CE onwards. By approximately 700 CE, Cu concentrations are more than ten times higher than the pre-mining background. In Finnhytte-Dammsjö – the lake upstream of Gruvsjön – Cu and Pb concentrations increase from around 400 CE. Although being approximately 800 years later than Gruvsjön, it still precedes the general trend for Bergslagen by about 700 years. Interestingly, these findings corroborate the description in the mine map from 1769, which puts the origin of the mine in 'pre-Christian times' (hedna tider) based on oral tradition.

Our findings prompt some questions. Was Garpenberg the sole site in Bergslagen where mining commenced this early? Where did the copper produced in Garpenberg go? Answering the initial question requires further sediment studies in other potential locations. For the second question, it would be necessary to study the chemical composition (e.g., Pb-isotopes) in copper artefacts from different time periods. Earlier studies have shown that no "Bergslagen-copper" is found in Bronze Age artefacts, but what about copper artefacts from Iron Age and medieval times?



Falun, Runn
Period without mining
Period with mining
Cu-conc.
(mg kg-1)
1000
100
10
Garpenberg, Gruvsjön
Period without mining
Period with mining
Cu-conc.
(mg kg-1)
10000
1000
100
10
2000
1000
BCE/CE
1000
2000
Year

O101 - Prehistoric Ore Mining in Transylvania – The Mining District of Vâlcoi-Corabia, Bucium

1. Mines, Mining and Mining heritage

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Abstract text: The Carpathians is one of the richest regions in European prehistory. Large quantities of bronze, copper and gold were deposited in numerous hoards and yet represent only a fraction of the material that was once in circulation. Despite rich deposits, mainly in the Romanian Carpathians, there is still no direct evidence of an independent primary production of metal during the Bronze and Iron Age (Boroffka, 2009).

Alpine copper seems to have been the basis of the Carpathian metal industry until the Middle Bronze Age (Pernicka et al., 2016). With the beginning of the Late Bronze Age, however, indirect evidence of an independent primary production of copper can be found in Transylvania. Large quantities of raw copper must be regarded as products of this production. Alpine mining equipment, which appears together with other features of alpine traditions, allows the conclusion that the now tangible mining operations are connected with a transfer of technology that was carried out by alpine specialists (Thomas, 2014; 2022).

In the frame of the project "Copper and Gold - Ancient Ore Mining in Transylvania", a cooperation between the Muzeul National al Unirii Alba Iulia and the Deutsches Bergbau-Museum Bochum has now succeeded for the first time in providing direct evidence of prehistoric ore mining in the Romanian Carpathians. Within a Roman gold mining district, which can probably be identified with the ancient *Alburnus minor* (Ciugudean, 2012; Ciugudean & Thomas, 2020), there are mining structures that can be dated both relatively and absolutely to the pre-Roman Iron Age. Together with characteristic stone tools of alpine character, these findings not only confirm the transfer of alpine technology to mining sites in the Carpathians, but also the continued application of the introduced techniques until at least the Iron Age.

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O102 - The beginnings of metal mining and metallurgy in the Alto Guadiato and Los Pedroches valley (Córdoba, Spain)

1. Mines, Mining and Mining heritage

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Abstract text: Traditionally, two large metallurgical centers in the South of the Iberian Peninsula have been studied, being the Southwest (Huelva and Seville) and the Southeast (Almería, Murcia), but the studies on metallurgical production carried out in the central part of Sierra Morena (the area we are studying) is scarce or practically non-existent, despite copper resources and mining works being abundant.

This paper presents the mining survey and excavation work carried out in the Valley of Alto Guadiato and Los Pedroches, two extensive valleys located in the central zone of Sierra Morena, a very rich polymetallic area.

Archaeological surveys have documented 26 outcrops of Cu-rich minerals (malachite and azurite), of which 5 present evidence of exploitation during Recent Prehistory, due to the presence of mining stones and chalcolithic pottery. One of the main mines studied has provided 174 mining hammers, 8 anvils, 6 mills and 52 ceramic fragments, most of them dating from the Copper Age and to a lesser extent associated to the Bronze and Iron Ages.

Ores and hammers have been sampled for elemental characterization and provenance studies.

Along with these surveys, El Peñón, a Chalcolithic settlement, has been excavated where smelting and metallurgical production has been documented. A set of 151 fragments of unprocessed ore, 339 fragments of slag, 146 prills, 12 fragments of crucibles and 6 Cu-based metal objects has been recovered so far. This metallurgical workshop and mining works can also be related with other workshops in the area such as Sierra Palacio and Los Castillejos (Córdoba).

All this evidence indicates the existence of a Chalcolithic mining-metallurgical focus in an intermediate area between the Southwest and the Southeast to be considered for better understanding the metallurgical technology of prehistoric Southern Iberia.

Keywords: Recent Prehistory, Chalcolithic, Mining, Copper, Smelting.

O103 - Limonite ores in a hydrogeological context

1. Mines, Mining and Mining heritage

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Abstract text: The iron-bearing ores in the bloomery furnaces in Sweden have usually been various types of limonite deposits. Limonite FeO(OH) . nH_2O or iron ocher can be considered an iron(III) oxide hydroxide with varying water content but also ferrihydrite, $Fe_2O_3 \cdot 1.4H_2O$, is common in these ores. Ferrihydrite precipitates when dissolved Fe^{3+} ions are hydrolysed. The most common types of geological material used in bloomery furnaces have been lake ores and bog ores, but also more surficial precipitates, so-called “red soil” ores (Hjärthner-Holdar et al., 2018). The iron content in red soil can be up to 50 – 60% by weight.

An extensive area (~ 5 km^2) with red soil precipitates exists nearby a small village, Riddarhyttan in Sweden, 200 km westwards from Stockholm. Referring to ^{14}C – analyses, iron production has been run in the area from approx. 700 years BC to 100 AD (Hjärthner-Holdar, 1998; Grandin et al., 2000). The investigations at the so-called "Röda Jorden" area (the Red Soil area) show archaeological remains of ironwork sites with bloomery furnace remains, slag heaps, roasting sites, charcoal pits, blacksmith hearths and iron pieces. In the archaeological reporting on the “Röda Jorden” area, the common denominator is that oxidation processes of groundwater with subsequent precipitation can explain the genesis of the red soils. However, there is no clear, consistent scientific explanation as to why the limonite was deposited over such large areas and what are the reasons for the iron compounds being dissolved before the limonite ores were/ are precipitated.

A project is currently being carried out with the aim of investigating the hydrogeological and hydrochemical conditions in the “Röda Jorden” area. Two investigation sites, with ongoing red soil creation, have been established in the area. Initial project results show that several hydrogeochemical processes in combination with area-specific geological and hydrogeological processes during Holocene are of decisive importance for the extensive past and ongoing red soil formation.

The "Röda Jorden" is considered an “area of national interest for cultural heritage” in Sweden and is subject to re-examination in terms of geographical demarcation (Jensen, 2019). Hopefully, an improved geoscientific basis on red soil genesis will provide relevant input to a revised border for the area from a planning perspective.

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O109 - The Silver Mine of Shakin (Iran). Mining techniques and "Proxies" for dating early silver mining between the Aegean and the Iranian Highlands.

1. Mines, Mining and Mining heritage

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Abstract text: The Mines of Shakin, located in a lead-silver-zinc deposit near Takestan, Qazvin province, have been known in archaeology since the early 2000s and are considered as early suppliers of silver on the Iranian Plateau. Silver, its beginnings and its cultural significance is closely linked to the history of Iran. In the 4th mill. BC, there is evidence of the cupellation process on the Central Plateau at sites such as Tappeh Sialk and Tappeh Shoghali. Finds from Tappeh Sialk and from Susa attest to the increasingly use of silver since the late 4th millennium BC.

The Shakin deposit was already used in prehistoric times, as evidenced by stone tools for mining and processing the ore, as well as irregular, fire-set mines. Silver and probably lead was also mined in the Iron Age and later in the Sassanid and Islamic periods. Numerous mines and extensive galleries as well as mining halls and shafts with traces of iron tools bear witness. This goes hand in hand with an intensification of settlement in the valley of Shakin. Settlement mounds, which date back to the Sassanid period and later to the Seljuk to Ilkhanid periods, millstone quarries and several large Qanat systems indicate a flourishing mining and settlement landscape. The valley and the mines are investigated as part of the SPP 2176 Project "Mining Regions of the Central Plateau between Resilient and Precarious Societal and Economic Strategy" in close cooperation with Iranian colleagues. In a field campaign in 2021, the area was surveyed and the preserved features were examined with a focus laid on documenting the mining area using drone surveys and 3D documentation. This was of particular significance since the features are acutely threatened by recent open-cast mining for lead. In order to better understand the multi-phase mining in its respective phases of use, an understanding of the different mining systems and tactics in prehistoric and historic times is of great importance. Mining techniques and systems in prehistoric, protohistoric and historic mining between the Aegean and the Iranian central plateau show considerable parallels. By comparing the silver mining on Sifnos and in Laurion as well as examples from the Iranian Central Plateau, "proxies" are developed, which contextualise the features from Shakin in its various horizons.

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O110 - Mechanical Crushing and Washing – forgotten processes between mine and furnace

1. Mines, Mining and Mining heritage

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Abstract text: Nasafjäll, a 17th century silver mine, situated in a mountainous area above the tree line at the Arctic Circle in Arjeplog municipality, Norrbotten county in Sweden, has been mined in three periods. The archaeological fieldwork, "Expedition Nasafjäll", that started in 2015 in some sense implied a need to interpret and understand the remains after the mechanical crushing and washing that had occurred at the site.

The mechanical crushing and washing took place at the mine during the first two periods, with some differences. During the first period (1635-1659) the mechanical crushing and washing were at first placed at Silbojokk, situated c. 45 km east of Nasafjäll, where the smelting of the ore took place. Since the silver and lead content in the ore became lower and lower both the mechanical crushing and the washing was moved to the mining field instead.

During the second period of mining (1770-1812) only washing took place at the Nasa silver mine. The smeltning of the ore during this period took place in Adolfström, c. 65 km southeast of Nasafjäll. At this site a building for mechanical crushing and washing was built.

The fieldwork at Nasafjäll, and the work with interpreting the remains has shown that there is a limited archaeological and historical knowledge regarding this sort of remains in Sweden. In Sweden only a few archaeological sites with remains after mechanical crushing and washing are known, and the archaeological material of comparison is therefore small.

I will present a national overview regarding the mechanical crushing and washing in Sweden from medieval times to the 18th century, based on archaeological and written sources. Primarily the presentation is based on copper and silver production, but I will also include iron production in the discussion.

O111 - Dewatering strategies in mines (Castel-Minier 15th century): a matter of energy

1. Mines, Mining and Mining heritage

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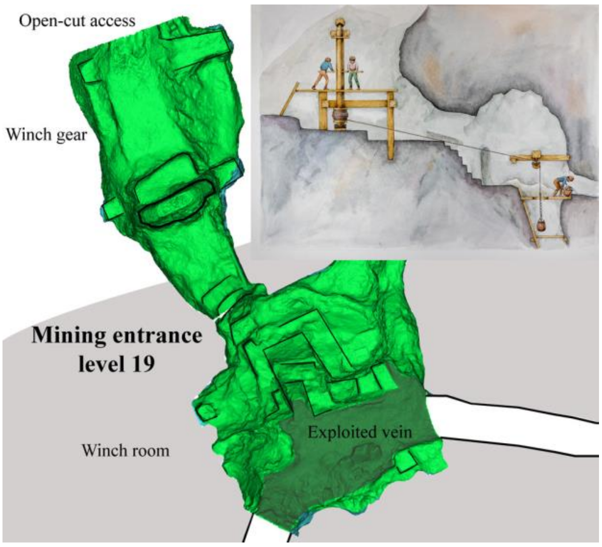
Abstract text: Water in mines is a significant challenge for miners as it can invade the system and disrupt mining operations. In ancient times, miners used various drainage strategies such as gravity drainage in a dewatering gallery, the use of winches, or pumps.

This study focuses on the Castel-Minier mine in the French Pyrenees, which was dig between the 10th and 15th centuries. In this mine, a man-powered winch was used to drain the water at the beginning of the 15th century. Subsequently, it was decided to dig a drainage gallery, which was never completed. The various dewatering strategies implemented over time in this mine provide an opportunity to study technical capabilities through the prism of energy expenditure. This sheds light on the choices made in the layout of the mining system.

The extraction of water using a winch necessitates a constant expenditure of energy, typically human or animal. However, this technique is restricted by the ratio between the maximum power supplied by the energy source and the flow of water to be extracted. Conversely, the construction of a drainage gallery can be seen as an energy and financial investment. Digging it requires a considerable amount of human or thermal energy. Once done, using it does not cost the miner anything as it is based on the potential energy of gravity.

We employ various strategies to quantitatively estimate energy expenditure. For the dewatering gallery, it is important to quantify the energy expended during mining. To achieve this, we conducted experiments to measure thermal energy through wood mass consumed and human energy using a triaxial accelerometer attached to a miner-experimenter. These data provide insight into the energy needed to extract a kilogram of rock and, by extension, to dig the gallery. A mechanical analysis of the winch allows us to calculate the energy required for mining. We can then compare these theoretical and experimental data with the flow rate needed to extract water from the mine.

Our study of energy enables a quantitative comparison of different techniques by proposing a common unit, the joule, regardless of the period or technique in use. This data can then be integrated into a more global energy model of the metal production system at Castel-Minier.


Open-cut access
Winch gear
Mining entrance
level 19
Winch room
Exploited vein

O112 - The Maritime Encounters Project in SW Spain. Copper minerals exploitation of Las Minillas mine, from Prehistory to Contemporary enterprise

1. Mines, Mining and Mining heritage

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Abstract text: Ten years ago, a controversial hypothesis proposed that Late Bronze Age (LBA) copper-based artefacts found in Scandinavia were consistent with the ores from SW Iberia (Ling et al.,2014). This hypothesis has gained support from analyses of copper-based artefacts dated to 1500–900 BC from Britain, Ireland and Poland (Berger et al., 2022; O'Brien 2022, Nowak et al., 2023).

To ascertain this hypothesis, the *Maritime Encounters* project initiated the archaeometallurgical research of possible Bronze Age copper mines sources in SW Iberia (Hunt Ortiz, 2003). Several mines, including Chinflón, have been revised and sampled, but for now the work has focused in Las Minillas copper nine, in the Extremadura region. There, the archaeological campaigns (2020, 2022 and 2023) have included intensive surface survey, geophysical Magnetometer and GPR surveys, and excavations. Mineral, furnaces walls, slags, metal-droplets, etc., have been analyzed for their elemental composition (XRF,SEM,ICP-MS), Lead Isotope ratios, and their contexts dated (C14, OSL).

The excavation revealed various successive phases of mining exploitation (LBA, Roman, and underground Contemporary), but most of the C14 results (17 out of the 21) dated to the LBA, indicating an intense open-cast trench-type mining works at that period, extending for over 200 m and with more than 900 associated stone hammers. The size of the mining works and the number of stone tools is extraordinary for both the Iberian Peninsula and Europe.

The lead isotope and geochemical data was compared with that of LBA copper-based artefacts from North Europe and Scandinavia, showing some of them consistency with the Spanish ores studied.

Using Alan William's (2023: 89) methodology to estimate the output of Great Orme mine, the production of Las Minillas was calculated, showing a lower copper output. But Las Minillas did not operate alone; we are finding evidence of other regional copper mines that were exploited in the LBA. To confirm this, complementary mining areas (such as Alcudia Valley-Los Pedroches-Jaén in South-Central Spain and South Portugal) will be surveyed as one of the next actions of the project.

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O119 - ...and up to the red mountain again. The Bronze and Iron Age copper mining district of Cotschens (Grisons, Switzerland)

1. Mines, Mining and Mining heritage

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Abstract text: Alpine copper ores were important sources of metal in prehistoric Europe. Large-scale production is documented, especially for the Bronze Age, by mines and production facilities in the Eastern and Southern Alps (Stöllner, 2009). From the Iron Age onwards, there is less evidence of primary copper production (Lutz & Schwab, 2015). This applies in particular to copper from chalcopyrite, which, however, is still strongly represented in the analysis of Late Bronze Age and Iron Age finished objects (Grutsch et al., 2019).

In this context, the chalcopyrite district of Cotschens in Oberhalbstein (Grisons, Switzerland) is of particular importance. Based on research by the University of Zurich (Turck, 2019; Reitmaier-Naef, 2022), this district has been investigated since 2017 in a collaboration between the Archaeological Service of the Canton of Grisons and the Deutsches Bergbau-Museum Bochum. At an altitude of around 2200 m and in a confined space, there are extensive traces of mining here, covering a period from the Late Bronze Age to the Late Iron Age (Reitmaier-Naef et al., 2020). Largely undisturbed by more recent activities, the archaeological features are very well preserved. Several mines and processing sites can be described, the products of which were smelted on the smelting sites in the lower parts of the valley, thus representing the entire *chaîne opératoire* of copper production.

In the course of the fieldwork carried out in recent years, the visible structures were documented in detail using drones and image-based modelling. Field surveys, geophysical measurements, corings, and sondage excavations also provide complementary results, which are supplemented by a series of dendro- and radiocarbon dates. A detailed documentation of the mine features and a range of well-preserved wood finds provide results regarding the mining technique in the various mining phases and the associated adaptation processes.

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O120 - Mining settlements in Saudi Arabia, Archaeological Study Halit (Al - Najadi) settlement Middle of Saudi Arabia

1. Mines, Mining and Mining heritage

Ajab Alotibi[1]
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Abstract text: Abstract:

Historical sources focused on Arab-Islamic expansion in military, religion, and trade aspects, yet state involvement in mining and manufacturing, the physical basis of the civilization, has been neglected. Such studies enrich our understanding of Islamic civilization and the medieval world. This project will study mining activities (raw materials, methods, features, and tools) in the Middle of Saudi Arab, notably at the Halit site, including the geographical factors which influenced its development. By establishing and dating the phases of occupation there, we can understand the economic played by this settlement in the Arabian Peninsula during the Islamic era, and metal prices fell in Hijaz and Iraq, according to the historical sources.

Halit site was renowned as a mine for the mining of gold near Al-Yamamah province in the Umayyad era (Riyadh) now and became famous between the seventh to eighth centuries AD. Most facilities found at Halit site are still at surface level, , The archaeological team discovered a group of Umayyad coins. The dispersal of architectural structures is more clear evidence of the importance of the site during the early and middle Islamic periods.

Finally, one of the most anticipated achievements of this project is to identify the tools, facilities and methods of mining and its contribution to the promotion of civilization.

Keywords:

Minerals - Mining, Mines - the Gold – Silver - Iron - Copper - Coins - The Early Islamic era - Umayyad - Abbasid era - Halit Site

O121 - Mining, Iron and Copper Production in the Swedish Middle Ages, 1100 – 1500

1. Mines, Mining and Mining heritage

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Abstract text: Iron- production has in Sweden been ongoing in the last 2 500 years. From the 1600s Sweden in periods has been one of the world leading producers of copper and iron.

The age of mining of rock ore and water driven blast furnaces and copper furnaces has been discussed in Sweden for more than one hundred years. Until the 1960s only written sources could be used to date the mining and it was then dated back to the late 13th and 14th centuries. The Coppermine in Falun is mentioned 1288 and the iron mines in Norberg 1303. The introduction of the blast furnace has been discussed as introduced in either 14th, 15th or 16th^{h} centuries. A new area started in 1960s with the introduction of Radiocarbon dating's and the first archaeological excavation was done of blast furnaces in the 1970s. The last 30 years it has also been done sedimentary and pollen analysis that have contributed with important information and dating of both mining and agriculture. The use of old maps from the 16th century and onwards has also been important.

The Results of the Project "Atlas över Sveriges bergslag" have now been presented and it's possilble to present the distribution and age of the Medieval mining and production sites.

It is the use of all the different sources that make it possible to conclude that we in Sweden during the Middle Ages had at least mining of rock ore and blast furnaces in the late 12th century. The water driven copper furnaces are probably from the late 13th century.

The area of Bergslagen was very rarely inhabited in the Iron age. In Europe, the period between 8th and 11th centuries was one of significant population increase. In parts of Bergslagen, as Norberg, the first traces of agriculture are seen in 800s – 900s and during 1000s and 1100s also increasing settlements and agriculture. The population and settlements increase more rapidly due to the mining and iron production from at least the late 12th century. After the Great Black Death it's possible to see a reduction of the number of blast furnaces. Probably the organisation of the iron production is reorganized and more connected to the villages and the best agriculture areas.

O128 - Mining legacies

1. Mines, Mining and Mining heritage
Roine Viklund[1]
Dag Avango[1]
[1] Luleå University of Technology

Abstract text: Mining legacies – Resource or burden?

The objective of this paper is to present results and conclusions from a research project aiming to explain post-industrial histories of mining regions in the European Arctic with a focus on post-extraction value making, and to critically discuss the conditions for using mining industrial heritage as a resource for sustainable and inclusive communities.

From the beginning of the 17th century, the European arctic has been the scene of various forms of natural resource exploitation, not least mining. Since then, mining has affected both landscape and local people in the region. Over the years, mines have been opened and closed at different time periods because of varying demand and raw material prices. Today, a rapid new industrialization of northern Sweden is taking place, linked to an increased demand for minerals, energy and products that can be defined as green, including mining for rare earth elements and production of Co2 free steel. This development takes place in lands where industry have competed with traditional land uses of indigenous people and national minorities, such as Saami reindeer herders and Tornedalians, which causes growing tensions about land use and the future.

Mining in the European Arctic has been structured in the form of large socio-technical systems connecting mines with people, settlements, institutions, and energy- and transport infrastructures. When mines were shut down, the systems turned into historical remains and imprints on the landscape. Since the breakthrough in the 20th century for the idea of an industrial heritage, cultural heritage actors have engaged in heritagization of socio-technical systems for mining. Other actors, such as companies and local communities, have converted them for other new uses, including re-mining of waste or new mining operations.

The research is based on archival research, oral history and archaeological field work.

O129 - Expedition Nasafjäll – revealing historical silver mining at the polar circle

1. Mines, Mining and Mining heritage

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Abstract text: Expedition Nasafjäll is a project on the historical mining operations in Arjeplog municipality in the north of Sweden – where the Nasafjäll silver mines are situated in roadless land, above the tree line, on the boarder to Norway, close to the Arctic Circle – at an altitude of approx. 900-1200 m above sea level.
The mining era at Nasafjäll started in a tumultuous 17th century, during the Thirty Years War. The silver was discovered by a Sami and a Swedish "pearl and diamond seeker" in 1634 and already in 1635 mining was underway. This first mining period at Nasa ended abruptly omly 25 years later, in 1659, as a result of a Norweigan – Danish “guerilla” attack. New attempts to create wealth from the silver at Nasa were made in 1770-1812 and in the beginning of the 20th century.

The work within Expedition Nasafjäll can be divided into antiquarian, scientific and educational activities, and annual weekly fieldwork has taken place from 2015. When the archaeological fieldwork started in 2015 only three objects where registered at the site – by now we have registered around 350 different mines, building remains, graveyard, markings for claims, remains from ore washing etc. within five different main areas on the mountain. In combination with historical maps and research in archives we are now starting to get an insight in the complex mining community in until then uncolonized land – a mining community populated by Sami, Swedes and Germans, mainly male workers but also some women and for a short period also children.

The location of the ore on the bare mountain at the Arctic Circle meant special adaptations, especially as the mining in the first period took place all year round. Darkness, cold and snow posed major challenges most of the year. The mining community was located above the cultivation and tree line and the distance was far to the associated smelting furnace and populated areas. The success of mining therefore depended not only on the quality of ore, but also on the costly and complicated transports to the coastal areas that were required.

O130 - The Bocard factory, Cévennes, France (1781-1894). The last preserved lead and silver production facility in France.

1. Mines, Mining and Mining heritage

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Abstract text: A research program is currently underway on argentiferous galena mining and processing facilities located in Vialas (Cévennes mountains, France). Ore has been extracted there in "ancient" periods, as materialized by traces of fire-setting discovered in some parts of the mines. But activities took on a whole new dimension in the modern era, following the rediscovery of the deposit in 1781. A washing facility and subsequently a foundry were established in the vicinity of the mines. The production reached its peak during the 1860s with an annual silver production close to two tons. However, the operations started to decline from 1869 due to an ore shortage and the facilities finally closed in 1894.

The Bocard factory is the only lead and silver foundry preserved in France, and as such, it has inscribed on the Historical Monuments list on 2014. Concurrently with this designation, a preservation and valorization program has been initiated, along with archaeological excavations and 3-D surveys. Archives, including reports from mining engineering students, publications and administrative documents, provide valuable insights into the constant evolution of the site, from its spatial organization to the technics employed. However, these reports from engineering students are, by definition, the work of students and not experienced engineers, containing numerous errors. Additionally, in these reports as in the rest of the archives, some equipment deemed secondary is either briefly mentioned or not discussed at all. Lastly, archives do not document the final decade of operation, with two factors explaining this absence. Once its decline had begun, this operation could not serve as a model to emulate. The second explanation relates to the dispersal of administrative documents upon the site's closure. Thereby, beyond confronting archives with vestiges, archaeological excavation is crucial to supplement and rectify this documentation and for a better understanding of the evolutions that occurred during the last period. Moreover, the excavation is essential for collecting evidence from different stages of the *chaîne opératoire* associated with the processing of the argentiferous galena, evidence studied through XRF, X-ray diffraction and scanning electron microscopy.

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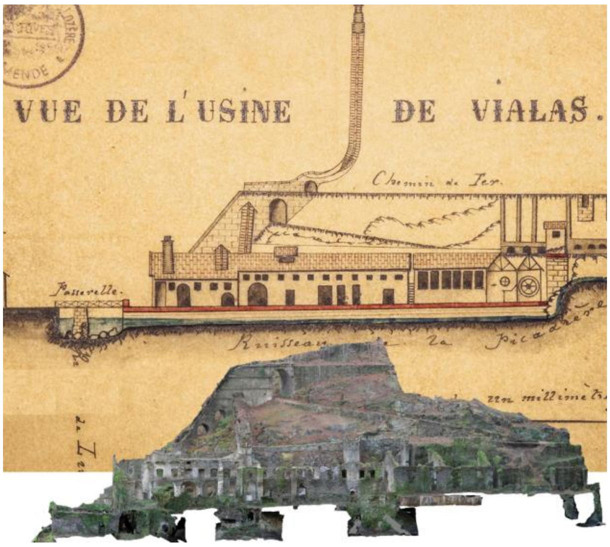
VUE DE L'USINE DE VIALAS.
Chemin de Fer.
Passerelle.
Ruisseau de la picadière

2. Metals, metallurgy and societies

O9 - Metalworking evidence from Viking Dublin in context

2. Metals, metallurgy and societies

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Abstract text: The excavations around Christchurch Cathedral in Dublin in the 1960s and 1970s were carried out by the National Museum of Ireland but have not been fully published. More recently I have recorded some 1700 finds from those excavations that relate to non-ferrous metalworking of the 10th or 11th centuries. This material includes crucibles that were used to melt copper alloys and precious metals, other vessels used to refine precious metals, a few ceramic wraps and piece moulds, a wide range of tools, and many stone bar ingot moulds. Fragments of ingots cast in these moulds as well as bars, rods and wire were also present, most of them zinc-rich copper alloys. Study and chemical analysis (mainly by X-ray fluorescence) of this material allows the metallurgical processes in use to be identified, and also demonstrates some of the types of objects that were being manufactured.

A full publication of these metalworking finds from Dublin is in preparation, but meanwhile comparisons can be made between this material and contemporary finds from other sites both in Ireland and in Britain, especially the equally large assemblages from York and Lincoln. There are similarities as well as differences, and possible reasons for these will be explored.

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O10 - The Northerners' role in European copper networks 2000-500 BCE

2. Metals, metallurgy and societies

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Abstract text: This paper will present the synthesizing results of an interdisciplinary research programme on the issue of metal provenance in the Nordic Bronze Age. This collaboration, a suite of interlinked projects (2010-2013, 2012-2014, 2015-2018 and ongoing), has produced a dataset of lead isotope and chemical analyses of c. 375 objects, mainly of bronze, dating to c. 2000-500 BCE. The artefacts cover a time span of 50 generations, from the second half of the Late Neolithic through to the very end of the Nordic Bronze Age, and derive from archaeological sites, mainly closed contexts, in present-day Denmark, Sweden and Norway. Available for comparison is a dataset of c. 500 analyses of bronzes from Denmark dating to 2000-1300 BCE, published by Nørgaard and colleagues.

The large body of artefact analyses now available from the Nordic realm has, together with a steadily increasing set of reference data from ores, allowed more informed discussions about the possible origins of the metals, inter-regional exchange networks and potential trade routes, and increased our insight into complex issues related to metal circulation and production, i.e. mixing patterns. Previous publications from the project members have contributed to both validating and invalidating older hypotheses about metal circulation in the Nordic world. We have suggested a complex picture of shifting metal sources and trade connections between Scandinavia and Europe.

Besides investigating which sources Bronze Age communities in Scandinavia got the copper and tin they needed from, to sustain a flourishing metal industry, the overall purpose of the research programme has been to understand Scandinavia's role in the European metal exchange networks, and to deepen understandings of Bronze Age metalwork in its regional Scandinavian setting, when it comes to context, function, and socio-economic and ritual expressions and needs. This paper will present and sum up the results of the analytical programme, and address questions like: How are we to understand the integration of Nordic groups into a larger 'global' supply of metals? How was the metal trade between Scandinavia and Europe organized? To what degree did local workshop traditions reflect circulation chains and different access to copper and tin? How did shifting connections unfold across time and space?

O11 - New light on the circulation of Bronze Age copper alloys in the Central Alps (Grisons, Switzerland)

2. Metals, metallurgy and societies

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Abstract text: The prehistoric copper mining region "Oberhalbstein" in the Swiss Central Alps was subject of intensive mining archaeological investigations in the past ten years. Mining and smelting of local copper ores was proven for the Late Bronze and the Early Iron Age (Reitmaier-Naef et al. 2020, Reitmaier-Naef 2022, Turck 2019). The results fit in well with the overall picture of a spatially and technologically diversifying Alpine copper extraction towards the end of the 2nd millennium BC (Stöllner, 2010). At the same time, the state of knowledge on the subsequent processing and distribution of the metal produced is still inadequate. Although the large-scale provenance studies of the 20th and 21st century es (compiled by Pernicka, 2014) provide a good outline of the Circumalpine circulation of copper alloys in the Bronze Age, they only peripherally consider the area of present-day Grisons.

The results of new studies explicitly dedicated to this desideratum are presented here for the first time as a synthesis. A compilation and re-evaluation of metallurgical finds, including pXRF analyses of stone tools and ICP-MS analyses of ores and various metallurgical remains, show a specific development of copper metallurgy during the course of the Bronze Age. While the Early Bronze Age remains characterised by sporadic access to Alpine resources, evidence of local settlement metallurgy increases during the Middle Bronze Age. According to various analyses, however, local ore extraction cannot be assumed at this time; "foreign" raw materials - probably from the Eastern Alpine region - were primarily processed and used. In the Late Bronze Age, a general increase in specialisation becomes apparent: In addition to starting copper extraction, the establishment of large-scale settlements characterised by artisanship can be observed, particularly in the Chur Rhine Valley. The diversity of the processed raw materials points to a complex metallurgical supply and processing network in the vicinity of the transalpine mobility routes.

A subsequent, in-depth investigation was dedicated to the question of these materials and alloys circulating in Late Bronze Age Grisons. A series of ICP-MS analyses on 45 objects revealed both parallels to neighbouring areas (e.g. mixed copper, increased lead content) and striking differences (e.g. absence of pure fahlore copper). The extremely heterogeneous composition of some ingots from two deposits proved to be particularly interesting and can be linked both to local copper production (trace element patterns) as well as to the pan-European phenomenon of pick-ingots (see e.g. Pellegrini, 1989, Trampuž Orel, 1996).

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O12 - Iron Age Iron in Scania, Sweden.

2. Metals, metallurgy and societies

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Abstract text: Since 2020 we have carried out a project with the aim of studying the Iron production in the province of Scania in southernmost Sweden. The project was initiated after a contract archaeological investigation of a site with two slag heaps and several bloomery furnaces in northwest Scania called Ruggaröd. The site was presumed to be of medieval origin, but all the ^{14}C-datings made showed that it is in fact dated to a short time of use, during mainly the Migration period (ca 450-600 AD). The relatively large scale of the production had never been seen in Scania before in prehistoric contexts, and this made us wonder if it would be able to locate other comparable sites of Late Iron Age dating in the middle and north of the province.

Field work was carried out at 8 different places with slag heaps, and they showed to belong to Pre-roman Iron Age, Roman Iron Age and Medieval time. The results show that relatively large iron production was carried out already at an early stage after the introduction of iron technology in Scandinavia. The results were compared to archaeobotanical studies of how exploitation of natural resources developed in the area, considering the economic view with a large demand of iron in agrarian areas without forests, and probably also driven by the emergence and growth of large central places of regional importance, like Uppåkra and Vä.

After comparing our results with previous results, we can conclude that there is still a gap in the today known iron production in the province, roughly corresponding to the Viking Age (ca 800-1000 AD). If this has to do with for instance a technological change, making it harder to locate the production sites, or a consequence of an expanding trade in iron in the Baltic Sea area at that time, is yet to find out. Analyses of iron objects in the area is a much-needed objective for the future research on iron production in southern Sweden.

The project has been funded by several research funds (mainly Berit Wallenbergs stiftelse, Ebbe Kocks stiftelse and Prytziska fonden nr 1 at Jernkontoret), to whom we are very grateful. The project team is Fredrik Larsson, Ylva Wickberg and Tony Björk, Sydsvensk Arkeologi, and the results of the project will be available in an open-source publication later this year.

O25 - Illicit iron trade and osmund forgery in Medieval Livonia

2. Metals, metallurgy and societies

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Abstract text: The paper presents research results on iron trade on the basis of written historical records: correspondence, inquisitorial interviews and materials related to judicial litigation at the papal court. I will discuss three individual cases, two involving illicit iron trade and one regarding forged osmund iron. All three cases date from the 14th and early 15th centuries and relate to the history of Medieval Livonia, a historical region on the territory of modern Estonia and Latvia.

Case one involves the trade of iron to pagan Lithuanians. The papacy had banned the sale of war materials, including iron, to 'the enemies of Christianity' in 1179. In the early 14th century, the town of Riga and the Teutonic Knights accused each other of selling illicit goods, including iron, to the pagan Lithuanians. These accusations inform us on how effective the papal ban really was. Despite the nearly constant crusade waged by the Teutonic Order against the Lithuanians, Christian merchants nevertheless sold iron and possibly even weapons to the Lithuanians.

Case two involves smuggling of iron from Tallinn to Tartu in the years 1395-1396. Due to a political conflict between the Teutonic Order and the Bishop of Tartu, the Teutonic Order had banned the sale of war materials to the Bishopric of Tartu. Certain merchants in Tallinn began to smuggle iron to Tartu by packing iron into herring barrels and claiming that the herring was to be sold to Pskov. Why the need to re-pack iron? Probably because iron was commonly not traded from Tallinn to Pskov and a sudden emergence of such an iron trade would have looked suspicious during a time of conflict

Case three involves the sale of forged osmund iron by a Tallinn merchant to two smiths in Tartu in the winter of 1416-1417. The smiths discovered the forgery quickly and refused to pay. The Town council of Tartu organized an examination of the iron by the foremen of the Tartu Guild of Smiths who said that the fake osmund was made from *keesyseren.* A further examination of historical sources mentioning the term *keesyseren* resulted in defining it as a product of locally produced bloomery-iron.

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O26 - Iron and networks at Brånahult- examples from 400 and 1400 AD

2. Metals, metallurgy and societies

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Abstract text: In south east Småland, Sweden, over one thousand remains of bloomery iron production are known. They are remains of a, mainly mediaeval, large scale iron production that has left few traces in historical records. This seems to have been one of the largest iron production areas in Scandinavia but knowledge about the complex is scarce. Very few excavations have been conducted concerning the bloomery sites.

In 2019 a rescue excavation was done at an iron production site at Brånahult. It concerned several steps of the production from digging up bog ore to the melting in the furnaces. The excavation included two production sites. Geoarchaeological analyzes showed large similarities concerning techniques used at the two sites but also some differences. Surprisingly ^{14}C-datings showed that the production sites were separated in time by almost 1000 years. One had been in use during the fourth century AD, and the other in the fourteenth century AD. During both periods production had concentrated on the manufacturing of a high-quality carbon steel.

Brånahult is situated in a forested and densely populated part of Småland. No prehistoric monuments are found in the vicinity and the region was colonized during the medieval expansion. The economy has been based on small scale agriculture combined with outland production. In the medieval period several actors were engaged in the production and export of outlands products, especially iron. Actors like the aristocracy, the church, the crown and the farmers competed, or cooperated, on the iron production. Brånahult was situated in a medieval parish where the king was the dominant landowner and it is possible that the expansion in the area was organized from the royal castle in Kalmar. In other parts of Småland other actors have been dominant.

No graves or other remains from the Roman Iron Age are found around Brånahult, but an extraordinary rich Iron Age region is situated on close by island of Öland. It is manifested in ringforts, roman import and gold hoards. Several, seemingly competitive, local centers, have be identified in the region. Iron for tools, ships and weapons must have been of importance to these Iron Age nodes.

The production of iron was important to the regional society in Roman Iron Age as well as in the medieval period. Iron production sites, as in Brånahult, gives opportunities to recognize and investigate networks in societies during different periods.

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O27 - Reconstructing bullion sources of 5th-3rd centuries BCE silver coinage from the Balkans

2. Metals, metallurgy and societies

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Francis Albarède[1], Janne Blichert-Toft[1], Liesel Gentelli[1], Eftimija Pavlovska[2], François de Callataÿ[3]
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[2] National Bank of the Republic of North Macedonia
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Abstract text: Silver coinage issued between the 5th and 3rd centuries BCE testifies to emerging use of silver in the Balkan interior, possibly related to extraction of the metal from abundant local ore deposits. However, little is known about the accessed raw material sources, the location of minting centres and their potential material connections, and the possible role of these coinages in the circum-Mediterranean silver cycle. Here, we present Pb isotope data of silver coins (n=84) issued by local Paeonian tribes and settlements (Derrones, Laeaei, Kings of Paeonia, Pelagia) and Damastion, a Greek-founded city. For comparison, we also analysed coinage of the potential Greek *emporia* Dyrrhachium and Apollonia (n=17), advantageously situated in modern-day Albania for trade with both inland and seaborne exchanges, for their Pb and Ag isotope ratios and elemental compositions.

Cluster analysis demonstrates close material connections between minting authorities in the Balkan interior and a common principal metal supply that was stable throughout the investigated coin series. Contemporaneous coinage struck by Dyrrhachium has similar Pb isotopic ratios but the small number of data (n=2) does not permit an unambiguous conclusion. Concentration of all analysed issues from Damastion's first minting phase (prior to 360 BCE) within this main Pb isotope group is in agreement with Strabo's description of the settlements' silver mines (7.7.8) which, besides other sources, were already used in the first half of the 5th century BCE for coinage of the Derrones and Laeaei. Matching reference data are from deposits in the Balkan interior, partially overlapping the circulation area of the coins suggesting a local raw material supply. Permissible sources also include deposits in e.g. southern France, Romania and northern Spain that might be proxies for hitherto unidentified mineralisation. Data of coins with the geologically oldest Pb isotope ratios (Derrones, Kings of Paeonia) are similar to endmembers identified for Thasos and the Macedon kingdom [1], further adding to the hypothesis of a potential metal provenance in northern Greece and the Balkans. Comparison of data from Greek city-states and semi-autonomous coinage under Roman control issued by Apollonia and Dyrrhachium demonstrates a change in the type and origin of raw materials and bullion composition, indicating a shift in monetary practice and presumably a different conception of silver ores.

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O28 - The Celtic Brass Coins project: production and use of coined brass in Gaul at the end of the Late Iron Age. First results

2. Metals, metallurgy and societies

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Abstract text: The communication proposed here is part of the *Celtic Brass Coins* project (*Brass monetary alloys in La Tène Culture: new perspectives on the monetary practices in the Celtic Society*) funded by the ANR for 4 years (2023-2027; ANR-22-CE27-0013). This project aims to better understand the arrival of brass in Celtic coinage in a multidisciplinary study associating numismatics, archaeometry, archaeology and digital humanities. The project revolves around the development of a pXRF analysis campaign on French national public museum coins collections (Bibliothèque nationale de France, Musée d'archéologie nationale and several museums in Normandie and Northern France) and on the non-monetary objects from Bibracte, an archaeological reference site for the material culture from the 1st century BC. The project has four main objectives: 1/ Identify the brass monetary series and specify the dates and modalities of the introduction of brass by projecting the archaeometric results into the typo-chronology established for the objects analysed; 2/ Determine the monetary practices, circulation and hoarding patterns, and technology transfers; 3/ Renew and increase the interoperability of the Celtic coins databases while including the archaeometric data; 4/ Develop non-destructive analysis of antique brass coins by LA-ICP-MS. The confrontation of the archaeometric results with typo-chronologies, contexts and site of discovery, has to help comprehend the arrival and use of brass in monetary practices (production, spread and hoarding) of Celtic societies for the Late Iron Age.

In this talk, we would like to present the first analysis results and discuss the production and use of brass as a monetary alloy in Gaul. The results obtained to date, in particular by Fast Neutron Activation Analysis at the IRAMAT, in Orléans, allowed to identify brass issues in Central and Western Celtic Gaul, and in Belgic Gaul, at least as early as 52 BC. The zinc content ranges from 10 to 23% and the main trace elements, As and Sb, make it possible to distinguish the Celtic coins which have Roman iconographic influences from those with an iconography close to that of Celtic gold coins. The latest analyses carried out by pXRF, in a strictly non-destructive mode, are not intended to provide the precise elemental composition of the coins, but they at least enable us to identify the brass issues and extend our survey to the whole of the Celtic Gaul territories.

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O40 - The Damhus Hoard: new insights into some of the earliest Viking silver coinage.

2. Metals, metallurgy and societies

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Abstract text: In August 2018, a hoard of 262 silver pennies was found just outside Ribe, on the Wadden Sea in southwestern Jutland, the first town in Scandinavia during the early medieval period. With the exception of four (ship/forward facing deer), they are all of the same type, showing a face on one side and a forward-facing deer motif on the other (Feveile & Moesgaard 2018, Moesgaard 2018). Not only is the discovery an exceptional hoard find, but the coins represent a significant addition to the previously known KG4 type (‘kombinationsgruppe’ = combination group), representing some of the earliest Viking silver coinage. Prior to 2018, only 13 examples were known.

The KG4 pennies, dated to the 820s CE, represent a continuation of a motif from the earlier Wodan/Monster type (i.e. face/deer) silver coins (known as *sceattas*) minted earlier around the 720s. Despite the hiatus in coinage, the continuity of motif style from *sceattas* to pennies reflects the initiation of a monetary system. Twenty-five (approximately 10%) of the Damhus coins were sampled and analysed for their lead-isotopic and chemical compositions to learn about the origin(s) of the silver as well as the minting technology used to produce them. The data was compared with reference material from potential anthropogenic (i.e. existing coinage/silver) and geological sources in Western Europe (Kershaw *et al.* forthcoming) as well as from potential sources farther afield in relation to known trade connections.

The results shed light on the incipience of a monetary system in Scandinavia contextualised within the wider economic and political developments of Northwestern Europe. The research was funded by the Krogager Foundation and has subsequently led to a much larger project being established (*Dark Age Economics: the rise of silver, monetisation and cashless currencies in Northern Europe and its relevance for today*, Independent Research Fund Denmark) for investigating earlier *sceattas* and silver hoards related to the development of the North Sea trade zone, monetary systems and establishment of *emporia* (trading centres).

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O41 - Swords and Oath Swearing: How the study of the "ULFBERHT" Swords sheds Light on Early 10th Century Social Dynamics

2. Metals, metallurgy and societies

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Abstract text: The ultimate purpose of archaeometallurgical research is to learn about the people who lived before us and in what ways their lives contributed to shaping the world we live in today. Swords played a unique role in past societies not only as weapons, but also in the stories and symbolism, as well as the logistics and necessary resources needed to create and acquire such as weapon.

Swords with inlayed images or characters are known from various contexts throughout Europe and those with the characters ULFBERHT inlayed into the blade have been the subject of numerous studies because of their frequency and distribution across Europe and into Asia. The research has suffered from the repetition of ghost citations and speculations with without supporting evidence or a cohesive theory that also fit the archaeological evidence and textual accounts. The most notable are that ULFBERHT was a smith from Germany, the swords were produced over centuries, there was one “authentic” type and those that differ in any way are poor imitations.

A fresh review of the evidence originally classified by Stalsberg (2008) concluded that some of the blades were distributed by King Athelstan to his nephews (foster sons), and those found in Norway and Sweden were distributed by Hakkon the Good to his nephews (Feuerbach and Hanley, 2017). Furthermore, the marks on the reverse are runes or knots representing a specific group of people, who are identified by comparing the locations of the blades to the people discussed in the textual accounts (Feuerbach,2020).

Metallographic and technological investigations have shown that different methods and materials were used to manufacture the blades, the ULFBERHT inlay and the pommels. All the evidence indicates multiple influences from different regions. This is not surprising as genetic studies also indicate direct contact and mixed populations. This does not negate local technological development as well.

This study will address two of the metallurgical traditions used to produce ULFBERHT swords: the crucible steel and pattern welded, in their broader archaeological and historical context. It will become apparent that some of these people are the forebearers and forerunners of the Varingian Guard.

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O42 - Elemental composition and lead isotopes of copper-based artifacts from Tel Bet Yerah (Khirbet el-Kerak): New insights on the Kura-Araxes Dispersion

2. Metals, metallurgy and societies

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Abstract text: Tel Bet Yerah (Khirbet el-Kerak) is a large, fortified site on the shore of the Sea of Galilee. During the earlier part of the Early Bronze Age (EB) III (c. 2880–2700 calBC) it attracted the interest of producers/consumers of "Khirbet Kerak ware" (KKW) – a Levantine variant of the Kura-Araxes ceramic tradition that originated in the southern Caucasus and eastern Anatolia. This phenomenon, which is often considered as an indication for the arrival of people from the Caucasus to the southern Levant, has been subjected to various interpretations, especially in regard to the process of migration. Here we aim at shedding new light on this process through the study of the metal artifacts from the site. The 2003–2019 excavations yielded approximately 30 metal items from the EB III (from both contexts with KKW and without), and the preceding EB II (c. 3100 – 2880 calBC). They include mainly copper-based objects (short rods, pins, wires, and fishing hooks) as well as a gold nail and a gold bead. We analyzed ten of the copper-based artifacts for elemental and lead isotope composition in order to assess their quality and to identify the geological origin of the copper. The results indicate that already during the EB II the copper used in Tel Bet Yerah originated in northern and north-eastern regions (Anatolia and the Caucasus or northern Iran), and that this source remained dominant during the period associated with KKW finds. Only one of the artifacts (from the EB III) originated in the "local" source of the Aravah Valley. The early trade with northern metals can be seen as a precursor of the ensuing movement of people, who most probably chose destinations based on existing connections and the world known to them at the time.

O54 - "Puddlages" from process to products: historical documentation and development of non-destructive methodology

2. Metals, metallurgy and societies

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Abstract text: At the end of the 18th century, the shortage of wood made the use of new fuel urgent in the English iron and steel industry. On February 13, 1784, Henry Cort, a master forger, obtained a patent for the invention of an innovative metallurgical process: puddling. In this process, cast iron, mixed with slag rich in iron oxide, is refined in a coke-fired furnace. The adoption of puddling enabled a greater volume of cast iron to be processed, thereby considerably increasing and accelerating British iron production, which quadrupled in around twenty years. At the beginning of the 20th century, puddling gradually disappeared, supplanted by mild steels.

The history of puddling, like its product, is little studied; in the 19th century, however, puddled iron was ubiquitous: railway rails, ironwork, ships' breastplates, cannon barrels, metal halls, frameworks, bridges... The process underwent numerous improvements and modifications, giving rise to "puddlages": steam puddling, water puddling, gas puddling, or even mechanical puddling... In France, its adaptation gave rise to a "mixed process" combining regional methods of refining cast iron and the use of the reverberatory furnace. These various techniques produce different grades of iron with varying chemical composition and mechanical properties, which need to be recognized, organized and classified.

The aim of this new research program is to increase general knowledge of the process chain for this ancient metal. Furthermore, in the context of reusing existing buildings and safeguarding the metal heritage, the study of the properties and performance of puddled iron will enable us to consider renovation solutions for the built heritage. Today, the conservation and reuse of puddled iron buildings is hampered by the supervisory authorities; the age and unfamiliarity of this material lead to legitimate mistrust.

For this reason, structural analyses carried out on site and in the laboratory, combined with archival research (production or construction treatises, lessons given in engineering schools and grey literature from the 19th and early 20th centuries), aim to respond to this issue by providing objectified elements of analysis. 55 sites from the database of project partner A-CORROS, a company specializing in steel structure diagnostics, will serve as the primary corpus for this study.

The strength and originality of this work lies in the integration of this predominantly historical research within an interdisciplinary consortium (archaeometallurgy, history, engineering science), as well as in the cross-fertilization of skills between practitioners and researchers.

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O55 - The Peter Flötner plaquettes within the European post-Medieval copper-alloy production

2. Metals, metallurgy and societies

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Abstract text: European post-Medieval copper production has received less interest from scientific research, compared with that of the preceding Medieval period. This interest has also predominantly focused on medium and large-scale statuary by renowned artists, overlooking plaquettes, medals, and small bronzes. However, archaeometallurgical studies of other periods (in particular, prehistoric Europe and China, e.g. Pollard 2018), have demonstrated that insights into the use, reuse, and economic value of metal can be gleaned by examining commonplace objects with potentially complex biographies that incorporate changes in use, ownership, and location. Motivated by this, our study delves into the examination of 23 metal plaquettes from the BM collection linked to Peter Flötner (1490-1546) aiming to scrutinise their composition and production techniques.

Microscopic analysis, employing optical, digital, and electron scanning microscopes (SEM), was conducted on the plaquettes. Non-destructive qualitative analysis of their composition was carried out using the Oxford Instrument Energy Dispersive X-ray detector connected to the SEM (SEM-EDX). Based on composition, the plaquettes were categorised into two groups: lead and tin-based alloys, and copper alloys. The latter group underwent abrasion and re-analysis using a Bruker Artax X-ray Fluorescence spectrometer (XRF) for enhanced quantitative composition understanding.

Microscopic examination revealed distinct differences in the definition of design details, hinting that those with less defined designs may have been produced from the cast of an already existing medal or mould. No apparent correlation between the design definition and the composition was observed.

Copper-based plaquettes exhibited a gunmetal composition, with zinc as the major alloying element, followed by tin and a small percentage of lead. All displayed a chemical signature typical of central European copper ores, with traces of arsenic, antimony, silver, and nickel. When comparing their composition with a larger copper-alloy dataset, the analysed plaquettes fit in a hypothesizable trend of reuse of metal from larger bronze artefacts in the production of smaller, transferable objects.

These results pave the way for advocating further research, both in the production and biography of this specific plaquette category and in understanding the circulation and reuse of metal during post-Medieval Europe more broadly.

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O56 - MEDIEVAL MINING DISTRICTS IN SWEDEN – THE ESSENTIAL OUTLANDS

2. Metals, metallurgy and societies

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Abstract text: For 30 years this project has been compiling and analysing archaeological remains, historic sources, place names and maps in 23 mining districts with medieval origins. The results of the project *Atlas of Sweden's mining districts* have been published in 23 reports by 20 authors. The aim has been to present the archaeological and historical source material from the mining areas in Sweden that have medieval origins, but where the mining industry in most cases has had continuity into modern times. All remains from all times are thus presented, but combined with other sources to date each unique locality whenever possible.

The Swedish mining area Bergslagen is situated north and west of the lake Mälaren. Stockholm, the capital of Sweden, is located by the rapids, where the lake meets the Baltic Sea. The introduction of industrialized mining has had a crucial bearing on medieval Scandinavian history and the urbanization of the Mälar areas. Stockholm was founded where the iron and copper were controlled before it was exported from Sweden on the Baltic Sea and out into the world.

Seven historians and archaeologists has worked on a synthesis of the results, and an overall picture of the medieval metal and mining industry and the mining districts effect on the landscape, economy and social transformation. The interdisciplinary approach in our project provides opportunities of further interpretations and a deeper understanding of the ancient mining landscape and the dynamic role of iron and copper in the modernization process in Sweden 1150–1350 AD. The source material used in the project are: written documents, laws, charters, tax documents, business agreements and archaeological remains amounting to 13 000 mines, 1 100 smelting sites of which at least 750 are medieval.

The project is coordinated by the historical Committee of Jernkontoret (The Swedish steel producers association) in cooperation with several county boards. The synthesis presents a new and more complex picture of medieval mining in Sweden and its impact on Swedish and European history.

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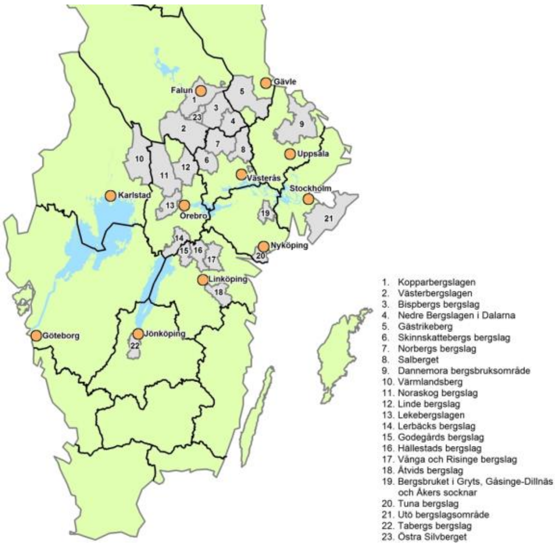

O66 - The Kengis industries. A bold Arctic enterprise from the 17th century

2. Metals, metallurgy and societies

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Abstract text: Metal extraction industry was introduced in northern Sweden in the 1630s as a response to the drastically and globally growing demand for metals due to the 30 years' war. The peace in 1648 halted particular industrial branches in the Swedish realm. However, copper and bar iron production kept on growing, and included the Torne River Valley. In 17th century trade grew global and there was a growing demand for products of the Swedish mining industries. Dutch capital, through the Momma-Reenstierna consortium was invested in Torne River Valley and a blend of Dutch, Finnish, Sámi, and Swedish workforce was contracted, creating a multicultural consortium several hundred miles north of the Arctic circle. All this resulted a unique ethnic, technological and logistic mixture.

Rapid changes in metal prices and closed borders due to wars between England and the Netherlands, in combination with failing global demand meant the demise of the Torne industry by the end of the 1670s and the bankruptcy of the Momma family. This was the biggest private bankruptcy in Sweden leaving an enormous private archive concerning the metal industry. Three works and several mining areas with villages were abandoned, leaving an extremely well-preserved physical industrial heritage. It is only in the late 19th century with the expansion of the railroads and the massive global demand for steel, that the range of the metal extraction surmounted that of the 17th century.

O67 - New findings from old data: Copper Age and Bronze Age archaeometallurgy in Mallorca, Spain

2. Metals, metallurgy and societies

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Abstract text: In this paper, we present and reconsider archaeometallurgical data from Mallorca, Spain previously available only in a doctoral dissertation and in other unpublished forms. These data were gathered in the 1980's and comprise compositional, metallographic, and lead isotope data from artefacts excavated at nine Copper Age and Bronze Age sites located in the northwest of the island. At the time these data were collected, they represented a new departure: while compositional data had been acquired, the addition of extensive metallographic and lead isotope studies were novel, and there were still many gaps in our understanding of archaeometallurgical contexts in other regions of Mallorca. This limited our ability to provide much more than a local and descriptive understanding of these data. However, major archaeometallurgical programs in Mallorca and beyond have been conducted and now allow us to place these unpublished data in a much broader context. At the time of the original research, there was only limited evidence for local copper resources and their possible exploitation, but this has now changed. For an island economy there was always the question of its connections with the mainland and neighbouring islands, and the data presented here add new dimensions to the picture of what is insular and what is imported. The metallographic data are tabulated and treated in the same way as the compositions and lead isotope ratios. Besides highlighting the daily use of objects, the results also illuminate the metallurgy of deposition. Beyond increasing our knowledge of the Copper and Bronze Ages in Mallorca, this study has also highlighted the continuing relevance of heritage sample collections and analytical data.

O68 - The historical remains of the mining history within the project "Atlas of Sweden's Mining Districts"

2. Metals, metallurgy and societies

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Abstract text: The aim of the project Atlas of Sweden's mining districts has been to present source material from the mining areas in Sweden that have medieval origins, but where the mining industry in most cases has had continuity into modern times. All remains from the mining industry, mainly from the iron, copper and silver industries, from all times are thus presented and during the course of the project geographical databases covering the archaeological and historical remains have been built up.

The fact that the databases have been created over such a long period of time means that both opportunities and problems have been built in. On the one hand, the remains have been linked to geographical positions with associated information, which means that it is easy to structure the material, and to get a good overview and access to detailed statistics. On the other hand, separate databases have been established for each report, with partly different coordinate systems, structure and information, which means that the material has been partly uneven. This has meant that direct comparisons between different mining areas, county-wide comparisons, etc., have previously been somewhat problematic.

Information from the various geographical databases has now been brought together into a common basic structure and additions of relevant information have also been made, especially regarding the medieval phase. During the time that the project was ongoing – and partly because of it – previously unknown medieval historical mining remains, and information about such, have emerged. Currently more than 10,000 sites with historical mining remains, with a total of at least 24,500 foundries, forges and mines registered in the database.

Through the database, it is now possible to obtain various statistical data about, and maps of, the geographical distribution of different information of the remains. All in all, this provides rich and unique opportunities to analyse and interpret the vast material.

O76 - Digitally Reconstructing an Iron Production Landscape: The Spatiality and Chronology of Iron Production Sites within Northern-Middle Sweden

2. Metals, metallurgy and societies

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Abstract text: I intend to present my upcoming MA-thesis, which analyses bloomery iron production sites within northern-middle Sweden from a landscape scale, through the use of GIS analyses, statistical calculations and statistical modelling. Although the spatial dimension of iron production within the study area has been addressed and discussed in previous research (e.g. Magnusson 1986; Svensson 1998), there exists a general lack of GIS-based studies within the subject. By applying the latest digital methods, my thesis will be able to nuance our current understanding of the iron production spatial organisation within past societies and untangle chronological phases of past iron production. The material that is being analysed consists of the spatial position of all the known registered iron production sites within the study area (n=3951), as well as a database of all the known radiocarbon dates associated with bloomery iron production within the study area (n=603). The database of radiocarbon dates has been compiled in collaboration with Andreas Hennius, Upplandsmuseet, and contains all the known radiocarbon dates associated with iron production in Sweden (n=1250). The sites are analysed from a comparative methodology. Eight local study areas have been defined based on the extent of the watersheds of the major rivers and waterbodies of northern-middle Sweden. The iron production sites within each study area are analysed separately. In that way, regional differences and similarities in the organisation of iron production in the landscape can be observed and discussed with the aim of nuanceing our current understanding of the role of iron production with past societies. The sites are analysed in relation to several different landscape variables, such as distance to major rivers, resource accessibility and the terrain. The thesis also aims to assist future archaeological research, by applying predictive modelling as a way to narrow down the area of search for iron production sites within archaeological surveys. The radiocarbon dates are analysed through KDE-modelling, which provides the most representative way of modelling past fluctuations in the intensity of iron production. The KDE-modelling indicates that iron production peaked during the Late Viking Age. Multiple chronological trends within the different study areas can also be observed, which previously hasn't been discussed. The early 500s AD seems to be an interesting point in time since a clear increase in iron production can be seen in multiple study areas, simultaneously as decreasing iron production can be observed in others.

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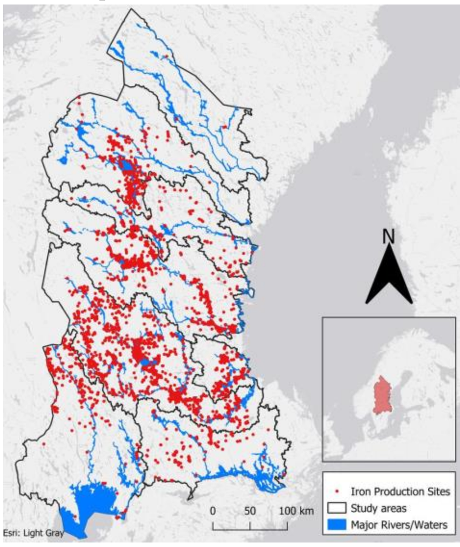

O77 - Technique and Social Change

2. Metals, metallurgy and societies

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Abstract text: In between Viking period and Medieval times the Swedish society went through a deep change in many different social spheres. Christianity broke through and for a couple of hundred years the whole country was divided into parishes. A kingdom first emerged in southern Sweden, Öster- and Västergötland, but during the 13th century the center of power moved to the area around the lake Mälar and Stockholm emerged as the most important trading port alongside Kalmar and Visby. During the 13th and 14th centuries, significant legislative work was carried out to organize the kingdom and society. Much of this took place in the farming society, but at the same time there were significant colonization in the forest areas around the lake Mälar agricultural areas, where significant deposits of iron, copper and silver ore were found. In order to utilize the natural resources, new technology was required, which in turn required a new social organization. The older bloomeries were run by the people who were available within farming household, even though the production might have been far so big. The know – how were known among the population. Here there was an opportunity to mobilize available labor. Mining and the blast furnace techniques required various specialists, mentioned already in the medieval letters of privilege, such as draftsmen, blowers and blacksmiths. The work was organized at both the mines and the blast furnaces in popularly organized work teams, and already in the 14th century there was also the concept of a foreman, (masmästare), who functioned as a supervisor within the cabin team. Here a group of skilled people appeared, who primarily were not as attached to the land as the farmers. They had knowledge of ore, production systems and the properties and qualities of metals. Across Europe, such specialists worked for wages and were mobile, unlike farmers and tennants. Studies of the mining legislation and how it has been formulated against a reality, as seen in the archaeological excavations of Lapphyttan. Here you can follow the entire process in the archaeological finds from ore to finished metal. Most of the works were codified in the 1649 Masmästar Ordinance. The different production processes have created the special "industrial" landscape, with a thousand years of development and reflecting the social change according to technical development.

O78 - Iron production in medieval Sweden: legislation and social organization

2. Metals, metallurgy and societies

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Abstract text: Social relations of iron production were in medieval Sweden structured by privileges and statutes. The eldest known are from the province of Närke 1340. The copper production site of Kopparberg (Copper Mountain) in Dalarna received detailed privileges in 1347. The iron production of Norberg was granted privileges in 1354, preceded by a later lost charter from late 13th century, possibly similar to those known from 1340. The charters were renovated at shifts of regency and thus there are eight later and similar versions of the Norberg charter, the last in 1528. Norberg served as a model or master copy for other iron mountains. It was only the blast furnace production in central Sweden that was granted similar privileges.

The mining legislation developed from customary rights, which was the general case in Europe. The legislation for one important site of production was transferred to others. The mountain legislation for the silver production at Jihlava in Bohemia from 1249 was the model for other silver mountains, not at least Kutná Hora. In a similar way Norberg and Kopparberg were models for the Swedish iron and copper production sites respectively. While in Central Europe it was silver production was regulated be legislation it was iron and copper in Sweden. Mining legislation was a general European phenomenon, but without direct import of rules. The legislation was adjusted to local and regional circumstances and requirements. The iron production was specialized, separate and different from the agrarian world. The iron and copper production created new forms of communities. The privileges and regulations were therefore necessary and created distinct administrative units and legal communities. Privileges and charters created a social identity and coherence for those who lived and worked there.

O79 - Large-scale iron production in Sri Lanka from about 100 BC to 500 AD with a bloomery related process

2. Metals, metallurgy and societies

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Abstract text: An advanced bloomery process using magnetite ore has been identified at a large-scale production site (KO 14) at Alakolavava in the Sigiriya-Dambulla region.[1] Crushed magnetite and limonite were found around the excavated furnaces, as well as adhering to pieces of furnace walls in the surrounding slag heaps. This means that KO 14 is one of few sites, where it is possible to study the iron production process in some detail, by allowing the essential combination of chemical analysis of both ore and slag. The crushed ore at KO 14 is very rich in iron, with an average iron oxide content (Fe_3O_4) of around 98 wt%.

Aluminium was found to be a mayor impurity in both ore and slag from the KO 14 site. This is a troublesome impurity, as it causes aluminium oxide networks to be formed in the slag, making its separation from the reduced iron, difficult. According to the slag analysis the viscosity of the slag has been lowered during the smelting process by additions of quarts and limonite. The smelters at KO 14 had a technology that yielded a slag with a significant lower iron content than bloomery slags found in Sweden. This suggests that they reached a high yield in spite of inherent difficulties with a low viscosity slag. They were skilled in separating the slag from the reduced iron bloom, as is corroborated by the fact that we only found a few pieces of iron enclosed in the slag in all our collected samples. The iron was of high purity. The phosphor content was below the detection limit, indicating that the iron would be suitable for making crucible steel.

The iron production was obvious on a large scale, as evidenced by the huge slag heaps remaining on the sites. Several similar sites have also been identified. At that time the ancient capitals in Sri Lanka were also connected with the iron production sites, indicating their importance to the economy at that time. So why was this large-scale iron production abandoned? Probably deforestation contributed, similar to what happened in the Roman empire. At the time of Pliny most of the forests had been consumed in Italy.[2,3]

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O88 - Why did several techniques co-exist? Explaining the selection of bronze alloying techniques through a case study from Northeast Iberia (2100-200BC)

2. Metals, metallurgy and societies

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Abstract text: Five different techniques were used in Antiquity to produce tin bronze: natural alloying, co-smelting, cementation, co-melting, and recycling. Their past use can only be discerned through microstructural and compositional analyses of production slag. The latest archaeological evidence from all around the world shows that the oldest techniques were not replaced by more modern and 'advanced' ones. Instead, several bronze alloying techniques often co-existed within the same production contexts. The logic behind this peculiar technological behaviour has not been explained so far.

This paper uses a case study from prehistoric Northeast Iberia to understand, for the first time, bronze alloying technique choices. To do so, slag and technical ceramics from different sites dated between 2100-200BC were analysed using pXRF, OM, SEM-EDS, and LIA to characterise technological choices through time. The resulting choices were then considered in relation to the technical affordances of each alloying technique, and contextualised within the relevant environmental and socio-economic dynamics. This is the first diachronic study of the development of bronze alloying technology anywhere in the world.

Results show that alloying technique choices were dependent on (1) the degree of instability associated to raw material procurement networks, and (2) the selective pressures on the performance possibilities of each technique. Discrete combinations of these two variables can explain instances of co-existence of different alloying techniques (e.g. Minferri, Mas Castellar, and Ullastret sites) and cases of commitment to a single one (e.g. Vilars site). The derived behavioural rules are applicable to other case studies.

We argue that understanding bronze alloying technique choices is fundamental to re-question existing models of bronze production organisation and technological diffusion across Europe and beyond. Such models have not considered so far the co-existence of techniques and, by extension, the protracted use of the most rudimentary techniques (co-smelting and cementation) over centuries.

3. Archaeometallurgy of copper and copper-based alloys

O1 - Archaeometallurgy of Copper Alloys in Medieval Iberian Lordships: new compositional, technological and provenance data

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text:
Introduction & Methods:

In this proposal we present the preliminary archaeometallurgical results obtained from the analysis of copper-alloy artefacts recovered in several archaeological records related to the expansion of feudalism in Iberia, a period where Archaeometallurgy has had a scarce development in Spain, particularly in the field of Medieval Archaeology.

Specifically, into the framework of the "MEDGREENREV project" (ERC SyG project Ref. 101071726) we focus on compositional (pXRF), technological (metallopraphy) and provenance (MC-ICP-MS) analytical methods in order to characterise parameters such as copper metallurgy resources, most disseminated types of alloy, recycling and re-smelting practices, operational chains and distribution of metal between the 12th and 15th centuries.

Results & Discussion:

Thus, we aim to trace the degree of craftsmen specialisation and standarisation of production taking into account the different economic, socio-cultural and technological constraints. Also, to document some inherited practices from the copper manufacture of al-Andalus and how technological knowledge was possibly transmitted. Finally, we propose a first distribution pattern of copper in the Iberian feudal kingdoms, inserting it into the trade and exchange networks displayed in the Western Middle Ages.

Conclusion:

In short, we try to generate a predictive model for the analysis of copper-based artefacts in feudal Iberia such as the ones recently proposed in other European medieval territories (cf. e. g. BOURGARIT y THOMAS, 2012; GAUDENZI y MARTINON-TORRES, 2016; BOTTAINI et al., 2022; SAUSSUS et al., 2023), starting to define a material and cultural horizon for the Iberian medieval lordships metallurgical production.

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O2 - About the ancient copper metallurgy of mountainous Colchis (archaeometallurgy, geology, written sources, myths, ethnology)

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The Caucasus region occupies an important place in the study of world metallurgy, it is one of the regions where ancient metallurgy originated and developed. As well as Georgia as a part of the Caucasus, especially the mountainous regions of Colchis (Lechkhumi, Kvemo Svaneti), where many archaeometallurgical sites have been recorded over the past decade.

Legendary Colchis was known in the Old World through early Assyrian, Urartian, Greek, Roman, Armenian written sources, Georgian ethnology, and Greek mythology for its richness in metals and metallurgical traditions. Best known of these is the mention in Homer's Odyssey of the journey of Jason and the crew of the Argo to search for the fabled Golden Fleece, described in more detail by later Apollonius of Rhodes. During their travels, in the upper reaches of the Phasis/Rioni River, the Argonauts are also said to have seen Prometheus chained with fetters of bronze to one of the mountains of this region which centers on modern Lechkhumi. Strabo considered and analysed this tradition and came to the conclusion: "The richness of this country (Colchis) in gold, silver, iron and copper explains the real reason of Argonaut campaign. Phrixus was the first person to organize the expedition for this purpose." It is clear from these written sources and archaeological findings that metallurgy was the basis for the establishment of the Colchis Bronze culture and statehood.

In 2011-2022 archaeological research and geological exploration in Lechkhumi and Kvemo Svaneti has revealed more than 25 unknown prehistoric smelting sites with smelting debris: partially processed ore, slag, crucible, and toyère fragments, and associated hearths.

Thus, through the interdisciplinary studies of the metal smelting sites of Lechkhumi-Kvemo Svaneti and the smelting debris obtained the following new data about the ancient metallurgy of the mountain region of Colchis: the sites dating back 13th - 8th cc. BC; typological investigation of slag and technical ceramics shows few types of slags, toyères and crucibles; the results of typological and petrographic investigation of slags show several stages of metal smelting; the geochemical analysis of slag and ore indicates the same genetic origin, and confirms that the Colchian metallurgists used the local ore; the sites are associated with copper production; palynological studies confirmed - warm climate, forest types and plant species, created appropriate conditions for copper smelting.

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O3 - Axes of power, axes of toil: the production and use wear of the ancient Egyptian and Nubian copper alloy axe blades within their contexts of use

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: In 1987, Egyptologist Vivian Davies published a catalogue of the ancient Egyptian and Nubian axe blades within the collection of the British Museum, London. Their standard typological research was aided by a broad archaeometallurgical dataset, encompassing all discussed specimens. Not only that, a corpus list of all known Chalcolithic and Bronze Age axes known from Egypt and Nubia, provenanced and unprovenanced, was included. With the addition of material published after this date, it totals altogether more than 1,900 known specimens of full-size and model axe blades from the entire periods and regions mentioned. The present paper is focused on the macro- and micro-evaluation of this dataset, as the recent upsurge in online publication of museum collections enables to gather more information on the artefacts than ever before. This is aided by the meticulous study of the production and use wear of the tens of artefacts, which were available for direct inspection, and compared with rich Egyptian iconographic and textual sources. And by the addition of the elemental composition data, not only from the literature (more than 300 analysed artefacts), but also newly gathered by the portable XRF and more precise techniques, such as e.g. NAA and metallography. The dataset enables us to address anew the questions of the distinction between the battle axes and artisan ones (used for woodwork and stonework), as well as identifying the unclear category in between both of these. Further dimension is the connection to the frequent and wide use of stone axe blades, initially, in Chalcolithic, inspired by stone forms, in the Bronze Age often reverted as skeuomporhs of metal shapes. The paper is an interim report on a post-doctoral project *EgypToolWear – Metalwork Wear Analysis of Ancient Egyptian Tools*, supervised by Prof. Andrea Dolfini.

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O4 - The cutting edge: giving shape to the Sögel-Wohlde blade tradition and the breakthrough of the Nordic Bronze Age via a multi-proxy approach

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The early Nordic Bronze Age (NBA period Ib; 1600-1500 BC) is considered as the breakthrough of bronze metallurgy in northern Europe which is facilitated by a considerable increase in the availability of bronze and the appearance of refined metalwork in regional styles. The blades of the Sögel and Wohlde types are prime examples of this development as they suddenly appear in northern Germany and southern Denmark without evidence of local precursors. Additionally, the blades have been historically linked to Hajdúsámson-Apa metalwork from the Carpathian basin or similar blades from the northern Alpine region. As a result, there is much debate as to whether the Nordic blades can be considered as an indigenous development, imports or cultural translations from similar blades elsewhere.

The ongoing interdisciplinary research project "Origin, development and technology of the Bronze Age blades of the Sögel-Wohlde-Kreis", aims to characterise the Sögel-Wohlde metalwork as well as study the relationships between the Nordic, Carpathian and northern Alpine blades by integrating multiple analytical proxies such as their chemical composition (ED-XRF), lead isotope ratios, as well as tin and copper isotope values (Neptune Plus MC-ICP-MS). The aim is to determine if the chemical and isotopic signatures can distinguish between archaeological and archaeometric typologies to assess whether they are interrelated. Additionally, statistical methods will be applied to the multi-proxy data to check for groupings and possible correlations. In so doing, metal groups and mixtures of copper types or bronze batches could be identified which aids in understanding the origin of raw materials, relationships between blades and to identify imports or production centres.

The current results indicate that the metal supply mainly consisted of low-impurity copper of chalcopyrite quality from the Mitterberg mining region and the Slovakian Ore Mountains. Signatures of these main ore suppliers are present in both the Sögel-Wohlde and the Carpathian metalwork. However, some of the Sögel-Wohlde blades appear to have been made from different copper sources as well, such as the Great Orme mine in Wales or the Trentino region in northern Italy. In comparison, copper from these ore sources is only present in the Sögel-Wohlde district, which suggests that the NBA became increasingly interconnected into a larger Bronze Age economic structure. Furthermore, the presence of additional copper suppliers speaks in favour of local production albeit stylistically influenced by the Hajdúsámson-Apa metalwork from the Carpathians or northern Alpine region based on decorative similarities.

O17 - The phases of copper flow in Eneolithic Italy (4th-3rd millennium BC) sourced by lead isotope tracers

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The Alpine area presents many small copper deposits, mostly exploited since Late Medieval times. This led to the widespread assumption that these ores were exploited much before and that most circulating prehistoric metal objects were produced with local copper sources. This assumption was largely validated for the Bronze Age through the use of lead isotope tracers, and well supported by the archaeological and archaeometallurgical evidences. However, the scarcity of available lead isotope data for pre-Bronze Age metals precluded to date the reconstruction of the metal flow in the 4th and 3rd millennia BC. Based on 49 new analyses of archaeologically important artefacts, it is now shown that the Northern Italian Eneolithic (or Copper Age, approximately 3500-2200 BC) includes three chronologically distinct periods of metal production: Balkanic, Tuscanian, and Alpine copper. The Alpine ores were massively exploited only starting from the middle of the 3rd millennium BC, in connection or slightly earlier than the Beaker event.

O18 - Archaeometallurgical analyses on metals from the famous cemetery of Hallstatt, Austria - Copper procurement during the Early Iron Age in Europe

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Introduction

The discovery of the famous cemetery of Hallstatt, Austria, with its rich and spectacular grave goods gave its name to an entire prehistoric culture – the Hallstatt culture (ca. 8th to the 4th cent. BC). The total number of excavated metal objects, coming from approx. 1500 burials, is currently estimated up to many thousand pieces. They are nowadays housed in the Naturhistorisches Museum Wien (NHM). Within a recently funded EU-Horizon2020-IPERION project (PI M. Mehofer) these finds underwent first systematical analyses as they represent a to date unexplored archaeometallurgical pool to examine the wide-ranging exchange connections of the prehistoric salt miners.

Materials and methods

A set of 130 metals (gold and copper-based objects) like swords, daggers or personal implements, covering the time span of the 8th to the 4th century BC, was sampled. Furthermore, to investigate the exchange systems over a longer period of time, Late Bronze Age objects and ingots from the surrounding regions (Upper Austria, Styria and Salzburg) were also included. The chemical composition was analysed by energy dispersive X-ray fluorescence analyses (ED-XRF) and the stable lead isotope ratios of the copper metals by a High resolution - Multicollector-Inductively Coupled Plasma Mass Spectrometry (HR-MC-ICP-MS) at the Curt Engelhorn Centre of Archaeometry, Mannheim.

Results

Within this lecture the results will compared to previously published results of copper ores, slags, ingots and artefacts from the European region to examine the exchange systems of the copper and gold. The preliminary results show, that tin bronzes, leaded bronzes and raw copper are present. The element patterns indicate both, chalcopyrite-based and fahlore-dominated copper, which was used for the production of the artefacts. This in good accordance with previous research results for Central Europe, which describe a noticeable increase in fahlore dominated copper from Ha B onwards. While the tin concentration decreases since the Late Bronze Age, lead becomes an important alloying agent in the younger periods (Ha C-D).

Conclusion

For the first time it is possible to examine the metal procurement of this mining community over such a long period. The generated archaeometallurgical database of the Hallstatt metals will allow for in-depth analyses of Late Bronze Age and Iron Age exchange to the Hallstatt mine, driven by the need for salt.

The financial support by the Horizon 2020 Programme of the EU (IPERION HS Grant Agreement n.871034) is gratefully acknowledged.

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O19 - Aspects of technology and provenance of the Early Bronze Age Mesi-Glyfada hoard, northern Greece: new information based on archaeometric analyses

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: During the Bronze Age, hoards composed of metal tools were common in western and central Europe. Many hoards of this type, dating back to the Early Bronze Age, have been discovered in the Aegean region (e.g. Petralona in Chalkidiki, Rhodotopi in Ioannina, Eutrisi in Boeotia, Keros island, 'Kythnos' hoard). Until recently, 42 metal tools comprised the largest of these hoards. Fortunately, this perception has changed after the accidental discovery of a hoard in 2008 in the sea area of the contemporary settlements of Mesi and Glyfada in the Rhodope Prefecture, northern Greece. At least 116 tools (primarily axes) and 23 ingots are included in this hoard, along with four conglomerates containing an unknown number of tools. Furthermore, two ceramic vessel bases were found.

An archaeological study of the assemblage is conducted by the Ephorate of Underwater Antiquities. Parallel to this study, the Paleoenvironment and Ancient Metals Studies laboratory of the N.C.S.R. “Demokritos” has undertaken an archaeometric study. As a first step, 64 finds were analysed using the non-destructive XRF method. Based on the results of this method, it appears that the findings contain mainly copper along with arsenic, zinc, antimony, and lead. In order to understand the technologies employed, 41 samples from 32 finds were collected and microstructure and microhardness analyses were performed. According to these analyses, all examined items were cast in moulds without further mechanical treatment, and their hardness was not greater than 60Hv. Afterwards, the samples were analysed using Scanning Electron Microscopy with Energy Dispersive X-ray Spectrometry (SEM/EDS) to determine their elemental composition. Analyses have shown that both categories (tools and ingots) contain copper, along with varying amounts of arsenic (<2%), lead (<6%), and zinc (<2%).

Considering that the assemblage weighs over 60 kg and comprises the same components in both categories of items, several theories have been advanced regarding its provenance. In order to investigate the source of the raw materials used to manufacture the items, lead isotope analyses were conducted on the sub-sections of the samples: thus 22 tools, 13 ingots, and 16 ore samples deriving from the surrounding area.

This presentation aims to provide an overview of the results of the analyses performed so far. However, a particular focus will be placed on analyses related to investigating the origin of the raw material used.

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O20 - Copper based production technologies and metal circulation during the Balearic Islands Prehistory (ca. 2300-850 cal BCE).

3. Archaeometallurgy of copper and copper-based alloys

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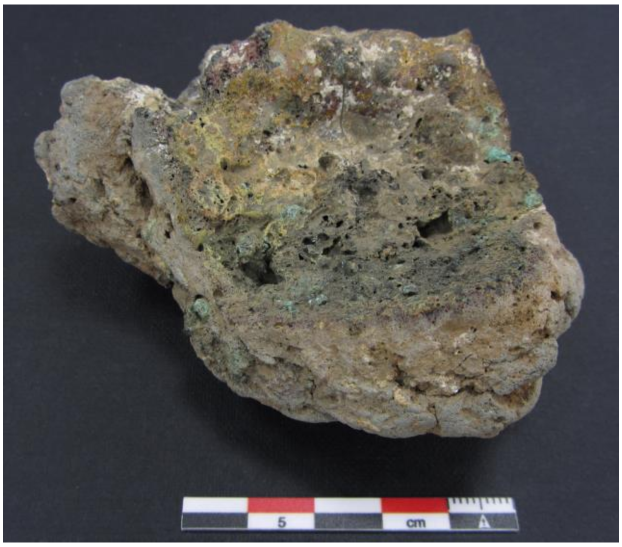
Abstract text: The Balearic archipelago (Western Mediterranean, Spain) unites the last Mediterranean islands to be colonised. This happened at the end of the 3rd millennium cal. BCE, when Bell Beaker peoples settled there. During most of the 2nd millennium BCE, they developed broadly homogeneous communities later denominated 'Naviform societies'. Their isolation, external influences and/or connectivity with other groups have been under discussion when attempting to explain the key social and material changes identified in the archaeological record over time. Importantly, copper ores are scarce in the Balearic archipelago, which contrast with the substantial amount of metal documented in different contexts and sites. This suggests that much of the metal could arrive from outside of the archipelago.

Against this background, we present different data to characterise metallic production technologies and metal circulation in the Balearic archipelago during Prehistory (ca. 2300-850 cal BCE). 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. Further objectives are to explore the role of metal in each island, to isolate different production particularities, and to approach how metal exchanges have influenced (or not) the production strategies and historical dynamics of Balearic populations throughout Prehistory. Ultimately, we will explore how technological knowledge was transferred and adapted to the Balearic insular environment. To this purpose, different kinds of metallurgical artefacts, ingots and production remains have been recovered from different sites representing the whole archipelago such as Cap de Barbaria II (Formentera), Arenalet de Son Colom (Mallorca) or Son Mercer de Baix (Menorca). The methodology applied involves elemental analysis performed by pXRF, metallography (including optical and SEM observations and microanalysis) and lead isotope analysis (LIA) performed by MC-ICP-MS.

Initial results show that Menorcan sites were the main metal production centres in the Balearic Prehistory and also concentrate most of the ingots found. Besides, different technological choices and resources were documented and used to produce copper, tin bronze, or leaded alloys. Furthermore, most objects present isotopic matches with Menorcan copper ores while other artefacts can be related with mainland outcrops instead. Thus, this information is relevant for a better understanding of the metal production dynamics, for the interpretation of technological practices, and to approach metals circulation and the connectivity between islands.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O32 - Doors to Paradise: the manufacture of bronze and brass doors from the 11th-12th century

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: From the 11th and 12th centuries, around 30 doors in various copper alloys have survived to the present day, making it the only complex of large medieval bronzes to have survived. Most of the doors are located in Italy. The doors were made either completely of metal or single metal plates were attached to a wooden base. Some of these metal plates have inlays of various materials, which may be colored illustrations of various biblical scenes or saints. Previous art and cultural history studies of the doors have paid little attention to the production itself and the interaction between the material and the images.

This presentation will discuss the first results of the FWF-funded three-year research project at IMAREAL (University of Salzburg). These doors have been fully documented for the first time in high resolution and 3D, the chemical composition has been non-destructively analyzed (XRF) and the type of wood and date of the support material on selected doors has been determined. This will provide information about the materials and techniques used, how and which craftsmen, artists and patrons were involved in the manufacturing process. Through comprehensive material analyses of all the doors on site, questions of production and material selection can now be answered for the first time.

O33 - WARRIORS AND SWORDS. A STORY TALE WRITTEN IN BLADE

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The sword has always been associated with war and warriors and they always had a close connection. Throughout the Bronze Age and the Iron Age, swords were a symbol of the warrior, of the military elites. After their deposition, they are waiting to be rediscovered to be able to tell their story. Using interdisciplinary investigative methods, metallographic analyses, CT scans, and traceological analyses, these stories can be read. In the space between the Carpathians and the Prut, there are extremely few swords dated to the end of the Bronze Age and the beginning of the Iron Age discovered, which is why they require careful analysis. One such example is the sword discovered on the territory of Vaslui County, being the only one of its type discovered in this region. The metallographic analysis and traceological analysis allowed us to better understand the way of use both during its "life" period and from the moment of deposit.

O34 - Studies on Bronze Age metal procurement in the western and central Balkans - Ingots from Italy, metals from the Mitterberg

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Introduction

In this lecture, we will present the archaeometallurgical results which were obtained within a recently finished research project. Based on the analyses of 1000 samples (ores, slags, copper-based metals) dating to the period between 2000 and 800 BC, various conclusions on the copper production as well as the supra-regional metal trade in Southeastern Europe will be discussed. Special emphasis will be set on plano-convex ingots, many of which were found in hoards, dated to HA A1.

Methods and materials

A set of 49 plano-convex and rod ingots found in 18 hoards in the study area was sampled and analysed. The chemical composition of the copper-based artefacts was analysed by energy dispersive X-ray fluorescence analyses (ED-XRF), and the stable lead isotope ratios by a High resolution -Multicollector-Inductively Coupled Plasma Mass Spectrometry (HR-MC-ICP-MS) at the Curt Engelhorn Centre of Archaeometry, Mannheim (methods described in: Lutz- Pernicka 1996; Niederschlag et al. 2003).

Results

The archaeometallurgical analyses allow us to conclude that the ingots can be traced back to either the mining fields in northern Italy (Trentino) or to the eastern Alps (e.g. the Mitterberg - Hochkönig ore fields). Additionally, we mark Cyprus as a further (subordinated) origin of the metal. The plano-convex ingots themselves contain raw copper, which is only alloyed in rare cases with lead or tin (a marker for recycling). Surprisingly, the analytical evidence for objects made of Eastern Alpine copper remains scare, bronzes connected to the Trentino mines prevail. The lead concentrations in the ingots connect to the eastern Alps are generally lower than those in the ingots assigned to the Trentino mines. Therefore, their isotope ratios are superceded when mixed with southern Alpine copper. As will be discussed, the results of the finished objects indicate, that this was a common metallurgical practice.

Conclusion

The presence of copper from different mining regions within the same hoard gives insight into the distribution mechanisms of this object type. It shows that ingots from both major mining areas regularly circulated in the region under study. Furthermore, ingot fragments with comparable geochemical patterns can be found in different depots, which allows us to conclude that their copper comes from the same mining region. One might hypothesise that they travelled along the river routes (Danube, Sava, Drava), arriving together at the Balkans and then being distributed (project funding: FWF-Austrian Science Fund, project no. P32095, PI M. Gavranović).

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O35 - Scandinavian influences on 10th-11th century bronze finds from the Carpathian Basin

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Since 2005, interdisciplinary research has been carried out on the Solt-Tételhegy site located in the floodplain of the middle region of the Danube in Hungary. The fieldwork, which was completed in 2022, has uncovered remains of settlements from the Bronze Age to the Early Modern period at the site, which covers an area of about 100 hectares.(1) Among the metal objects unearthed a few stray finds made of bronze from the 10^{th}-11^{th} centuries were isolated. They differ from the local artefactual material in form, design and function, suggesting Scandinavian and East Baltic parallels.(2) Their archaeological and archaeometrical analyses were compared with the results of similar examinations of similar finds from Hungarian collections. Non-destructive examinations with ED-XRF and SEM-EDS on 20 objects from Solt-Tételhegy and on 12 finds from ten other Hungarian sites were carried out. These analyses were complemented by examinations of 10 objects using neutron diffraction method. We sought an answer to the question of whether these stray finds indeed reflect connections between the Scandinavian and Baltic peoples and the ancient Magyars settling in the Carpathian Basin and how they are integrated into the local cultural context of the period. The examined belt fittings, ornamental plates, and belt ends were all made by casting. It seemed that some artefacts were worked after casting. A wide variance in their chemical composition were observed, however, the finds could be grouped based on the zinc, tin, and iron content. Some copies of Solt-Tételhegy artefacts have been found in Hungary, with almost the same shape and ornament but different chemical compositions. In some cases, traces of former tin coating could be observed. Our experience showed that the surface of bronzes can be highly segregated in certain components (tin, lead) compared to the composition inside the material. The main objective of the neutron diffraction analysis was to characterize phase composition and microstructure. A multiphase quantitative analysis provided a clear picture of the composition of the alloys (the relative amount of copper, tin, lead) and the microstructural proportions of the crystalline phases. Comparison with XRF and, where available, SEM-EDS analyses were also performed. A general conclusion can be drawn that the „Scandinavian-style” metal objects and ornaments, that appear in a well-defined region of the Carpathian Basin in the 10th-11th centuries were most probably the products of local craftsmen, in some cases with a new composition of raw material, slightly modified design techniques and decorative motifs.

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O47 - Origin of the copper supply in Northern Italy between the Middle and the Final Bronze Age (17th-10th cent. BC)

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The exploitation of copper mines in the Italian Eastern Alps during the Late Chalcolithic is well-documented by the presence of smelting sites and archaeometric investigations of related slags (Angelini et al.2013; Artioli et al.2015). However, the majority of copper production contexts in the area belong to the Late Bronze Age, corresponding to the Recent Bronze Age (RBA, c.1350/1300-1175/1150 BC) and Final Bronze Age (FBA, c.1175/1150-900 BC) in the Italian chronology. Surprisingly, recent chemical and LIA investigations of Central European and Scandinavian finds have demonstrated a considerable exportation of South-Eastern Alpine copper to the North from 1500 BC, and even earlier (Melheim et al.2018; Ling et al.2019; Nørgaard et al.2020).

In order to better understand the Alpine copper exploitation during the Bronze Age, we decided to enhance the analyses of finds from the areas south of the mines. In this work, we present the investigation of 63 Northern Italian objects and ingots from 13 sites, mainly belonging to the Veneto region. The finds were chosen based on their specific typology and/or the age of the provenance context, providing a well-defined date for the materials from the Middle Bronze Age (MBA, c.1650-1350/1300 BC) to the FBA.

The finds were sampled, and a complete chemical and isotopic investigation by OM, SEM-EDS, EPMA, metallographic, and LIA analyses was performed. In general, the objects are made of bronze, while ingots are composed of both copper and bronze. Only a few finds are produced with copper from falherz ores. The chemical and the LIA results show that copper from the South-Eastern Alps is used in the entire chronological range considered here. However, while in the MBA there is also a considerable supply of copper from other sources, in the RBA and FBA, the copper essentially derived from the Alps. .The results will also be compared with data from 90 finds of the same age (MBA-FBA) in the neighbouring Friuli Venezia Giulia region (Canovaro et al.2019, and unpublished data). With the interesting exception of the metals from one site, the general trend appears to be confirmed.

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O48 - Beyond Biplots: Bayesian Perspectives on the Diverse Lead Sources in Early Western Zhou Artefacts

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Lead isotopic data from ancient copper alloys has widely served as an essential tool in establishing correlations or disparities between artefacts and potential geological lead sources. The conventional methodology for interpreting such data involves visually assessing isotopic biplots utilising three key ratios ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$). While more advanced techniques such as statistical distance, cluster analysis, and kernel density estimation have been employed to discriminate between ore sources in provenance studies, they often struggle with the complexity posed by mixed source scenarios.

To address this challenge, this paper introduces a Bayesian framework designed to quantitatively evaluate the contribution of potential lead sources to metallic objects. While this method has been applied to archaeological metal (Longman et al. 2018 and Sun et al. 2023), widespread adoption remains a theoretical and technical challenge for the archaeological community due to insufficient documentation. To bridge this gap, we propose breaking down the Bayesian model into comprehensible steps, each accompanied by thorough descriptions and evaluations. This approach aims to empower non-specialists, enabling them to replicate the model and apply it to their own case studies where a mixture of different sources could be present.

We deliberately selected a dataset of 392 bronze artefacts from the Chinese early Western Zhou based on the period's distinctive manufacturing style and extensive trading network. The model's outcomes, when coupled with archaeological evidence, reveal that lead sources for early Western Zhou bronzes are primarily linked to two mining regions: North China (Western Henan) and the Middle Yangtze, with South China (Nanaling) serving as a secondary source. This consistent trend across numerous contemporary sites in the Yellow and Yangtze River basins indicates a highly interconnected resource management system among vassal states of the Western Zhou. This remarkable phenomenon may have been motivated by the movement of skilled artisans as well as the circulation of (raw) materials.

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O49 - As Long as It's Blue: Ore selection and arsenical copper production in the Early Bronze Age Balkans

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Copper metallurgy in the Balkans is famous for its massive copper metal implements circulating this area throughout the 5th millennium BC. The first known copper alloy, arsenical copper, occurred in the Balkan Late Chalcolithic cultures by the end of this period. However, very little evidence is found related to the production of this alloy, and the lack of findings is commonly ascribed to the slagless nature of the early metal extraction process.

Here we present copious evidence on the earliest documented arsenical copper smelting in the Balkans, from two sites in Serbia and Croatia, dated to the mid-4th millennium BC. Exceptionally well-preserved crucibles, slags and a few metal artefacts offer a rare insight into the technology of smelting and working arsenical copper in this part of the world. After the completion of our mineralogical, compositional, microprobe and provenance analyses, we argue raw materials for smelting arsenical copper come from a very rich and colourful mixed oxidic ore, available locally. The enrichment of crucible slags with specific transition metals such as Mn, Zn and Fe, together with the occurrence of fayalite and delafossite in several slag areas, confirms the smelting of an original ore charge rather than the re-melting of pre-existing metal smelted previously elsewhere. Since arsenical copper was preferred during much of the Late Chalcolithic/Early Bronze Age in the Near East and contemporary cultures in central Europe, this research is of wide-ranging relevance to our understanding of the early stages of copper alloy metallurgy in Eurasia.

O60 - Understanding the metallurgy of the Únětice culture: Copper types and metal mixing disclosed by multi-proxy research

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The Únětice culture (2200–1550 BC) represents an important cultural entity of the Central European Early Bronze Age and is characterised by an abundance of metal objects. Thousands of artefacts are known from the various regional groups, which were deposited in hoards and tombs or as individual finds. The study focuses on the metal hoards of the Central German Circum-Harz Únětice group, in which flanged copper and bronze axes make up the majority of artefacts. Axes are therefore predestined objects for understanding metallurgical practices in their entirety. Since the 1990s, most axes and associated finds have been archaeometallurgically analysed using elemental and lead isotope analysis as part of several large projects. In addition, the copper and tin isotope composition of metal objects from several specific hoards was determined as part of an ERC project. Thanks to these investigations, we now have a very good understanding of the metallurgy of the Únětice culture, its organisation and the procurement and processing of metal. Overall, the research results indicate a chronological evolution in copper usage: arsenical copper in the earliest phase, followed by nickel-rich fahlore and *Ösenring* copper as well as fahlore copper with varying nickel contents, all of which may be associated in individual hoards. In the younger Únětice phase, a transition from high-impurity fahlore copper to low-impurity chalcopyrite copper can be observed along with an increase in tin concentrations in bronzes. According to the isotopic and chemical signatures, the western and eastern (Inn valley) Alps as well as the Slovakian Ore Mountains are the most likely regions as copper suppliers. From the combined assessment of chemical and isotopic data, it is even possible to clearly reconstruct mixing of different copper types and the mixing of bronzes as a widespread metallurgical practice already in the early Únětice phase. The latter result has major significance to the interpretation of metal origin and the development of metal use, but also for social and economic aspects, and for understanding the Únětice's role in controlling and distributing metal resources throughout Central Europe. The lecture gives an overview of the Únětice copper types and uses the example of the Kanena III hoard (of the city of Halle-Saale), in which axes of different copper types are associated, to show how the mixing and recycling of metals can be inferred.

O61 - Materialising Roman Diplomacy: a Pb isotope study of Eggers 92 bronze basins in Denmark – A link to Tiberius's naval expedition to the North in 5 AD?

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Roman style bronze and silver objects first appear as grave goods in Denmark, in the middle of the first century A.D. Among these, eight bronze basins of the Eggers 92 type have been found in separate graves across the country, making these the most numerous and most broadly distributed type of Roman bronze good found in Denmark. Study of the composition of these basins provides an opportunity to investigate whether the basins may have arrived as diplomatic gifts during the Roman naval expedition in 5 A.D. If the basins share a common chemical signature, it would indicate that they likely were made using the same materials, possibly even in the same workshop.

Each Eggers type 92 bronze basin consists of an approximately 40 cm wide thinly-hammered bronze bowl, characterized by cast fittings consisting of a foot ring, and handle rings with fittings and decorative palmettes. In order to investigate the variation between the basins and the components, multiple samples were taken from the bowls and from their ornamentation. The bowls themselves are composed of low-lead (< 5 wt.%) high-tin (8-10 wt.%) bronzes, whereas all the fittings except two are composed of leaded bronzes (> 10 wt.%). Lead isotope data reveals that three smaller bowls (Ø 38-39 cm) have similar compositions, whereas the larger bowls (Ø 41-42 cm) are differ from the smaller bowls and from each other. Each of the small bowls and one of the large have leaded fittings that are similar in lead isotopic composition to its bowl, suggesting that the copper and lead in the bronzes come from the same region, whereas the remaining large bowls have leaded fittings of differing isotopic compositions, suggesting the lead and perhaps also copper in the fittings have a different origin than those in the bowl. The two non-leaded fittings have a unique lead isotopic composition, which likely represents a Germanic repair.

The results provide a nuanced insight into the varied makeup and fabrication of what has been classified as a single type of basin (Eggers 92) The decorative fittings show lead from mixed sources. Despite the variations, three of the basins can be attributed to a common source. The locations of these three basins coincide with the route most recently proposed for Tiberius's naval expedition to the Northern Seas in 5 A.D. Thus, this study may provide physical evidence for a remarkable historic event–the first Roman contact to the North.

Tornebuskehøj
Hedegård
Balslev
Tombølgård II
Hoby
Stangerup 1
Dorow
Lalendorf
Glövzin
Silver vessels
Bronze basin type Eggers 92
Other types of bronze vessels
Pugio
0
50
100 km

O62 - The production of early arsenical copper in the Aegean

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The early arsenical copper objects -of various categories- excavated from many sites in the Greek mainland, Crete and the other Aegean islands predominate by far over the bronze ones, of the same period. Besides, as concerns associated mineral resources, arsenic-bearing occurrences, occasionally hosting even native arsenic, are not unusual in the same territories, whilst the tin metallogenetic potential is considered questionable. Based mainly on the above data, many archaeologists have adopted the plausible view that these arsenical copper objects, particularly the high As-containing ones, were manufactured from intentionally produced Cu-As alloys. It was clear, however, that these views lacked metallurgical justification as well as data from studies on highly diagnostic associated remains, as explained below.

We tackle the above abeyance by providing evidence about early local production of arsenical copper, along with data from associated metallurgical residues, deriving from three areas or sites directly associated with Cu-As alloys. They are: 1) the site of Chrysokamino in eastern Crete, where minute fragments of unsmelted ore, escaped from the furnace, clearly show that copper and arsenic coexisted paragenetically and constituted the main metalliferous raw material, 2) the island of Keros, where a recently analysed copper ingot, coming from an old excavation of Prof. Ch. Doumas, exhibited an arsenic content of well over 3%, so that it actually consists of a Cu-As alloy and 3) southern Kythnos, from where two, currently being studied, copper ingots appear to be As-containing Also, we highlight the specific importance of a Cu-As mineralization consisting of conichalcite, [CaCu(AsO4)(OH)], discovered at Koutalas site in the southern tip of Seriphos island.

Moreover, we take into account the analyses of Cu-based ingots from the sunken hoard of Mesi/Glyfada (in north Aegean/Thracian Sea) that exhibit a slightly elevated arsenic content.

Finally, we examine the technological query of whether early Aegean arsenical-copper production consisted of one or two-stage operation. Based on the so far available data, we rather accede to the view that both approaches might have been followed. However, this would have depended on the raw materials available at the time.

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O69 - Insights to the Tin Bronze Metallurgy in the Early-Middle Bronze Age of Iranian Plateau: The Case of Deh Dumen, Southwestern Iran

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Although, the evidence of tin bronze metallurgy has been observed in the third millennium BCE (Early/Middle Bronze Age) in the Iranian Plateau but there is no comprehensive image about rise and development of this metallurgical technology in this region. Recent archeometallurgical studies revealed that the western/southwestern Iranian Plateau should be known as the region in which the production of tin bronze objects has begun, while this alloy was predominant in central and northern parts of the Plateau later in Late Bronze Age and Iron Age (second-first millennium BCE). Furthermore, tin bronze has not been used in eastern Iranian Plateau eighter in bronze Age nor in the Iron Age and copper and arsenical copper were predominant metals in that region. The Bronze Age graveyard of Deh Dumen located at the southwestern Iran in the Zagros mountains, is one of the recently excavated archaeological sites in which numerous ritual metal objects have been discovered from the graves. Although, some analytical studies have been performed on few objects from early excavations of the site, but the studies were developed in the recent years and some new results are achieved. In this paper, results of chemical and microscopic analysis of a newly studied group of metal objects of Deh Dumen graveyard are presented. The objects were analyzed using ICP-OES, SEM-EDS and metallography techniques due to identification of their alloy composition and manufacturing processes. Furthermore, the new results were compared with the previously available data. The results revealed that the tin bronze has been used as the predominant alloy for objects production while some evidence of arsenical copper and leaded copper are also visible. The results well prove the rise and development of tin bronze application in the southwestern Iranian Plateau during the third millennium BCE.

O70 - Minoan Copper Trade in East Crete

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: In the economy of the Aegean Bronze Age, copper was an essential material, even though the local deposits were relatively small, and they could not meet the demand as it grew over the course of the millennia. Copper sources in the Aegean changed during the Bronze Age from reliance on deposits north of Crete including Lauvrion and Kythera to much larger deposits in Cyprus and occasional imports from much farther east.

A case study on the role of copper in the trade network that focused on East Crete is important as a microcosm of the challenges faced by Bronze Age communities across the Aegean. This paper will address both the origins and the important practices governing the role played by copper. Recent analyses of finds from Mochlos and Gournia in eastern Crete provide new information on the metallurgical tradition of the Minoan civilization.

The studied pieces come from Gournia and from Mochlos, and most of them consist of fragments of oxhide ingots (altogether 4 fragments from Gournia and 112 from Mochlos), but there are also smaller irregular pieces, scrap, working remains, and semi-worked materials. A few pieces of ingots had been analyzed by N. Gale and Z.A. Stos-Gale in the past to determine their origin, and they all seem to come from the copper mine of Apliki in Cyprus. The new analyses by XRF and SEM-EDS elucidate the circulation of metal and the working habits of the metalworkers.

Blanks for the production of small tools and strip bundles were important semi-worked materials for the local workshops and indicate a multi-staged trade and organization.

O71 - Metal procurement and exchange on the north coast of Cyprus during the Early and Middle Bronze Age

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Metal procurement and exchange have often been considered the backbone of the socio-cultural changes occurring during the Prehistoric Bronze Age in Cyprus (*PreBA*; c.2500-1700 BCE). Nevertheless, despite some early studies (e.g., Balthazar 1990) and a few more recent ones (e.g., Charalambous and Webb 2020), only a small sample of the island-wide corpus of metal artefacts has been systematically analysed in terms of their composition. The present analytical work concerns the interdisciplinary investigation of more than 280 copper-based artefacts, coming from the *PreBA* sites of Lapithos *Vrysi tou Barba* (excavations of the Swedish Cyprus Expedition) (Gjerstad et al., 1934; Webb 2020) and Bellapais *Vounous* (Dikaios 1940; Stewart and Stewart 1950), located on the north coast of Cyprus. The analysed material consists of various artefact types (e.g., weapons, tools, ornaments), originating from multiple mortuary contexts of different chronological sub-phases of *PreBA*, which were non-destructively analysed using a handheld XRF instrument for determining their alloy-type. The results of the chemical analysis show that, at least for the latter phases (c.2000-1700 BCE), the predominance of arsenical and unalloyed copper artefacts is clear in both cases, with the presence of tin-bearing alloys and other rare alloys also noted. Tin occurs slightly more extensively in Lapithos (16%) than in Bellapais (9%), while the higher tin concentrations were mostly detected in specific artefact-types, similar at both sites. Of much interest is the analysis and identification of one speiss fragment, the only example ever found in the north coast of Cyprus. The results interpretation clearly demonstrates the importance and crucial role of both Lapithos and Bellapais during PreBA, suggesting that the two sites were involved in the maritime metals trade, which linked southeast Anatolia and Aegean (Cyclades) with the north coast of Cyprus, providing the local metalsmiths with alloying materials that were not available on the island.

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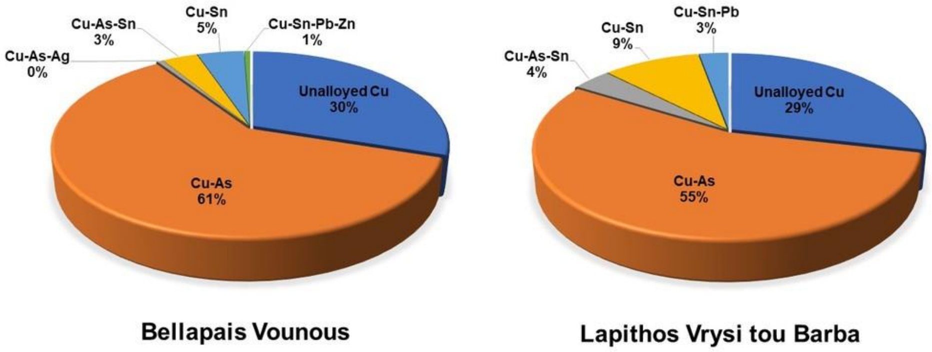

Figure 1. The alloy distribution in Bellapais Vounous and Lapithos Vrysi tou Barba

O72 - THE WIND FURNACES OF THE ATACAMA SALT FLATS, NORTHERN CHILE: EXTRACTIVE METALLURGY OF COPPER ON THE INKA ROAD

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The extremely arid conditions that characterize the Atacama Desert defined the character of the metallurgical operations that took place in the region. The location of the copper mines, in remote and low-productivity areas, made transportation a critical aspect of the mining-metallurgical organization. At the same time, the lack of availability of wood fuels led to the search for innovative solutions, highlighting the use of wind as a defining feature of this metallurgical tradition, starting with the location of metallurgical reduction furnaces in naturally well-ventilated places, in addition to a specialized use of vegetables fuels. These would be strategies of adaptation to the fuel sources available in the most arid desert of the world.

This contribution reports the main results of the study of the metallurgical reduction furnaces of the Catarpe Túnel site, where six semi-buried stone furnaces have been identified with a rectangular plan and lengths of between 2 to 4 m, located in cliff edge sectors on the edge of a ridge of hills on the western margin of the Cordillera de la Sal (2. 640 m asl), showing an orientation perpendicular to the direction of the prevailing winds, in association with the section of the Inka Road and in proximity to Catarpe Este, the most important Inka administrative center in the Atacama salt flat. These characteristics suggest a technology like that of the furnaces of the southern highlands of Tarapacá in Collahuasi (northern Chile) where more than 50 natural draft furnaces were found with the use of wind as a key resource for the development of metallurgical operations (Figueroa et al., 2015, 2018).

The development of excavations carried out in the furnaces allowed the recovery of an abundant amount of slag, metallic copper, charcoal and seeds remains, copper ore, ceramics, clay, and highly fragmented bone remains. Although the operations would have been carried out by a group of local metallurgists, the processing of five radiocarbon dates allowed to place its operation in contemporaneity with the Inka expansion. On the other hand, a series of archaeometric analyses of elemental chemical composition determined that the operations were oriented to obtain unalloyed copper prills from the reduction of atacamite, clinoatacamite, brochantite, chrysocolla and azurite.

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O82 - Spread of the products and technology of copper metallurgy in the Carpathian Basin from 5000 BCE to 3000 BCE

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Although present-day Hungary is rich in Copper Age copper artefacts and the country is surrounded by areas rich in copper ore deposits, many of which are well examined geochemically, the origin of the raw material of these copper objects is not known due to a lack of appropriate archaeometric investigations. The Carpathian Basin was an important link between South-eastern and Central Europe, so it is likely to have played an important role in the spread of the technology of metallurgy, but little is known about the details. Therefore, our project combines lead isotope and chemical compositional analyses with radiocarbon dating to investigate the origin of the raw material of the copper artefacts, whether potential Carpathian Basin sources were exploited, whether there were differences in the use of sources between Western and Eastern Hungary, and whether supply areas changed between periods. The studied objects comprise Late Neolithic, Early, Middle and Late Copper Age copper artefacts from Hungary. Additionally, copper ores from several deposits in Hungary and from the Banat and Bihar regions in Romania were also analysed due to the lack or low amount of lead isotope data.

The raw materials of the Early and Middle Copper Age artefacts originate from several different ore sources. In the case of the Transdanubian artefacts, copper probably originated from the North-western Carpathians (Siklósi et al. 2022), whereas the majority of raw material of the copper objects from the Great Hungarian Plain sites derived from the Balkans (Siklósi & Szilágyi 2019).

The copper artefacts of the Early Copper Age Magyaregres hoard are homogeneous in terms of their raw material, and they probably originated from the same source area, were made in the same workshop, or even at the same time (Siklósi et al. 2022). In contrast, in the case of the grave-goods on the Great Hungarian Plain, they probably did not originate from the same ore source (Siklósi & Szilágyi 2019).

From the Middle Copper Age onwards, there are traces of local metallurgy, and the exploitation of north-western Carpathian or probably north-eastern Hungarian sources is highly probable. By this period, the centuries after 4000 cal BCE, access to Balkan sources ceased.

The project is financed from the NRDI Fund (NKFI FK 124260, ’The spread of the products and technology of metallurgy in the Carpathian Basin between 5000 and 3000 BC’ PI: Zsuzsanna Siklósi). The chemical compositional analysis was financed by the IPERION HS (TRENCH project).

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O83 - From Ricardian productivity to matrilocal consumption in Iron Age Cambodian and Thai copper-base metallurgy

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Lopburi Province in central Thailand has been known as a major centre for prehistoric Southeast Asian copper production since the late 1970s and was, for decades, assumed supply the whole region. This assumption unravelled from 2008, when the Southeast Asian Lead Isotope Project gradually exposed the near total absence of the central Thai copper production signature from regional copper-base consumption assemblages. This was partially predicted, based upon technological analysis of the Bronze Age (ca. 1200-500 BC) Non Pa Wai and Nil Kham Haeng copper smelting assemblages, which indicated low-efficiency-low-effort, and higher-efficiency-but-very-high-effort production, respectively. Both behaviours are suggestive of low productivity, which according to Ricardo's Law of Comparative Advantage, would suggest that smelters could not obtain good terms of exchange.

Fifteen years on, and a new archaeometallurgical study of satellite copper smelting sites in Lopburi Province: Khao Sai On, Prommatin Tai and Tha Kae, reinforces this by demonstrating a range of low productivity later Iron Age and Early Historic (ca. AD 200-800) production behaviours. Finished copper-base artefacts from these sites were analysed for their lead isotope ratios and, astonishingly, not one was compatible with the local production signature. Comparison with central Thai lead isotope datasets for Bronze and Iron Age sites confirms this trend, with hundreds of artefacts found in the vicinity being incompatible with local copper sources. This strongly suggests Lopburi Province copper smelters had no access to relatively nearby tin mineralisations and were forced to import bronze. Indeed, it appears that copper was produced to exchange for exotics like glass and carnelian, and thus enable Iron Age central Thai populations to participate in networks that extended from China to the Mediterranean.

Furthermore, the study of 79 metal artefacts from Non Ban Jak, in lower Northeast Thailand, gives us an opportunity for a high resolution examination of copper-base consumption behaviours only 165 km east of the production sites. Again, there is no sign of central Thai copper being consumed, even given the presence of west-central Thai lead signatures, the metal for which would have passed through the copper producing areas. Adding Non Ban Jak to the database of several hundred copper-base artefacts for northeast Thailand and northwest Cambodia, it is now possible to identify precise shared signatures within and between sites, even down to the level of individuals. As all linked individuals are male, it would appear confirmation of regional Iron Age matrilocality, as identified by dental strontium isotope patterning.

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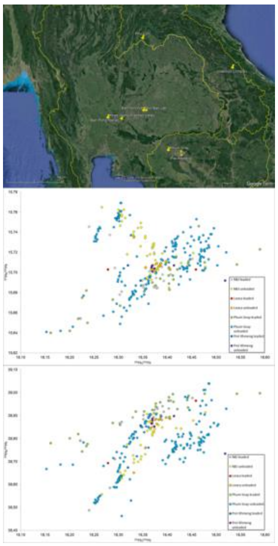

O84 - Copper-based metalwork and social interaction in Atlantic Iberia: Late Bronze and Early Iron Age palstave hoards as case study

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Palstaves are the most abundant metal object in the hoards of Atlantic Iberia from the Late Bronze and Early Iron Ages. These hoards provide relevant information about the technology and provenance of copper-based metalwork in the Atlantic façade as well as its social implications, but relatively few of them have been systematically studied using current approaches.

In this contribution we present the results of the study of three important palstave hoards from northwestern Iberia: Agro Vial (Quiroga, Lugo), Bardaos (Tordoia, A Coruña) and Ameixenda (Ames, A Coruña). A total of 32 palstaves have been examined and analysed. Our research included the analysis of their context and circumstances of discovery, the visual examination and documentation of the objects, their typological assessment and the elemental and lead isotopic analysis of a selection of palstaves. The new XRF analyses made both on the bulk metal and drill shavings have been compared with legacy data obtained by Atomic Absorption Spectroscopy, and considered in the light of our analytical database.

The results show that the palstaves were produced using tin-bronze (Agro Vial) and leaded-bronze alloys (Bardaos and Ameixenda), which probably reflects chronological differences between them. These results are consistent with the analyses available for palstaves of the same types belonging to other deposits. Some of these types have a smaller distribution, while others have parallels in central and northern Portugal. Nevertheless, the three hoards share a very specific feature: the presence of decorated palstaves. In addition, lead isotope analyses carried out on several axes from the Bardaos hoard suggest that the lead comes from the south of the Iberian Peninsula.

Taken together, these data offer interesting perspectives for the study of metallurgical production and social interaction in the Late Prehistory of the Atlantic Iberian façade. At the same time, the methodological issues addressed are useful for the study of other bronze hoards.

O85 - A 17-century alchemical scam inspired Mozart to an opera but chemistry developed it to an industrial copper production process in Sweden

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: By arranging an international meeting in Brno 1786, Ignaz von Born sought confirmation for his chloridizing roasting process of silver ore using common salt (NaCl). The process was later developed for treating copper ore at, for example, “Syran”, "Urlakningen" in Falun.

Born was inspired by alchemists but salt was not one of its original principles. The idea came from an alleged medieval alchemical manuscript that later was attributed to Johann Thölde owner of the saltworks at Frankenhausen. Who in his turn was inspired by the alchemist Paracelsus. Mozart and von Born participated both in the local Freemason community and Sarastro in the Magic Flute has a lot in common with the experimenting von Born in the opera.

Since the Enlightenment, chemistry has been very important for developing mining and metal production to great importance for our society.[1] Alchemy on the other hand had a much longer history, but was engaged in finding signs of the presence of higher deities in matter. Alchemist focused on chemical reactions involving phase transitions and colour changes. As exemplified by reacting the other two principles mercury and sulphur to create a blood-coloured mercury sulphide.

In this aspect chloridizing roasting was of interest as the metal chlorides produced have significant lower melting points than the corresponding metals or metal oxides.

The proper chemistry behind the process was described by Th. Witt i Jernkontorets annaler after he had left the British company ”The Swedish Copper Company Ltd” for Falun.[2]

The Swedish Copper Company further developed the chloridizing roasting process by introducing a step where the dissolved copper from the roasting process was precipitated on iron scrap. The precipitate was sent in barrels to England for the final refinement. Jernkontoret constantly complained at the British company for not supplying proper statistics of their production.

The development that starting with a alchemical misunderstanding took two centuries before ending up in an industrial copper process in Falun.

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O94 - Potential of Os Isotope Analysis in Distinguishing Copper Sources of the Southern Levant and Sardinia

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The limitations of the Pb isotopic method for discriminating between copper ore deposits of similar geological age and formation conditions have long been known. In the Southern Levant, similar Pb isotopic characteristics are attested for the copper ores of two major ancient production centers, Timna and Faynan, which are indistinguishable isotopically from the ores of Southwestern Sardinia. The latter region, rich in metal sources, became an integral part of the Mediterranean metal trade network during the Late Bronze Age. We offer a possible solution to a long-standing problem of overlapping lead isotopic signatures of the three named copper-producing centers by applying a new powerful tool: Re-Os isotopic analysis.

Due to the highly siderophile behavior of osmium, it is enriched in Fe/Mn oxide minerals and deriving metal products. The conscious (i.e., as flux) or unintentional utilization of Fe/Mn-oxides in Cu smelting was one of the key features of the Bronze and Iron Age copper technologies of the Arabah. In such smelting systems, the original Os isotopic composition (Os-IC; $^{187}Os/^{188}Os$) of the copper ore, characterized by low Os contents, became overprinted by the Os-IC of the Fe/Mn-oxide. For Faynan, this effect is indirectly attested in the radiogenic Os-IC (5.6-9.0) and high Os concentrations (avg. 3964 ppt) of Fe-rich Cu production wastes (Liss et al., 2020). Likewise, according to our preliminary data, the copper smelted at Timna has Os-IC (1.4-1.7) and Os content (avg. 3351 ppt). The variation in Os-IC of copper from Faynan and Timna is due to differences in the geochemical environment of iron/manganese oxides of the DLS unit at Faynan and Amir/Avrona unit at Timna. Thus, for example, based on radiogenic Os-IC (2.7-6.9) and high Os contents (avg. 756 ppt), Faynan can be preliminarily identified as the provenance region for several IBA copper ingots from Har Yeruham in the Negev highlands.

The Os isotope analyses also prove effective for distinguishing between the copper of Southwestern Sardinia and the Southern Levant. The analysis of several Nuragic bronzetti statues from the sanctuaries in Central Sardinia reveals extremely radiogenic and variable Os-IC (9–74) and high Os contents (avg. 2974 ppt). This is well consistent with the use of copper from the Iglesiente region (SW Sardinia), where Cu and Pb deposits are associated with molybdenite mineralization (i.e., the source of rhenium). The Os-Re isotopic analyses therefore show high potential for disentangling the LBA and EIA copper trade networks of the eastern Mediterranean.

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O95 - Archaeometric Analysis of Metals from Sardurihinili: Copper-Based Alloy Compositions and Metalworking Techniques in the Urartu Kingdom

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The Urartu Kingdom, a dominant political and economic power in Eastern Anatolia during the Middle Iron Age, has left a rich archaeological legacy in the form of fortresses strategically situated within mountainous terrain. As well as providing natural defense against Neo-Assyrian campaigns, these fortifications also served as repositories for agricultural products, metal ingots, and artifacts. The Çavuştepe Fortress, built under the rule of Sarduri II (764-735 BC), was personally named Sardurihinili (The city of Sarduri) by the king, as recorded in inscriptions at the Irmushini temple. Archaeological excavations initiated in 1961 at Çavuştepe, revealed the fortress's complex structure, comprising a royal court, housing and barn, kitchen, cereal depots, cistern, two temples, and a metal workshop placed on an elongated hilltop. In addition, 2017 excavations 1 km north of the Çavuştepe Fortress unearthed a necropolis characterized by simple burials and urns containing skeletons, some of them accompanied by a range of elaborate grave goods, including seals. This discovery suggests the presence of an elite population associated with the fortress, highlighting the complex social stratification of the region during this period. Therefore, metal finds, including jewelry, metal belt pieces, and tools that were revealed from recent excavations in Çavustepe necropolis and fortress, hold significant potential for understanding the alloying and metalworking practices of products used by the Urartian elites. Following this aim, this paper presents the results of our ongoing archaeometric research on Çavuştepe. The pXRF, metallography, SEM-EDS, and microhardness studies of gold, silver, bronze, and iron objects will be presented with a special focus on copper-based alloy craftmanship and alloy compositions. Preliminary evaluations of the copper working remains from the metal workshop, and metal belts with gunmetal compositions (copper, tin, and zinc) will be exclusively discussed with reference to current studies on Urartu metals in other collections.

4. Archaeometallurgy of iron

O5 - Cast Iron Production in Southern Germany without blast furnaces since the 10 th Century AD.

4. Archaeometallurgy of iron

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Abstract text: In southern Germany, east of Stuttgart in the foothills of the Swabian Mountains, there are marine sedimentary iron ores that have been mined extensively since the early Middle Ages in thousands of pits. At the beginning of these activities, the ore was smelted using modified bloomery furnaces, which produced a bubbly, foamy slag, rich in olivine. This produced malleable soft iron. From the 10th century AD onwards, this smelting technique developed into a new smelting variant with which pig iron could be produced on a larger scale. From then on, the metal was smelted in more advanced shaft furnaces, which were somewhat larger in size. The furnaces had an oval footprint of max. 1 m2 and were perhaps 1.50 to 2.00 m high. The wall thickness at the base was approx. 20 cm. As with simple bloomery furnaces, the enlarged shaft furnace was also used to reduce the metal to pig iron without the use of water power in locations partly far from the water. The smelting furnaces did not run permanently and had to be opened from time to time to remove the metal formed. However, the slag formed during smelting could be continuously tapped off. The refinement of the process used was the targeted addition of lime as a slag-forming agent. However, this required higher smelting temperatures along with carburization of the metal reduced from the liquid phase. This made it possible to achieve a much higher iron yield than in the direct process, but the result was high carburised iron that could not be forged without post-treatment. This was done by a downstream refining process out of the furnace. Nevertheless, with the addition of lime, it was possible to exploit the relatively iron-poor marine-sedimentary deposits in the surrounding area to a large extent in order to extract metals from them. The addition of lime created calcium-silicate glasses during slag formation, as they are also formed in the modern blast furnace process. These were continuously tapped whilst the pig iron presumably remained at the bottom of the flat-bottomed furnace and was not tapped.

Future material investigations will be reserved for clearly distinguishing between bloomery iron and freshed metall in the medieval period and investigating the fresh processes in more detail

O6 - Iron armatures in Notre-Dame de Paris: a new understanding of iron provenance and uses based on multifactor study for network analysis

4. Archaeometallurgy of iron

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Abstract text: Following the fire at Notre-Dame de Paris on April 15, 2019, the setting up of the scientific program coordinated by the French National Centre for Scientific Research, coupled with the restoration works on the cathedral, presents an unprecedented opportunity to study the monument. The clearing, sorting and inventory process of the remains of Notre-Dame de Paris first revealed a great diversity of iron reinforcements within the gothic building. The study of these armatures not only contributes to our understanding of the monument but also unveils economic and social practices and their evolution throughout its construction phases. More specifically, the archaeometallurgical analyses of the iron armatures can provide information on metal production and circulation, the manufacturing processes or their role in the structure of the building, along with the dating of the material.

Cramps are the main armatures found in the masonry of the tribunes and in the upper parts of the monument. The restoration works also revealed various tie-rods, pins, ridge caps and framing irons such as nails, bolted rods or keyed dowels. The cathedral's restoration work in 2023 enabled on-site observations of various types of iron reinforcement, encompassing a corpus of over 400 cramps located on the upper walls. Currently, over 120 objects were collected for analysis and 50 of these ferrous armatures from different collections have already been studied. The quality of the metal production was highlighted by metallographic analyses. Artefacts with sufficiently high carbon content underwent radiocarbon dating, revealing the different construction and repair campaigns within the cathedral's history. Slag inclusions were analyzed by SEM-EDS (major elements), providing insight into iron manufacturing processes, while LA-ICP-MS (trace elements) was used to help determine iron provenance. Trace element composition of slags from 32 archaeological iron production sites near Paris was also determined by MC-ICP-MS, to compare them with the composition of slag inclusions and propose or discard provenance hypotheses for the supply of Notre-Dame's building yard.

These archaeometallurgical studies reveal a great diversity of iron sources and contribute to a renewed understanding of iron circulation and trade in medieval Paris. They reveal potential recycling of the iron employed in the cathedral's construction and highlight the craftsmanship of blacksmiths through discernible forge marks, particularly on cramps. These observations and analyses will be emphasized through network analysis considering at the same time the iron sources, the forge marks and shaping of the iron, their dating and location in the monument.

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O7 - The use of steel in Scandinavia from the Iron Age to the Viking Age.

4. Archaeometallurgy of iron

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Abstract text: The introduction of steel and the changes it brought about in forging techniques seem to have had a different course in the Nordic countries. While steel was already known on the continent in the La Téne period, knowledge of it comes later to Scandinavia. While the number of examined objects from Norway and Sweden is limited, so that the development in materials and forging techniques can be difficult to follow, several hundred objects in Denmark have been analysed. A more detailed picture can therefore be drawn here.
In Denmark, steel is apparently recognized as a special material later than in Norway and Sweden, and it only gains real traction in the Viking Age. However, there are some examples of imported objects as early as the 1st and 2nd centuries AD. There are even examples of the use of an extreme type of steel with up to 1.4% carbon, which is otherwise only known from the VLFBERHT sword of the Viking Age. It is thus found in what is probably the most specialized tool from the period, namely the crescent-shaped knives, which have often been taken to be razor blades.
These knives seem most often to have been made of iron with an unusually high content of phosphorus. Something that has made them more resistant to corrosion; but which has also made the metal brittle. This must have been of great importance, as the knives are often only about 1 mm thick, and avoiding corrosion may have played a large role in the choice of material. In some cases, however, steel with an unusually high carbon content has been used. Something that has both made it difficult to forge the very thin knives; but also a material that will break easily with rough use. The steel type has been associated with the production of crucible steel in India and Pakistan; but in these cases it is rather steel from Norikum in present-day Austria.
The blades for VLFBERHT swords are most often assumed to have been forged in the Frankish Empire; but in recent years several forging sites from the Viking Age have appeared in Denmark and Norway, where small processed pieces of high-carbon steel suggest that the difficult forging of the material has also been mastered locally. There is even the indication that, by carburizing, it has been possible to produce smaller quantities of the unusual steel type.

O8 - Understanding bloomery smelting through currency blooms from Estonia

4. Archaeometallurgy of iron

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Abstract text: Close to 40 currency blooms have been found from Estonia. The few of them that have been dated were made in the 11th to 13th century AD and many of them have been found as hoards containing from 3 to 9 blooms (Figure). They were probably buried into the ground in times of conflict, but were never retrieved. They can be defined as a product of one successful smelt in a bloomery furnace after which they have been consolidated and given a certain shape, which can be rectangular, loaf-shaped or round. They have not been folded and forge welded. The uniform shape of many blooms indicates that the rectangular shape was to most standard one and it is likely the shape that was used for trading.

Recently many of these blooms have been sampled for provenance and metallographical analysis. The provenance analysis enabled to link some of the finds to certain Estonian smelting sites. However, the focus of the paper will be the metallographic analysis as it gives valuable information about the bloomery smelting process. The currency blooms enable to look at the iron just after the smetling process before it was hammered or carburised.

They also provide useful information about the volume of one smelt: the weight of the bloom reflects what could be considered a "normal" output. This is compared to the recent successful smelting experiments, where the output has reached a comparable or even larger weights than we see in the case of archaeological currency blooms. Hence, we can say that in terms of weight, the experiments have reached an understanding deep enough to draw meaningful conclusions.

O21 - Metallurgical investigations of osmund iron

4. Archaeometallurgy of iron

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Abstract text: For several centuries, Swedish osmund iron was a major commodity on the European iron market. Yet, despite substantial research, the nature of osmund iron is still not fully understood. Medieval written documents such as tax and customs records may reveal how many osmunds were produced and exported, but they do not explain how osmund iron was produced, or how it differed from other iron types. One approach to answering such questions is by investigating the quality and composition of osmund iron. Such analyses were initiated already in the 1970’s, and were able to provide some answers about osmund production. Following the discovery of the Swedish Osmund ship in 2017, which had about 100 barrels of osmunds in the cargo, there has been a renewed interest in understanding the quality and properties of osmund iron. Unlike debris from production sites, osmunds from cargo ships were clearly intended for export. They therefore represent the best osmund quality of their time. Here, we present the current understanding of what osmund iron is. We review, assess and interpret the main results of technical examinations of osmunds from four different archaeological sites and time periods: Lapphyttan, a Swedish blast furnace production site in use circa AD 1150 – 1350; the Tarvastu order castle in Estonia, dating to the 14th c., together with neighbouring Medieval sites; the Copper Ship, a 15th c. cargo ship found in Gdansk harbour, Poland; and the Osmund Ship, a 16th c. cargo ship found in the Stockholm archipelago, Sweden.

O22 - The Osmund wreck- A unique wreck found with a unique cargo

4. Archaeometallurgy of iron

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Abstract text: In 2017 a ship wreck was found in the Stockholm archipelago. The wreck is unusually well preserved for a ship built with clinker technique. It also has its cargo still in place. There are a little over 30 barrels visible, mostly containing so called osmund iron. No similar wreck has ever before been found in Swedish waters.

The wreck has three masts (the main mast still standing in its original place) and all it's the rigging seems to be intact at the site. It seems that the wreck is almost totally intact so it's a unique ship wreck in many ways.

In October 2022 an excavation was conducted. A 4x2 meters shaft was dug with an airlift. The result was that 20 really well preserved barrels was found and most of them with Osmund iron. The results also showed that that ship contains about 80-100 barrels.

Iron exports was then, and still is, one of Sweden's most important exports but the knowledge of historic cargo ships, the trade routes and the quality of the iron is almost unknown. This ship is one of the most important finds to date and can tell us much more about how the iron was transported, how export was organized and what kind of ships were constructed for iron cargo.

Methods: The date of the ship is based on dendro. It date´s the wreck to 1540´s (provenance Stockholm) and has been repaired in the 1550´s (provenance, south of Finland).

Results: Based on the archaeological surveys this paper discusses the shipwreck, its construction, export, the rigging, the cargo and the possibilities for further study of the history of the Swedish iron industry through a ship wreck still fully equipped and comparable to a time capsule from 1550. This is the time just after the Swedish king broke with the Hanseatic league and wanted to control the export himself.

Conclusions: When the well preserved barrels was documented it was clear that the barrels with Osmund iron had a different construction. The construction might have to do with custom in Stockholm where you had to show the whole content before export. The excavation gave some stunning result that can give more clues to how the export was organized and how the ships looked like sailing the cargo.

O23 - On the Anvil or in the Fire ? Smithing Waste Quantification and the Measure of Loss of Iron during Smithing.

4. Archaeometallurgy of iron

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Abstract text: Plano-convex bottom slag (PCB) and hammerscale are the most typical waste formed during iron smithing. For 25 years, they are recognized as such and, more and more frequently, they are recorded by archaeologists and studied by archaeometallurgists. Several tens of PCB's assemblages are described in the literature, including morphology, morphometry, chemistry, mineralogy and metallography. The study of archaeological hammerscale is much less developed with only a handful of papers.

Recent material studies using chemical (XRF), mineralogical (XRD) and textural (SEM) techniques were performed on hammerscale from several archaeological sites in Switzerland (Sévaz FR, Grandson VD, Vufflens-la-Ville VD, etc.). Combined with studies of the other associated types of waste (PCB's etc) and with the results of experiments with African smiths in Mali, those data provide a new insight for the interpretation of smithing waste assemblages.

In the archaeological record of smithing workshops, it is striking that the mass ratio between hammerscale and slag is highly variable from one site to another.

There are main biases caused by the unequal conservation patterns of the different types of waste in the archaeological sediment and the variable recording methods (sampling, sieving) used during excavation. Despite these difficulties, we will address some technical parameters contributing to the high variability of this mass ratio. The consequences on the quantification and interpretation of the waste assemblages will be discussed.

O24 - The iron industry in the eastern half of the Pyrenees from Antiquity to the 17th century: new data and research perspectives

4. Archaeometallurgy of iron
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Abstract text: The eastern half of the Pyrenees has been involved in the iron industry since ancient times, from the Roman Antiquity to the modern era. This mountainous area contains very large deposits of high-grade iron ore and enormous timber resources. It is also a component of trade networks linking the Iberian Peninsula and Gaul on the one hand, and the Atlantic Ocean to the Mediterranean basin on the other. Despite high-quality archaeological and historical studies led previously on the Roman Antiquity (Dubois 2000) on one hand and the late medieval (Verna 2001, Téreygeol & Gauthier 2016) and modern periods (Cantelaube 2005) on the other hand, the long-term dynamics of iron production remained imperfectly known, due to numerous chronological gaps. This concerns especially the late Antiquity and early Middle Ages periods. In addition, certain aspects of the siderurgic economy needed to be studied more thoroughly, in particular ore supply strategies and the distribution of metal products.

The aim of the FERMAPYR (2019-2022 – FEDER L'industrie du FER dans le MAssif des PYRénées) and FERAPO (2021-2026- PCR Le FER en Ariège et dans Pyrénées-Orientales) programs is to draw up a synthesis of new data on iron industry based on interdisciplinary research. This is done at the scale of the eastern half of the Pyrenees over the long term: from Ariège to the Pyrénées-Orientales departments; from Antiquity to the middle of the 17th century. The work is based on the interdisciplinary collection and processing of data: fieldwork (prospecting, test pits, field surveys, etc.); examination of archive collections and extraction of unpublished documentation; laboratory work (typological and archaeometric studies of artefacts: ceramics, slag, iron bars, charcoal, ore, C14 dating, etc.); recording of data in a shared computer database with the support of the Huma-Num Paris Time Machine Consortium.

After more than 5 years of research, we would like to present these interdisciplinary and diachronic projects and their archaeological and archaeometric results.

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O36 - A 14th-century Baselard dagger from Bystrá, Czech Republic – some notes on its manufacture

4. Archaeometallurgy of iron

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Abstract text: The dagger was found in 2019 during preventive prospecting of abandoned roads in the forest area between the village of Bystrá and the town of Humpolec. The artefact was found under the forest floor, stuck into the ground at an angle of about 45°. The find can only be generally dated between the 14th and 15th centuries, although the 14th century is more likely, and can be considered as an object lost in connection with traffic on the local road connecting Humpolec and Jihlava (in general the historical territory of Bohemia and Moravia).

The blade of the dagger (now in two fragments) is relatively wide at the shoulder and has two parallel fullers running roughly halfway down the preserved parts of the blade. It is therefore a type of high to late medieval dagger, the so-called Baselard, which was not very widespread in north-eastern Central Europe but was characteristic of the area of the Swiss cantons, southern Germany and northern Italy. It is likely that the examined specimen originates from this area. In addition to the blade, metallic components of the hilt have also survived. In particular, there is a non-ferrous crossguard with downward coiled ends decorated with beast's heads, for which we have found no analogues in Central Europe, and a sheet metal fitting for the grip.

As part of the conservation-restoration treatment, an extensive survey was carried out to obtain as much information as possible about this interesting artefact. Among other things, X-ray radiography revealed pattern welding in the fullers and metallography showed that the blade edges, at least in the upper part of the blade, were made of phosphoric iron.

Considering all the information gathered so far, the dagger can be presented as one of the very few examples that improve our knowledge of the manufacture of these objects. In addition, as phosphoric iron could be used both accidentally and deliberately, especially in combination with pattern welding, the question of its use in 14th-century (luxury) iron products will also be discussed.

O37 - Discovering the wheel-lock mechanism of a 16th-century weapon from Brescia Museum of Arms, Italy: microstructural analysis and production technique

4. Archaeometallurgy of iron

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Abstract text: The invention of a fully automatic igniter using the so-called wheel mechanism dates back to the early 1500s [1]. This was a fairly sophisticated mechanism for the time, consisting of many pieces: a knurled wheel (which could be loaded with a spanner), a spring-loaded arm (the dog) holding a piece of pyrite between the vise-like jaws, and a pan with a lid (pan cover), filled with very fine gunpowder [2]. Until now, few studies have comprehensively characterized each component of the wheel-lock mechanism. Hypotheses have often been based on mechanical properties and production techniques, without actual confirmation [3,4].

This work aims to provide reliable information on the production technique of ancient wheel-lock mechanisms and the high degree of metallurgical specialisation in the 16th century. Analyses were carried out on a late 16th century wheellock from the Museo delle Armi 'Luigi Marzoli' in Brescia, and of German origin. The museum houses a collection of antique weapons and armour, which is one of the richest and most unique in Europe. Samples were taken from various components of the wheellock mechanism, including the wheel, wheel cover, main spring, pan, pan cover, dog, dog spring, and sear. The purpose of the study was to identify the manufacturing process of each individual part. Microscopic analysis was conducted using the Metallographic Optical Microscope (LOM) and the Scanning Electron Microscope (SEM). The characteristic microstructures and hot-forged lines detected were essential in identifying the thermal and mechanical treatments undergone by the materials during their manufacturing process.

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O38 - Knives, obeloi and swords from the Sanctuary of Zeus Parnessios. New evidence for ancient iron technology.

4. Archaeometallurgy of iron

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Abstract text: The present paper deals with the technological study and scientific analysis of iron objects of the early pre-Christian millennium. The material for this research comes from the excavation conducted in 1959, in a cave on the summit of Parnitha, the highest of the three mountains of Attica which from the limited until now study of the findings, seems to have had a religious function, and was dedicated to Zeus, with artefacts dating, based on the pottery, from the Late Geometric to the Late Archaic Period.

Among the artefacts, there are more than four thousand iron objects, mostly knives of various sizes and types, as well as a large number of spits (obeloi) and seven Naue II swords. In addition to their large number, the iron objects are of particular interest because of their very good state of preservation, covering at the same time a wide chronological range of more than three centuries.

The aim of this paper is to present the results of the analytical methods applied to study the microstructure and the history of the manufacturing processes of the artefacts, creating at the same time a specific protocol for the analysis of archaeological iron.

Thus, X-ray radiography (X-ray) that was first applied, after macroscopic and microscopic examination, was followed by the also non-destructive technique of X-ray fluorescence spectrometry, using a portable device (p-XRF).

Scanning electron microscopy (SEM) coupled with an energy dispersive spectrometer (EDS), optical microscopy (OM) and Vickers hardness test (HV), were the destructive methods applied on samples taken from specific objects, for more precise compositional and technological information.

The archaeometallurgical examination of the material and the multi-analytical approach used, within the framework of a recently completed doctoral thesis, to investigate iron technology (smelting, smithing, mechanical and thermal treatment), constitutes an original contribution to the study of iron metallurgy in the early historical periods. In summary, the research sheds light on a largely unknown aspects of the Early Iron Age, offering new insights into issues such as the deliberate production of steel and the smelting of iron from laterites.

O39 - The hoard from Prakhon Chai. A new insight for provenience and dating of the Buddhists bronze images from the study of their historical iron armatures

4. Archaeometallurgy of iron

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Abstract text: In 1964, a cache of Buddhist bronze images, the most important ever discovered in Southeast Asia, was found in a burial pit on the grounds of a tenth-century Buddhist brick temple in Lahan Sai district, Buriram province (present-day northeastern Thailand). The hoard, whose original term that referred to was Prakhon Chai, includes preaching Buddhas, four-armed Bodhisattva Maitreya and Avalokiteśvara. After discovery, the pieces of the hoard were dispersed to collections both within Thailand and abroad, resulting in a great loss of information.

The images are lost-wax cast in a copper alloy and for the larger ones, iron armatures were used to build and/or secure the clay core, and provide stability during the casting process. Interest in these religious objects has largely focused on their aesthetic/religious traits and stylistic chronological associations facilitated by analogy with stone images. A very few dating data were supported by thermoluminescence analyses of core material, and compositional analyses of bronze samples were done to determine the compositional range of the alloy usually identified on the Prakhon Chai bronzes. While the ensemble is relatively coherent in technical and stylistic terms, distinctive features have nevertheless been identified that may testify to several traditions.

Our research aims to document these statues in a new way, particularly in terms of their origin and dating, by providing data from the investigation of a previously undocumented component: the iron armatures. The milestones of our method are multiple. They depend both on the type of sample it has been possible to extract from the statues, on recent methodological developments, and on the content of the database of the IRANGKOR research project, which focuses on iron metallurgical activities in the Angkorian kingdom.

We propose to discuss the contribution of this ad-hoc approach which combines several analyses (metallographic, chemical, ICP-MS, SEM-FEG, LA-ICP-MS, 14C dating, Os isotopic), to document the provenance and dating of the heterogeneous set of samples. A network of multiple collaborations has enabled the study of a selection of statues from the Asia Society, the Metropolitan Museum of Art, the Asian Art Museum and the Rijksmuseum. The cross-fertilization of data makes it possible to provide unprecedented evidences on the history of these religious icons of the Angkorian world, while a more global comparison of the assemblage sheds light some distinctive features.

O50 - Comparison of Two Neighbouring Early Medieval Iron Production Areas in the Czech Republic

4. Archaeometallurgy of iron

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Abstract text: The iron production played a very important role in early medieval Europe, and it was no different in the territory of today's Czech Republic, especially during the existence of the Great Moravia. Iron was a crucial commodity for two most important pillars of the economy: the intensifying agricultural production and warfare (especially looting raids). A better knowledge of this industry is therefore very important for understanding the functioning of the society of the time. For this reason, I decided to focus on the early medieval (c. 550–1200 AD) ironmongery in the Boskovice Furrow, area adjacent to another, better known, iron production region: the Moravian Karst. These two areas are very different both in terms of the evidence of iron production and natural environment. On the one hand, we have systematically arranged ironworks with several pyrotechnological devices and large waste heaps in the wooded area of the Moravian Karst and on the other hand rather isolated finds of ironmongery activities from the fertile Boskovice Furrow.

For early Middle Ages approximately 13 ironworks localities are known from the Boskovice Furrow and, of course, a refuse of this production (slags, tuyères, furnace linings…) is mainly found. Thanks to the evaluation of this material, it is possible to get a better overview of production on the individual sites and also within the Boskovice Furrow as a whole (the nature of production, its intensity, diachronic development). For example, slags can be divided into several categories (smelting, smithing, ceramic and uncategorized) according to their morphological qualities. However, this method understandably has its limits, so in the case of site Bořitov archaeometric analyses (ED-XRF, pXRF, SEM/EDS...) were used to verify this division on 10 selected samples. Subsequently, several samples of iron ore, obtained from the vicinity of Bořitov, were also subjected to ED-XRF analysis for comparison of chemical composition. In the case of tuyères, according to the discoveries from the Moravian Karst, width of their wall should be theoretically usable for a dating.

After interim evaluation it seems that the iron production in the Boskovice Furrow was probably focused mainly on the needs of the local communities, in the vicinity of whose settlements the ironworks sites are usually being found. On the contrary, massive production in the neighbouring Moravian Karst was, especially in the period of Great Moravia, probably under the supervision of higher ranks of society.

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O51 - Evolution of Iron Productions at Didé Ouest 1 and Birandjikou (Senegal): First Archaeometric Results

4. Archaeometallurgy of iron

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Abstract text: Excavations at Didé Ouest 1, led by A. Mayor in 2018 and then by P. Lamotte in 2022, uncovered one of Senegal's earliest iron production sites, situated in the Falame Valley region. This site is part of a lager metallurgical district, but still seems to be one of the biggest workshops of the area. This technical tradition is characterised by massive tuyeres with perpendicular additional openings, scorified palm nuts, and remarkably high manganese contents in the slag. Small lateritic concretions were probably used as ore.

A complex scenario emerged from the examination of the stratigraphy and datations, with three successive workshops spanning from the 4th century BCE. to the 4th century CE. The spatial distribution of numerous furnaces is correlated with the development of the smelting site (Mayor et al. 2023).

Moreover, the technical tradition identified in Didé bears resemblance with several sites found in the area of Birandjikou, dated from the 1st to the 6th century CE (Walmsley et al. 2020). Some technical features show a clear evolution over the period of activity.

In depth archaeometric analyses have been conducted on slag and ore samples, including bulk chemistry (XRF) and mineralogy (reflected light microscopy, XRD, SEM-EDS). These analyses improve our understanding of the furnace management and on the efficiency of production, but also highlight the differences and evolutions between these sites.

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Walmsley, A., Serneels, V., Hajdas, I., Mayor, A., 2020. Variability of Earrly Iron Production in the Falémé Valley Region, eastern Senegal. African Archaeological Review 37.2, 225-250.

O52 - From the Lebanese mountains to the Carmel coast: the circulation of iron in the medieval southern Levant

4. Archaeometallurgy of iron

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Abstract text: Historians have long been interested in the circulation and trade of iron in the eastern Mediterranean. Because of its strategic role in equipping armies and arming fleets, iron was a key resource in the confrontation between Muslim and Christian powers, from the Arab-Byzantine Wars to the end of the Crusades. Faced with low levels of local iron production, the Muslim powers attempted to meet their needs through imports. To avoid arming their enemies, the Byzantines and then the Europeans tried to forbid the iron trade to the "Saracen" ports. For the historian of medieval trade, this true commercial war over iron was both an opportunity and an impediment. An opportunity because iron was often mentioned in trade treaties (notably between Egypt and the Italian merchant cities) and legal texts. An impediment because official restrictions on this trade tended to make it disappear from the account books, even though it was still carried out in practice. Although there is evidence of an important trade of iron in the Near East, there is still little information on the origin of the metal, or the quantities and forms in which it was transported.

The discovery of six shipwrecks with iron cargoes on the Carmel coast (Israel) between 1982 and 2004 has provided new evidences for this trade (Galili *et al*. 2015). Nearly four tons of iron semi-products were found in the form of bars and partly consolidated blooms. Archaeometric studies have been carried out on shipwreck A in order to formulate assumptions about their dating and provenance. The methodology used includes metallographic examinations, 14C dating on carbon steel and chemical analyses of slag inclusions by SEM-EDS and LA-ICP-MS and the use of multivariate statistical analyses for comparisons.

Thanks to the analysis of six semi-products, a more in-depth look at the shipwreck's cargo is now possible. Radiocarbon dating places it between the 7th and the 8th century and not in the 12th century as previously established. Provenance analyses have revealed that bars and consolidated blooms are not from the same origin and that the bars are close to a production area recently characterised by Gaspard Pagès in the Metn region of Lebanon. These new information shed light on the spread of Lebanese production by sea to ports in the southern Levant and Egypt, and provides crucial information on the wider question of the circulation of iron and its organisation in the medieval Near East.

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O53 - Chronology and circulation of iron production in center-east of France: a diachronic perspective through the TerriFer project

4. Archaeometallurgy of iron

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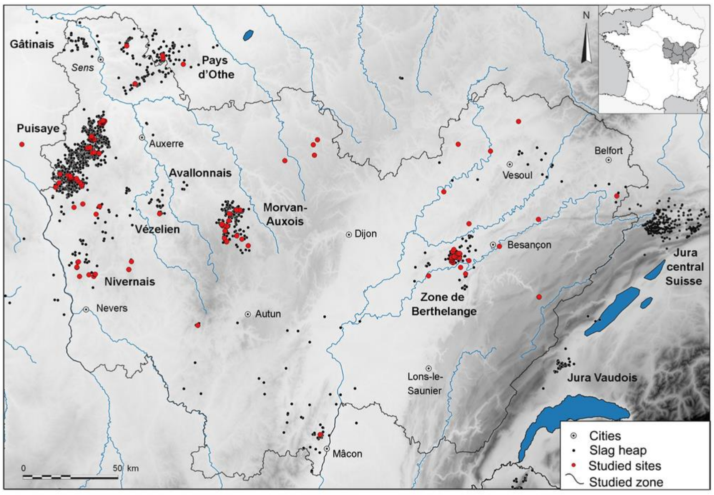
Abstract text: Since the 1980s, archaeological surveys carried out in the North-East and Centre-East of France have led to the identification of more than 5000 iron smelting sites that are unevenly distributed over this territory. Concentrations of workshops permit to identify several major raw iron production areas. However, chronological data remained scarce. Based on these inventories, in the frame of a recent research programme it was possible to date a large number of these smelting workshops by using radiocarbon dating. About 160 new radiocarbon dates were thus acquired. Metallurgical wastes were also systematically collected to characterise the different typologies of slag encountered. Another objective of this research program is to reconstruct the importance of the ironmaking sites in a diachronic manner, based on ore-slag-iron object filiation methodology. The approach is based on the comparison of the chemical signature of the production areas (chemistry of the slag collected in the reduction workshops) with the one of the slag inclusions (SI) trapped in the metallic matrix of iron objects. The study was conducted considering a rich set of objects, amounting to ~100 metal masses analysed, that are coherent from a functional (objects, semi-finished products, work off-cuts) and chronological (Iron Age - Antiquity – Middle ages) point of view. These objects come from major sites for the region (Entrains-sur-Nohain, Bibracte, Alésia, Autun, Mandeure-Mathay), which may have played the role of economic centres.

These results underlined a continuous iron smelting production from the Iron Age to the Middle Ages in major production areas localized in the west (Puisaye - Pays d'Othe, Nivernais), while other smaller production areas, situated in the east, were only active during the Middle Ages (Morvan, Berthelange). The study of the metallurgical debris, coupled with radiocarbon results, revealed also a succession of technical evolutions reflected in the morphology and chemical composition of the slag. At the scale of the studied area, provenance analyses evidenced the importance of some production centres for the Iron Age and the Antiquity who distribute their products several hundred kilometers away, in areas where raw iron is not produced. For the Middle Ages a reorganization of the exchange networks can be identified.

This communication will present the methodology and results of this new work, which substantially modifies our perception of the chronology of iron production in center-east of France, as well as the results obtained concerning the circulation of iron artefacts within the studied region from a diachronic point of view.



The area studied in the center east of France. Repartition of slag heaps (smelting wokshops) and of the studied sites
(credit : Berranger, Leroy, Laurent)

O63 - The technology of massive split bloom production in the early Middle Ages – experimental approach

4. Archaeometallurgy of iron

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Abstract text: The production of iron in the early Middle Ages on the territory of the Carpathian basin is testified by numerous sites with archaeological record on various steps of iron production (both reduction and post-reduction processes are recorded). The area in close focus is the southwestern part of the Basin, the Pannonian plain in today's Hungary and Croatia, where cultural connections are evident through similar technological solutions, dating from the 7th to 9th centuries. The phenomenon of massive split blooms (9–11 kg) is known from three sites in today's Hungary. To define the technology of their production, a layered methodological approach was undertaken – a detailed analysis of archaeological records, and macroscopic analysis of semi-products and waste, upon which a series of experiments involving both reduction and post-reduction procedures were designed and carried out. The results point to two possible technological solutions, with specific operational parameters: 1) smelting - with the objective of maximalizing the output in regards to the design of the furnace, 2) welding - with an implication towards recycling and/or direct welding of smelting produce. The technological possibilities of production showcase a complex set of skills required and point to the use of a new, innovative type of procedure within the chain of operation of iron production. The spatial and temporal background implies that the technological innovation could be an adaptation to emerging cultural and economic changes in the region during the early Middle Ages.

O64 - Exploring Hammerscale Geochemistry: Fresh perspectives on Metal Circulation during the Early Iron Age in Western Europe.

4. Archaeometallurgy of iron

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Abstract text: Understanding the nature and origin of iron processed in ancient smithing workshops is essential for unraveling procurement strategies and, more broadly, the circulation of iron. Studying smithing slags traditionally proves complex due to their diverse compositions influenced by hearth substances. Another technique, analyzing slag inclusions in metallic fragments, offers direct insights into the iron's chemical nature. However, the scarcity or absence of these fragments poses challenges in assessing sample representativeness. An alternative approach studies hammerscale, hot iron waste from hammering, providing insights into iron's chemical composition and source. A preliminary study (Rodier et al., 2024) conducted at the Weyersheim archaeological site (5th century BCE), renowned for its significant iron smith findings, situated in northeastern France has demonstrated the iron smith's dependence on primarily one source of iron. The iron ore utilized for producing this iron is notably distinct, characterized by a high concentration of rare earth elements (∑REE+Y>1500 ppm) and exhibiting a pronounced chemical partitioning between Light Rare Earth Elements (LREE) and Heavy Rare Earth Elements (HREE) (HREE/LREE>2). The prevalent bi-pyramid iron bars recovered in this region also exhibit similar geochemical anomalies. A different archaeological site, namely Sévaz, dating back to the same era but situated in the western region of Switzerland (400 km from the Weyersheim site), is presently under investigation. The archaeological findings highlighted several organizational similarities, such as the iron smith operating within a pit that was refilled after being used. A central inquiry revolves around whether the iron processed at Sévaz shares similarities with the specific iron worked on at Weyersheim. Moreover, despite the last 30 years of research in localizing and dating smelting slag heaps in the Jura Mountain none of them date back to the period of iron age. Examining 234 hammerscale samples retrieved from Sévaz uncovered striking resemblances to the findings at Weyersheim, displaying very similar enrichment levels and chemical partitioning of Rare Earth Elements (REE). Hence, it appears that the majority of the iron present in circulation during this period of the early iron age and in this region likely stemmed from a particular iron ore source or a specific group of ores. The striking resemblances between these two sites, despite being over 400 km apart, pose a puzzling question that remains unanswered definitively to date.

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O65 - Pathways to bloomery iron, smelting strategies during ancient and medieval times in the local communities of the Basque Country.

4. Archaeometallurgy of iron

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Abstract text: For more than 20 years, the archaeologists of the Basque Country Mining Museum are devoted into the research seeking the origin and development of iron reduction technologies in the Basque Country, a region in northern Spain renowned in Europe for its steelmaking tradition.

The continued activity of field-walking, geophysics, archaeological excavation, laboratory analyses of technical materials and experimental archaeology, allowed us to draw an exhaustive map of ironwork sites from Late Iron Age to Late Medieval chronology approx. from 5th cent. BC to 14th cent. AD, and the reconstruction of the complete *chaine operatoire* and to explore the economy model of exploitation during Late Middle Ages, at the peak of the production before the introduction of water-powdered devices. In essence, most of the ironworks were located on mountain ranges slopes adjacent to ore deposits, typically haematite, the ore was reduced in a truncated cone shape furnace and also primary smithed there whereas the manufacture of implements was developed elsewhere. Only recently we have realised that a second type of furnace which predates the medieval one, ─documented during the Late Iron Age, Late Antiquity and Early Middle Ages─ and presenting round or oval shape not excavated in the soil but built up from it, equally producing bloomery iron and generating tap slag.

The aim of this paper is to deep into the interplay of both models, exploring its technological and economical pros and cons, possible origins and evolution, to ultimately propose new hypotheses about the development of these technologies from a long-term historical perspective and its spatial or territorial organization. Specifically, an attempt to estimate the output of the furnaces through mass balance calculation is in process at the moment of writing this abstract, which hopefully will allow a comprehensive technological reconstruction.

Finally, we also want to highlight the substantial dissemination work addressed to non-academic audiences carried on during these years and developed together with the academic research. One of the happiest achievements of this project has been the inauguration of the first permanent open air museum in Spain on the topic, by the faithful construction of a fully functional typical 11th century bloomery iron furnace within the Bizkaia territory mountain rage where a smelting cycle was performed in an experimental archaeology public event.

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O73 - Exchanges networks and manufacturing techniques in the late medieval Aegean: a case study on the Chalcis Hoard

4. Archaeometallurgy of iron

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Abstract text: The late medieval Aegean was an active part of the eastern Mediterranean trade area, connected to numerous exchange networks. Arms and armor, made from ferrous alloys, were strategic commodities broadly exchanged over the Mediterranean. They constitute precious witnesses, which study is essential to ascertain the circulation of raw materials and technical skills.

If objects of this period remain rare, the Chalcis armors are an exception. Discovered in the city of Chalcis (Island of Euboea, Greece) in 1840, this set counts several hundred of various pieces, in large part preserved in the Metropolitan Museum of Art (New York), the National Historical Museum (Athens) and in other European museum collections such as the Musée de l'Armée (Paris). Most of them are identified as Italian made and dated to the 14th and early 15th century[1,2]. Nevertheless, several pieces showed particular stylistic features, contrasting with the Italian style. The objective was to determine whether the analysis of the metal could confirm these specificities and to decipher the homogeneity and geographical origins of the supplies.

Due to the very limited sampling possibilities, the study of such artefacts requires the implementation of a specific methodology. In addition to approaches based on samples examination, non-invasive techniques, such as X-ray diffraction (XRD), are well suited to identify the crystallographic phases and evaluate the heterogeneities of the ferrous alloys. However, its implementation presents analytical difficulties due to the complex shape of armor. This contribution will present the methodology tailored to study the nature and origin of the Chalcis armor by various techniques (metallographic examinations, LA-ICP-MS measurement, SR-XRD at the DiffAbs beamline of SOLEIL Synchrotron).

The results of the analyses carried out on around twenty Chalcis objects revealed the use of various alloys, including ferritic and steel alloys as well as phosphorous iron. A particular craftmanship have been implemented for some pieces, made from hardened steel or steel alloys of significant hardness. It suggests that a particular quality of metal was required for these objects. Furthermore, the analysis of trace elements of non-metallic slag inclusions revealed several chemical signatures, one of which is compatible with a group of Italian-style armors previously characterized. This result strengthens the hypothesis of an Italian manufacture for these artefacts, while other chemical signatures suggest the existence of a regional manufacture of armor. Overall, the results bring new insights into trade and arms manufacture in the Aegean area.

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Examples of armor from Chalcis examined, "A" upper arm defense with an Italian mark detail shown on the reverse side (MMA 29.150.57), "B" Helmet defense (MMA 29.158.42) "C" brigandine plate (MMA 29.150.90ii).

O74 - The field survey revealed a variety of wootz crucibles that show the size of the arm they made in Telangana region

4. Archaeometallurgy of iron

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Abstract text: ABSTRACT

The Wootz, a highly advanced metal from the ancient world, has held a historical hold over three millennia and has a significant control over three continents. The Damascus sword blades were famous since ancient times and all the warriors of the world desired to have a Damascus sword which was high priced. The development and widespread use of Iron and Wootz steel is one such an example. The metal was produced in Telangana region. This metal was having enormous demand all over the world. The Telugu word '*Ukku*' is the source of the word 'Wootz', which has been corrupted. In other Indian languages, such as Kannada *Ukku* and Tamil *Urukku*, the term "*Woos*" is referred to in Gujarati. That means boil or melt. It was produced in small clay crucibles to add more carbon to the metal. Not steel, but a metal with high carbon content of up to 1.8% to 2%. Iron processed with some past of leaves and a piece of wood. The crucibles were kept in a specially constructed furnace and blasted for Twenty four hours so as to melt the iron inside. They were taken out by breaking and kept for annealing for two days (48 hours). The ingots were made in different sizes because the arm was necessary. All the sharp tools were produced by this metal.

Field survey revealed a variety of wootz crucibles that show the size of the arm they made. One ingot used for making one instrument. If arrows were required to make, they were made in small thin clay crucibles. Such small crucible sites were identified in several places.

Since Islamic invaders used sword as an important weapon, then the use of Bow and Arrows was reduced in the later medieval period. Before 15th Century most of the kings were using a Bow and Arrows. The steel itself was produced not in Damascus, but in India and became known in English literature in the early 19th century as wootz steel. Jorge Pearson first used the word ‘wootz’ in 1795 CE in the Philosophical Transactions.

This work based mostly on field work (An Empirical Study) and next on published research papers, contemporary Sanskrit texts, Kaifiyaths, and translated Persian records, Travelogues, and monumental secondary sources.

Keywords: wootz, crucibles, Telangana, Ukku, arms, arrow heads.

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O75 - Iron production in the II Iron Age in the Southern Iberian Peninsula. The Sierra Boyera Oppidum.

4. Archaeometallurgy of iron

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Abstract text: Iron metallurgy in the interior of the Iberian Peninsula continues to be a problem in Spanish research, due to the lack of interest it has generated, as opposed to the numerous studies carried out in the Phoenician coastal area. For this reason, the task of identifying and understanding how iron metallurgy penetrated into Iberia after the arrival of merchants from the eastern Mediterranean to the Andalusian and Levantine coast seems necessary.

The arrival of this type of cultural loans was multifaceted, and the technical meanings were readapted by local populations, prompting changes in the organization of work, a reorganization of productive spaces and daily activities. The first research task that we must address is to identify the materiality of this production in Iberian contexts, how it transformed productive spaces, the mineral collection areas, and the movable and immovable elements related to said production (nozzles, anvils, ovens, slag...); the entire production chain.

The Iberian site of El Oppidum of Sierra Boyera, is located in the north of the current province of Córdoba, in the central area of Sierra Morena surrounded by polymetallic mining veins to which the inhabitants had easy access (Pérez L'Huillier et al., 2022a; Pérez L´Huillier et al., 2022b). The excavation of this site represents a great advance in archaeometallurgical research because it includes a complete blacksmith's workshop, with its respective reduction kilns, forge and anvils to allow the metal work and setting. In this same space, other elements related to this production such as ores, reduction slag, post-reduction slag and smithing slag, bloom, nozzles, furnace walls and their gates were recorded. In relation to the final products, we have found a whole series of tools related to agricultural production made of iron, characteristic of this period. The slags have been analyzed by SEM-EDX (Cristo Ropero and González Zambrano, 2020; Cristo Ropero et al., 2021; Cristo Ropero et al., 2022; González Zambrano et al., 2023a, González Zambrano et al., 2023b).

The Oppidum of Sierra Boyera, therefore, represents one of the few archaeological sites in the Iberian Peninsula in which it has been possible to document the entire operational chain of iron metallurgy in pre-Roman societies of the second half of the 1st Millennium BC., so it opens a new field of research for the future of Iberian archaeometallurgy and how the technology of iron production was modified since the arrival of the Phoenician world to the coasts of Iberia.

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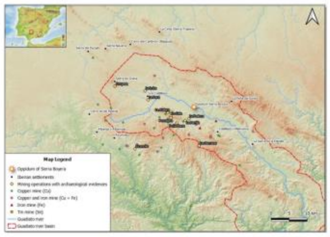

Fig. 1. Situation of the The Sierra Boyera Oppidum.with respect to other Iberian settlements and the polymetallic mines around them

Fig. 2. Photo 1-2 reduction kilns, 3 anvils and 4 forge

O86 - Remains of 10th-12th century iron metallurgy near Kazincbarcika - Archaeometallurgical analysis of slag finds

4. Archaeometallurgy of iron

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Abstract text: Excavations were carried out between October 2021 and August 2022 near Kazincbarcika, in the foothills of the Bükk Mountains in Northern Hungary. In addition to objects from the Neolithic, Bronze Age, Iron Age, and a Roman Age Germanic settlement, many remains of iron metallurgical activities and settlement of a 10th-12th century community were found, including 14 iron smelting furnaces with their associated small rounded or slightly oval slag pits, 3 smaller round reheating furnaces and 10 pit-houses of the period. The bloomeries were arranged in 6 groups. Four of the furnaces were associated with a single workshop, the others were in pairs and each pair was associated with a single working pit. In two cases, we observed that the furnaces were formed in blocks of yellow clay carried into a pit dug into the edge of the working area. The dimensions and wall thickness of the furnaces varied, and in several cases, we observed the remains of multiple layers in the wall of furnaces that had been renewed several times. The number of tuyeres fragments found inside and around the bloomeries and in the slag pits exceeded 100. The furnaces and their workshops can be well compared with the so-called 'Imola-type' bloomeries that were widespread in several regions of the Carpathian Basin between the 10th and 13th centuries. A large quantity of slags of various shapes, associated with different phases of slag formation, was found, from which several characteristic samples were selected and subjected to chemical analysis and microstructural examinations by ED-XRF and SEM-EDS. The slag samples analysed are by-products of iron metallurgy, essentially related to the first phase of iron production, namely smelting. Some of them can be well categorised according to the typical types of slag from medieval iron smelting. The characteristic tap slag was well identified, which is produced relatively early in the bloomery process and flows out of the furnace when it is possible to do so. Several samples could be defined as furnace slags, which are usually sponge-like blocks more heterogeneous than tap slags, usually with many gas holes of various sizes. Embedded pieces of charcoal and furnace wall fragments were also observed in this slag type. Some samples were transitional with the characteristics of both groups mentioned, as well as samples that presumably were detached during the compacting hammering of a hot iron bloom full of slag particles that were removed from the furnace.

O87 - What might iron circulation have looked like in the Merovingian north-western Europe ? From initial results to future research

4. Archaeometallurgy of iron

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Abstract text: Several recent research has shown that European societies were part of highly dynamic and far-reaching material exchange networks during the early Middle Ages. This is particularly true of certain materials, such as fine stones, textiles and glass (e.g. Périn et al 2007, Desrosiers, Rast-Eicher 2012, Gratuze et al. 2021). However, the circulation of other types of material, such as ferrous alloys, remains largely unknown at this time. Methodological developments regarding the provenance of iron are now revealing the initial characteristics of exchange networks dating from the Merovingian period. This paper compares the results of three studies carried out in archaeological contexts with distinct functions: vicus, coastal settlement and rural settlement (Disser 2014, Heal et al. 2024). All three are located in the Mosan and Rhine basins.
Given the relatively good availability of iron ore in Europe, it is traditionally assumed that iron production in the early Middle Ages was carried out in modest workshops, and that their output was intended to supply local demand. In contrast to this model, archaeometric studies suggest that metal supplies came from multiple sources, and that intermediate (i.e. iron bars) and objects were sometimes transported over fairly long distances, ranging up to several hundred kilometres. This led to a reconsideration of the models for organising steel production at that time.
This work also highlights the fundamental need for access to reference data to study the circulation of materials. It helps to formulate the direction that research should take in terms of the collection, processing and open dissemination of reference data. This is an important issue for future research into the archaeometallurgy of iron, and the availability of extensive reference data will make a major contribution to our understanding of the economic structures of the early Middle Ages.

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5. Archaeometallurgy of precious metals and other non-ferrous metals

O13 - The last goldbeater in Venice

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: This paper presents research recently carried out by visiting the very last gold beater's workshop in Italy and possibly in western Europe.

The workshop "Mario Berta Battiloro" we present in this paper is located in Venice in the Cannaregio district and in the very same house, in which the most famous painter of the 16th century Venetian school, Titian, or, in Italian, Tiziano Vecellio (1488-1576) had his atelier.

The goldbeater Marino Menegazzo has been working here since 1976, when he was 22 years old and is planning to retire.

His 8 kilograms heavy mallet beats gold ingots for about 30.000 times, until thin, almost sheer, gold foils, 200 times thinner than a human hair, are obtained. They are so thin that the specialized people working with them can blow the wrinkles out of the foil with their breath.

Methods: For this research all stages of production have been documented and details such as the way of properly holding the hammer, the number of strikes and the handling and cutting of the delicate gold foils have been recorded with photos and videos.

The difference between hand-made gold foils and machine-produced ones has been investigated by optical microscopy first and then by XRF and SEM-EDS.

Results: The gold foils from the workshop Mario Berta Battiloro are employed for the gilding of antique objects and works of art, such as for instance the angel at the top of the bell tower on St. Mark's square in Venice or the statue of the Virgin Mary at the top of the Cathedral in Milan and can be compared to the gold foils produced in ancient times.

Conclusions: The aim of this paper is that of recording the survival of this very ancient technique in all possible details, as a kind of "field investigation", and before it disappears completely.

O14 - The Sources of Viking Silver: A Synopsis of ERC Research into the Early Viking Age

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: 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 in the ninth century AD. 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 now-completed five-year ERC-funded Starting Grant project, we captured lead isotope and trace element data from early Viking-Age silver across the Scandinavian world of the Viking Age.

After carrying out hundreds of analyses of early Viking jewellery and bullion objects and coinages from Western Europe and the Islamic world, we are now able to draw far-reaching conclusions on the nature of Viking silver. We are able to demonstrate that eastern trade routes were supplying substantial volumes of Islamic silver to the Baltic and Scandinavia earlier than thought, in the early ninth century, and that this silver reached as far west as the Danelaw, though not Ireland. Denmark, the boundary between the Baltic and North Seas, received both Islamic silver and modest amounts of western European silver. Notably, however, elemental analysis indicates that the western European silver predates the large-scale military and colonisation campaigns in England and Francia from the mid-9th century, which begs the question: what happened to the loot? Instead of a major outflow of western European silver into Scandinavia, the evidence suggests either that the scale of loot has been exaggerated or that Western silver won by the Viking armies remained in the West. These results allow a re-evaluation of the timings, motives and location of the Viking expansion.

O15 - New data on early Medieval elite silver jewellery from Bohemia (Czech Republic) using Laser Ablation ICP-MS analysis

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Early medieval silver jewels from Bohemia (Czech Republic) constitute a particularly valuable archaeological set of artefacts for understanding the techniques used by the jewellers and the way in which such techniques developed and circulated during this period. These complex multi-component artefacts involved sophisticated techniques of fabrication and decoration and high levels of skill. The research conducted on the different types of silver elite jewellery (globular pendants, amulet containers, beads, earrings) over the last decade at the Institute of Archaeology of Prague, Czech Academy of Sciences has characterized these artifacts from a technical point of view. The materials, steps of manufacture, jewels´mounting, soldering and decorative techniques, tools marks, quality of the jewels have been identified for the first time with an array of archaeometric investigation methods including stereomicroscopy, X-ray radiography, SEM/EDS, metallography, and experimental archaeology.

To complete the characterization of materials used in these jewels, and to bring forth new data on the chemical signature of these artefacts, laser ablation ICP-MS analysis was performed in the Research Institute on Archaeomaterials (IRAMAT, Orléans, France). This technique of analysis allows the identification of trace elements which is fundamental to pinpointing the stocks of metal and metallurgical practices more precisely. The majority of the analysed samples are from one of the richest early medieval sites in Bohemia – the Lumbe´s Garden cemetery at Prague Castle, in which the family members of the ruling elite in the emerging Czech state were buried from the 9th until the 11th century AD. In addition, a new methodology was developed: instead of performing the analysis directly on the objects, analysis was carried out on available prepared metallographic samples. This new methodology has several benefits, including avoiding further manipulation of the artefacts, and greatly reducing the amount of bureaucracy required when sending precious artifacts. The use of previously documented metallographic samples, further increases the level of precision in determining the targeted place for analysis.

Presently, 53 different parts of 25 artefacts have been analyzed by laser ablation ICP-MS. The determination of the main elements (Ag and Cu) and minor and trace elements enable us to study correlations between the type of object (pendant, earring, bead…), the nature of the fragment (sheet, wire, granule, filigree…), the style and the level of technical skill. Those results allow us in turn to propose new interpretations for the choices made by the jewellers and for the provenance of the siver stock used.

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O16 - Technical investigations of ancient Swedish tools for wire-drawing

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Metal wire is in modern society produced by drawing metal rods through dies with tapered holes of increasingly smaller diameters. The origin of this wire-drawing technique is unclear. Current evidence suggest that it was invented somewhere in Europe during the 1st millennium AD, replacing earlier techniques for the manufacture of gold and silver wire such as hammering, block twisting, strip-twisting, strip-drawing, and roll-drawing. Clarifying the history of wire production technology is important not only to archaeometallurgists, but also to forensic scientists, as such understanding can help with authentication of antique jewelry involving elements of gold or silver wire. Here, we present the results of technical investigations of ancient Swedish tools for wire-drawing. These tools originate from different archaeological sites in central Sweden, namely: one iron drawplate from 5th – 8th c. Old Uppsala, one iron and one antler drawplate from 8th – 10th c. Birka, and various drawing tools of bone and antler from 11th – 12th c. Sigtuna. A particular focus of the investigations is SEM-EDS (Scanning electron microscopy with energy-dispersive spectroscopy) analysis of metal residue particles in the holes of the drawplates. These measurements are able to identify the materials of the drawn wires (e.g., silver and tin), the purity of these materials, and if any metal lubricant was used in the drawing process (e.g., lead). Because the age range of the studied tools cover a period from the 5th to the 12th c., the obtained results allow us to characterize the development of the wire-drawing technique during this time period. These results are furthermore compared to the current wire-drawing tradition of the indigenous Saami people in northern Scandinavia. In particular, we propose a technological continuity between the current wire-drawing of the Saami people and the Medieval period wire-drawing in central Sweden.

O29 - Making their mark: women silversmiths of Oman

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: The Sultanate of Oman has been at the centre of Indian Ocean trade routes linking Asia, the Middle East and Africa for millennia. The country is renowned for its long-standing tradition of silversmithing. Silver has been an important and fashionable material for centuries in Oman: Omani silver jewellery are markers of status, regional, marital and ethnic identity. However, public demand for silver jewellery in Oman gradually declined from the 1960s, due to the oil boom and the subsequent shift in tastes towards gold. Despite this, silver pieces from the 1950s are still sought after for weddings and special occasions and the last few decades seem to have witnessed a revival of the craft.

Although the profession is predominantly led by men, Oman has produced highly skilled, empowered and entrepreneurial women silversmiths since at least the early 20th century. This is illustrated by three practising craftswomen interviewed as part of this research project, who were trained by men and often belonged to families of silversmiths and who have adapted traditional designs and motifs to suit modern tastes.

This international research collaboration and recent fieldwork by scholars from the UK, Oman, Canada and USA aims at extending our knowledge and understanding of the traditions and trajectories of the silver tradition in Oman with a focus on the unique practice of women silversmiths. This presentation focuses on the scientific and technical aspects of the project and introduces the variety of well-known and established silver working techniques, documented through video recordings and personal testimonies of the silversmiths themselves. It also highlights the technical skills of these women and the intricate designs of their pieces, using optical and scanning electron microscopy, as well as 3D scanning. The hand-working techniques used to make these pieces, which include hammering, shaping, die-stamping, wire drawing and twisting, granulation, soldering, etc. were compared to those documented on jewellery from the 1950s within the collection of the British Museum, also using microscopy, to illustrate the continuity in silversmithing techniques.

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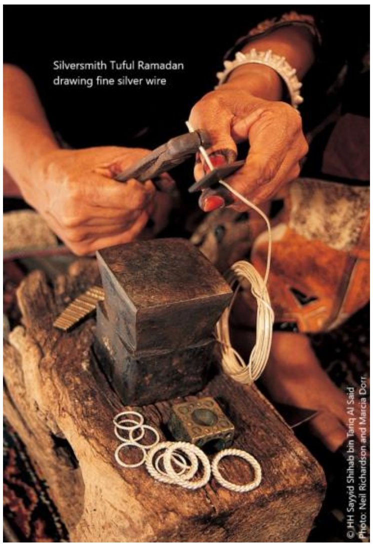

Silversmith Tuful Ramadan
drawing fine silver wire

O30 - The numismatic research of the nEU-Med project: the support of experimental archaeology for the study of medieval coins from Tuscany (Italy)

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Historic coins are artifacts that can be analysed with many different techniques for multiple archaeometric purposes. Due to the unique character and rarity of some coins, any type of analysis should be, as far as possible, non-destructive, which means that neither original sample material can be taken, nor any kind of modification is allowed. Moreover, ancient Ag–Cu coins are usually affected by silver surface enrichment, whose thickness can reach several hundreds of microns, far beyond the penetration depth of surface techniques such as non-destructive pXRF. Within the ERC nEU-Med project more than one hundred specimens had been collected, minted in a period between 9th − 14th centuries AD, coming mostly from archaeological sites of Tuscany. The composition of all coins was investigated using the pXRF analysis providing a large data set that were sometimes homogeneous and in other cases completely unexpected. Moreover, the comparison between the chemical composition obtained by surface techniques (pXRF), and SEM-EDS allowed to identify the real content of Cu and Ag both inside and on the surface of the artifact, the presence of levels of surface Ag-enrichment, to evaluate the preservation of artifact and, thanks to textural analysis, to obtain important information about production technology.

In order to gain insight into the composition and microstructure of ancient coins and to determine the reliability of data obtained with pXRF, the present contribution will describe some tests of experimental archaeology trying to reproduce Ag-Cu alloys, according to the mean composition detected in the various monetary series. The experimental reproduced, following bibliographical references retrieved in the treatises of ancient metallurgy and in recent scientific papers, a series of coins with morphology (size and weight) and composition similar to archeological sample that are under study. Experiments have produced coins with Ag silver content ranging from 25 to 85 wt%. All the materials used during the experiment, from the ingots up to the modern coins replica, were sectioned and analyzed with various techniques (in particular pXRF and SEM-EDS) to evaluate the accuracy and repeatability of the different analytical methods and to investigate in detail the internal textures of metals due to the employed production techniques. The experimental data allow us to investigate how coins' texture and thickness of superficial enrichment due to blanking process, varies with Ag concentration. The experimental data helps also to evaluate the penetration depth of pXRF within unaltered samples and its overestimation of "real coins finess".

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O31 - Material and technology of Celtic gold: comparative study of individual princely tombs from Germany (5th-4th c. BCE)

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: This paper presents a comprehensive study of gold ornaments retrieved from elite burials of the 5th and 4th centuries BC in Germany.
Within the framework of the Franco-German project "Celtic Gold," which spanned from 2017 to 2024, our interdisciplinary research delved into the analysis of gold artifacts originating from the La Tène cultures (LT A-D) in Benelux, France, Germany, Switzerland, and the Channel Islands, dating from the 5th to the 1st century BC. Building on prior research, which demonstrated the exclusive use of natural gold alloys during the preceding Hallstatt period (7th to 6t^{h} centuries BC), our investigation revealed the diversification of gold compositions during the early La Tène period (LT A). Furthermore, the number of burials containing gold grave goods doubled during this time.

Our current study focuses on a comparative analysis of the golden grave goods from elite burials of the 5th and 4th centuries BC (LT A phase) in what is now southwest Germany. At that time, this region was characterized by a new form of elite representation and, due to the many gold objects and exceptional craftsmanship, is particularly well suited to better understanding the contacts within the local elites, but also between different regions.

The artifacts were examined in terms of their chemical compositions, production techniques, and stylistic features to discern networks of contact and influence. Although two major LT A gold types emerged, there was no clear spatial distribution or correlation between gold type and decorative features. Some objects exhibited relative homogeneity in chemical composition, while others displayed heterogeneity, even with typologically and technically identical objects, illustrating the need for multidisciplinary studies.

The analyses provided insights into the techniques and tools employed in gold manufacturing, as well as the "chaîne opératoire." The artifacts bore testimony to the exceptional technical expertise and material knowledge possessed by the goldsmiths. The technical repertoire of craftsmanship was applied in alignment with the functional groups and stylistic characteristics of the gold objects.

Furthermore, our research integrates analytical, technological, and archaeological findings into network analyses. These analyses aim to unveil patterns within exchange networks and systems encompassing the distribution, creation, crafting, and consumption of La Tène goldwork.

This scientific exploration offers valuable contributions to our understanding of the intricate world of La Tène gold artifacts and the multifaceted networks that shaped their existence and provide us with insights into the social structures and communications of the elites at that time.

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O43 - First Analytical Results on Jabučje Roman Silver Vessels From Serbia

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Roman literature offers information about huge quantities of silverware in the 1st century AD to have been privately owned by rich Romans. This was archaeologically documented by discoveries of substantial hoards of silverware in houses in Pompeii and Boscoreale. These hoards included home sets (*ministerium)* which were part of dinner sets (*Argentium escarium*) and drinking sets (*Argentum potorium*). Such a find was discovered in Jabučje by Lazarevac as a result of a chance find during pumping sand out of the river Kolubara in 1972. This part of Serbia was among the first to become included in the Roman Empire and was within administrative boundaries of the Roman province Dalmatia. The preserved and restored parts amount to 32 items of various vessel types are now exposed in National Museum of Serbia.

Here we will present results obtained by ICP MS (iCAP Qc, Thermo Scientific, UK), analysis of seven objects, from this hoard and ED XRF analyses (AMETEC SSD-123 decetor and mini x-ray tube), made on gilded parts of objects. We took samples from the parts of objects that are presenting bottom of the plate or handles that are not reconstructed, some 100 mg of the body of each of seven analysed objects. Results are showing that objects are made of silver-copper alloy, silver approximately 96-98.5 % and copper about 1.2-3.4 %. Low amount of gold in the samples, ranging from approximately 8-55 ppm, indicates the galena ore as source of silver, whereas in Rio Tinto amount of gold in silver is about ten times higher due to use of jarosite tipe of silver ore. Other trace elements found are Cr, Co, Ni, Zn, As, Sn, Sb. Linear correlations between many elements like Ag/Au to Ag/Pb, Ag/Bi, Ag/Zn is indicating the same source for silver and lead used for cupellation of silver.

Gilded parts were examined with portable EDXRF. No mercury was detected so indicating diffusion process of gilding.

These first analytic results of silver finds from Jabučje, first century CE, show that silver is of the same origin as the lead used for its cupellation. Origin of the silver is other than from Rio Tinto mining site. Gilded ornaments, characteristic for some of the plates, are made by diffusion process.

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O44 - Hand of Prêles (Switzerland): An archaeometric approach to a unique Bronze Age object in bronze and gold

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: A unique bronze hand wearing a gold bracelet was found in Prêles, Bern, Switzerland. Situated in the Swiss Jura, at an elevation of 822 meters, the village of Prêles stands on the southern periphery of the Montagne de Diesse plateau, overlooking Lake Biel. The hand of Prêles was first unearthed by detectorists, then leading to rigorous excavations carried out by the Archaeological Service of Canton Bern in 2018, which revealed a heavily demolished burial mound and a poorly preserved skeleton. According to radiocarbon dating, the hand was buried during the Middle Bronze Age (BZB/C), around 1507-1431 BC. The hand of Prêles was associated with a hair-ring, a pin, a bronze dagger and two gold flakes, accompanying the body of an adult male. Given this exceptional discovery, questions raised about its presence in this particular context. Is it the work of a specialised craftsman? Is it an imported object? Or locally produced? To answer these questions, a better understanding of the skills of the craftsman who made this hand is crucial, as well as the origin of the raw materials, namely Au, Sn and Cu. Therefore, superficial observations of the metallographic structure of the hand are conducted, as well as the determination of the chemical composition by ED-XRF and ICP-OES and the isotopic composition of Pb, Cu and Sn by MC-ICP-MS. The gold bracelet contains 8.5% Ag and about 0.8% Cu. The presence of Sn and a low Ag content suggest the use of placer gold. This chemical composition is not compatible with Swiss alluvial gold–at least within the limits of the available comparative data–but seems to be close to other group of materials or workshops known in Northern Europe at this time. As regards bronze, the Sn levels range from 8-15%. The cumulative trace elements reach a maximum of 0.41%, with As and Ni as the predominant components. This trace element composition is typical for the Middle Bronze Age bronze objects in Switzerland. The variable Sn content and the microscopic study of the hand show that the Middle Bronze Age smelter and bronzesmith of the hand of Prêles knew the properties that characterise materials, but did not master the know-how techniques. This study places the hand of Prêles in the context of the circulation of raw materials and know-how techniques in Switzerland in particular, and in Europe in general.

KEYWORDS: Hand of Prêles, Middle Bronze Age, bronze, gold, craftsmanship, archaeometry.

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O45 - The Late Iron Age "Le Câtillon II hoard, Jersey". An interdisciplinary study of gold ornaments and coins

5. Archaeometallurgy of precious metals and other non-ferrous metals
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Abstract text: The Le Câtillon II hoard, discovered in 2012 at Jersey, Channel Islands, is the largest and most striking coin and metal hoard from the Iron Age, dating around the mid first century BC. Within the scope of the French-German research project "Celtic Gold" funded by the French ANR and the German DFG, precious metal artefacts from the hoard were analysed and examined for their compositional and technological aspects in the IRAMAT laboratory. All the gold artefacts other than coins (49 entire objects and fragments) and the 25 *globule à la croix* coins were analysed by LA-ICP-MS, using in particular an in-house cell for torcs. This paper aims to present preliminary results of this study, focussing on gold torcs and *globule à la croix* coins, by crossing archaeometry and technology viewpoints.

From the technological point of view, the gold work from Le Câtillon II and the torcs in particular, show a large variety of manufacturing technics, highlighted thanks to visible and X-ray images and observation of tool marks, that are coherent with the gold production during the end of the Iron Age on the continent.

The archaeometric study showed that the metals and alloys of the torques and coins analysed belong to two different traditions. Torques contain between 89 % and 98 % gold and are the most gold-rich category of objects from the hoard. On the other hand, *globule à la croix* coins are made of ternary gold-silver-copper alloys containing 71-50 % gold and silver and copper according a linear relationship. For the coins, the compositions and variations in fineness observed are actually consistent with those known for this type of coinage. The gold stocks used for the torques and the coins analysed are also different, as shown by the different chemical signatures based in particular on platinum and palladium contents.

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O46 - Bronze Age antimony and silver ornaments from Gizaburua (Solarzu, Basque Country, Spain)

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: A set of 5 silver and 2 antimony ornaments were recovered from the Gizaburua dolmen. Both antimony and silver objects are unknown in Chalcolithic and Bronze Age metallurgies in the Basque Country, but in the case of antimony it is also the first evidence in Iberia. The dolmen contains some remains of human cremated bones and other grave goods. Radiocarbon dating and grave goods suggest a chronology at the beginning of the Bronze Age (2200-2000 cal BC), the first moment of silver production in Iberia from native silver and silver halides (Cerargyrite).

The elemental analysis by pXRF (for calibration and working protocols see Rovira Llorens and Montero-Ruiz 2018) confirms that the fragment of olive shape bead is made of pure antimony (99%) and the V-perforated oval button is a Sb-Pb alloy (90% Sb and 10 % Pb). The silver items (rings or spiral) are very pure with only traces of copper (< 1% Cu) and no lead is detected. Some observations were also made by Scanning Electron Microscope (SEM).

Lead isotope analysis was also conducted by MC-ICP-MS on 2 antimony and 3 silver objects at the SGIker laboratory, following sample preparation and reference materials described in Rodriguez et al. (2020). The silver objects show similar results than other Bronze Age silver items from the El Argar culture in the South-East of Iberia, matching the Linares-La Carolina mining district in Jaen province. Antimony is well known in the Iberian Peninsula with several potential resources. Based on LIA results, the antimony items could have a provenance on the same Linares mining district than the silver objects, but no other antimony object has been found in this area. An alternative interpretation for both metals could be a more local production from the nearby Sierra de la Demanda (province of Burgos). What is clear is that antimony has no relationship with any of the other two European regions where this metal is known (mainland Italy and the Caucasus Mountains). This could suggest experimental production during the Early Bronze Age in Iberia.

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GIZABURUA 2017
Elgoibar-Soraluze
GIZ.UE4.38
Metal Colgante UE 4

GIZABURUA 2017
Elgoibar-Soraluze
GIZ.UE4.38
Metal Colgante UE 4

O57 - Proto-historic gold and silver metallurgy in Western Iberia: examples from the Gold.PT project

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: In the frame of the Gold.PT project (https://doi.org/10.54499/2022.02608.PTDC) more than one hundred Proto-historic gold and silver artefacts from the Archaeological National Museum in Lisbon (Portugal) are under study. The project seeks to contribute to studies on Late Bronze Age and Iron Age (first millennium BCE) goldsmithing from the point of view of its materiality and manufacturing technologies. A line of work has been organized that addresses the study of fine gold working during Proto-history, as filigree and granulation, besides the study of the composition (by XRF, PIXE and SEM-EDS) of the gold and silver alloys used in various types of manufactured pieces.

This presentation will provide a summary of results of finished case-studies comprising earrings and necklaces, and will provide preliminary results of ongoing studies on other artefact categories. It will also present a glimpse into experimental gold archaeometallurgy and to the comparison of ancient (Proto-historic) with more modern (late 19th–early 20th century) filigree techniques, namely to the Portuguese traditional filigree (certified craft skill) proposed for UNESCO Intangible Cultural Heritage.

Results so far have shown that the composition of Bronze Age gold artefacts is mainly related to the composition of native gold, which generally has between 5 and 25 % by weight of silver. Copper, if present, is usually <1%, although copper is not usually associated with native gold. In some artefacts, very low amounts of tin are also detected. In the case of four pairs of (ear)rings (pennanular type) relatively dispersed compositions, with 10 to 17 % Ag and <2.5 % Cu have been measured, and interestingly no compositional relationship was found between the rings of each pair.

The study of a set of densely decorated Iron Age gold earrings has determined the presence of gold wires produced using thin blades rolled and twisted using the strip and block-twist techniques in the S and Z directions, with diameters of less than 0.7 mm. Gold beads reached a maximum diameter of 1.2 mm, and were used as decorative elements on the outline or over the surface of the earrings. It was also possible to determine the use of thin sheets of gold (with thicknesses ranging from 0.04 to 0.19 mm) to create volumes, probably as an effort to save on the material when compared to the more solid Late Bronze Age objects.


1 mm

1 mm

O58 - Investigating pre-Columbian Gold and Copper in Costa Rica – Mines, Ores and Artefact Production

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: The wealth of pre-Columbian gold, copper and particularly *guanín* (an alloy consisting mainly of gold and copper) artwork of Costa Rica suggests that its abundant ore deposits already were exploited long before the Spanish conquest. Up to now, however, very little is known about pre-Columbian mining in the country or the raw material provenance of these artefacts. In a transdisciplinary project, we combine (mining) archaeological research with mineralogical and isotope-geochemical analysis of local ores and metal objects to reconstruct manufacturing and craftsmanship techniques, gold-copper supply and technological choices in artefact production, and their possible correlation with areas of origin or different workshops. This contribution presents first results of material analyses and fieldwork.

Available data link the alloy choice of objects with technological considerations related to their manufacturing technique (cast, cast and laminated, hammered). No (direct) correlation with their shape and potentially chronologically related stylistic characteristics is discernible, being in agreement with the assumption that metallurgical knowledge was introduced as fully developed technique. Silver contents typically are rather low in gold (-copper) objects (≤ 5 wt%) and comparable in finds from different archaeological complexes in Costa Rica. They are in the range of (paleo-) placer gold of the Diquís region in the south, which can be considered as a plausible source not only for some of the richest pre-Columbian metal finds from Costa Rica that were derived from this part of the country. Preliminary data suggest that epithermal gold veins in northern Costa Rica have significantly higher silver contents (> 20 wt%) exceeding the variation of most objects. These results demonstrate that silver-rich artefacts are not necessarily imports from e.g. Colombia but might have well been made from local ores. Finds of copper objects are concentrated in northern and central Costa Rica and could have been derived from prolific production centres in Mesoamerica. However, shallow, heavily weathered copper ore bodies mainly comprising Fe-free sulphides and oxidised minerals, and outcrops of native copper constitute comparatively easily accessible raw material sources that also render a local origin possible. The widespread use of *guanín* underscores the importance of copper and suggests some experience with its metallurgy in pre-Columbian Costa Rica.

Once the necessary basic data on ores and metal artefacts has been collected, we will focus on the chronology and development of metal working and use, raw material circulation and exchange networks and socio-cultural implications derived from these aspects.

O59 - Studying the evolution of lead sources over the long time scale: the case of Notre-Dame de Paris (12th-19th c.)

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Lead is a versatile material, easy to use and shape, yet always remelted and recycled for maintenance or salvaging purposes thanks to its low melting point and its malleability, leading to the mixing of different lead sources. Therefore, trying to reconstruct lead circulation is not straightforward, especially when the link between the mines and the consumption site is lost. Analytical studies though, especially the use of lead isotopes, are so far more regularly used for the provenancing of other metals than for lead material itself.

Monumental construction is an ideal observation post to take an interest into this question. The Notre-Dame cathedral fire in Paris reminded us of the massive use of lead in its construction over the centuries. Hundreds of tons of lead were implemented in the 12th-13th centuries for different functions: the cathedral first lead roof, the sealing of iron cramps and to join the stones of the gothic bays. Later, more than 200 tons of lead, partly recycled, were used in the 19th century for the last roof, its cresting and the spire. Thus, lead stocks from different supply and implementation phases coexist in the same structure.

The Notre-Dame CNRS/MC scientific project provided a unique opportunity to address the chronology of lead material appropriation throughout the building history. The coordination of archaeometric, archival and archaeological studies sheds light on the different lead uses and makes it possible to examine the lead supply markets, the practices of plumbers and their evolution. Three-hundred-fifty lead artefacts, mainly from the 12th-13th and 19th century campaigns, were sampled in place and from materials recovered from the burnt-out parts. Trace element contents determined by LA-ICP-MS allowed constituting a corpus relevant for the measurement of lead isotopes by MC-ICP-MS. Lead materials were also collected on coeval monuments (castles of Amboise and Pierrefonds, France) to provide first comparisons for the 19th century.

The elemental and isotopic results show highly discriminating signatures revealing different lead supply between the medieval period and the 19th century. For the latter, the archives and the historical context support the analytical results and specific mining areas can be identified as ores sources. The isotopic results highlight the use of lead produced from the large Andalusian ore deposits (Sierra de Cartagena, La Carolina), thanks to the dynamic Franco-Spanish trade. The elemental analyses also confirm the practice of lead recycling but this practice doesn't seem to alter the signatures in any significant way.

6. Technology transfers over space and time

O80 - Mind the Gap - comments on the gap in time between knowing iron as a material and knowing iron production as a chaîne opératoire - seen from Denmark.

6. Technology transfers over space and time

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Abstract text: The explanations for the introduction and spread of iron as a material and the introduction and spread of iron production as a chaîne opératoire has always been a matter of debate in Europe, in Scandinavia and in Denmark. It was not only a matter of introducing a new metal in line with all the others, but it was a completely new way of understanding and working metal.

The dark squiggly lines of the razors from Kjeldbymagle and Arnitlund (early Late Bronze Age, around 1000 BC) are often mentioned as the earliest examples of iron in Denmark. Recent metallurgical analyses have, however, shown that the lines are not in fact iron, but rather copper covered by a layer of iron-bearing corrosion (Lyngstrøm & Jouttijärvi 2018). This means that there is no evidence for the presence of iron in Denmark until the very end of the Bronze Age (around 700 - 500 BC) where some examples are the tweezers, the ear spoons and the needles in some rich graves on Fuen close to the barrow in Lusehøj.

At the same time new excavations of furnaces in connection with some very early pre-Roman Iron Age farms are found in Jutland – in Koustrup, Elia and Guldborgvej (Olesen et al. 2020). This show that some farmers around 500 BC had both the knowledge and the skill in relation to transform ore to iron. Moreover, the slags from Store Holmegård, Stude and Stenhusager show that the farmers on Zealand learned it too – perhaps, perhaps not – with a little delay (Lyngstrøm 2020). All these early furnaces fits well with the iron in needles and belthooks from the early pre-Roman Iron Age graves in Årupgård and Krogslund.

The time gab between knowing iron as a material and knowing iron production as a chaîne opératoire has narrowed.

I will discuss this new issue in my presentation - inspired by several recent Danish studies that are dealing with the identification of the transfer of knowledge and skill in material culture (a.o. Sternke & Sørensen 2009; Ravn 2012; Knudsen 2014).

Photo: The razor from Arnitlund, Nationalmuseet København

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O81 - A new chronology for iron production in bloomery furnaces in Sweden

6. Technology transfers over space and time

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Abstract text: Iron production in bloomery furnaces was fundamental for societal development in Scandinavian prehistory at least from the 6th century BCE. This mode of production continued up until the early modern times. Gert Magnusson's dissertation "Bloomery iron production in the county of Jämtland, Sweden" has been a cornerstone in iron research ever since it was published in 1986 and his curves on the chronological developments in different regions in Sweden have been reproduced in updated forms several times.

The last decades have seen a massive growth of new data but also advances in statistical methods to analyze large data sets, which actualized a total reworking of the older chronology of iron production. Therefore, in the last years, work has been going on to collect recently analysed radiocarbon samples and to update older databases, as well as calibrate the results using Kernel Density modelling. The outcome is modern, statistically reliable, curves of the development of iron production in bloomery furnaces for the different regions in Sweden.

In this paper the work on the updated database and the chronological curves will be presented. Using similar methods facilitate the comparison between different types of production and activities and the curves can also be used to study regional developments in iron production.

O90 - Early iron production in Southeastern Norway – new data, new perspectives

6. Technology transfers over space and time

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Abstract text: The introduction of the technology to produce iron from bog ore was a game changer in the Scandinavian societies. The region became self-sufficient in iron, and at times there was massive surplus production. However, knowledge of when this happened, what the earliest ironmaking technology was like and how iron production was organised is still poorly understood. This study examines the chronology and geography of the earliest iron production in Norway – when the technology was introduced and where in the landscape iron production took place.

The research is based on excavated and well documented iron production sites in Southeastern Norway. We use five case studies to explore the earliest iron production: in Vestre Slidre, Eidsvoll, Hamar, Gausdal and Gjøvik. In addition to a number of radiocarbon dated samples from well documented contexts, metallurgical analyses of slag and ore from these sites have also been carried out. The results are compared with the older investigations from By in Løten and Flakstad in Hamar with same furnace technology, datings and location. Datings from the last period from the Bronze Age are considered and rejected.

The research presented in this paper indicates that iron production technology was introduced in the 5th and 4th century BC, and that iron production was initially located close to the farmstead in agricultural areas in the inner part of eastern Norway. This seems to initially have been a small-scale production. The expansion seems to take place from the end of Pre-roman Iron Age and in the Early Roman Iron Age (c. 200 BC–200 AD).

Methods: -

Results: -

Conclusions: -

Selected references

-

O91 - "Between Faith and Knowledge" - Technological Development and Knowledge Transfer in Stora Kopparberg's Copperworks during the 18th Century.

6. Technology transfers over space and time

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Abstract text: When Sweden's leading copper producer, the mining company Stora Kopparberg in Falun, experienced a significant decrease in production in the early 18th century, several major projects were initiated, both in the company's organization and in the copper production itself, aiming to increase production. The main challenge was to increase the extraction of ore, but an important driving force behind several of the reforms was also to enhance the refinement and quality of the copper. The main reason for this was to make Swedish copper more attractive, especially in the export market. Another reason for developing production was that customers had complained on several occasions about the poor quality of the copper. There were significant organizational difficulties for Stora Kopparberg in controlling the refinement of the ore. An important reason for this was that metal production was managed by hundreds of individual miners ("bergsmän"), who in turn had their own employed roasters and smelters.

The purpose of this lecture is therefore to discuss how the production of copper developed within the Stora Kopparberg company during the 18th century. The overarching questions to be answered concern the details of this process, when and how technological development took place, and how the knowledge of this development was conveyed between different levels in the company. Were there changes in how the company was governed from Stockholm, in Falun, and among the miners in the region? Or was it among the miners' employees, all the roasters and smelters who handled the production itself, who were responsible for technological development, and how were the knowledge transferred within these professional categories? What role did, for example, the so-called "smältartinget" where the smelters gathered play? Based on this overview, the lecture concludes by discussing the effects of the various projects during the 18th century. To what extent did the miners and their employees assimilate the knowledge considered to improve the quality of the copper? To what extent did this knowledge transfer actually result in the Stora Kopparberg company increasing production in both quantitative and qualitative terms?

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O92 - Canals and the Iron-industry during the early Industrialisation Era

6. Technology transfers over space and time

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Abstract text: Sweden's main exporting industry until the broader industrialisation era from ca 1850 was the iron industry. The industry went through a stepwise liberalization from the early 1800s with openness to change and restructuring. Canals promised to reduce transportation costs, and to create new trade-flows and growth in the economy. Canals had different origins as regards which parties initiated the projects and also as regards what trade-flows they came to serve; either primarily iron-industry related or with the iron-industry as one among other important users.

The paper analyses the Göta kanal and the Strömsholms kanal. The iron industry in focus of the study is the Stjernsund mill with its different production units in the regions Närke and Östergötland. Canal construction had both backward and forward linkages to the economic development. Effects of both these concepts are traceable in the study. The primary focus of the study is 1780 - 1830.

The government's dismantling of the detailed regulation of the iron industry and support to canals is discussed and analysed in the paper. It is suggested that the gradual shift in the government's growth policies is a sign of a successive adjustment to new circumstances. But it also reflects a gradual learning of what kind of government measures that could be effective in a new more liberal era. In this way the interrelation between the iron industry and the canals is illustrating the origins of a more liberal stance in Swedish economic policy and growth-oriented policies in the decades well before the 1850s, where the liberal reform era is generally placed in time. Transport infrastructure investments in this way were connected to the development of the iron-industry in different ways.

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O93 - Diachronic Spatial Analysis of the Timna Valley and Southern Aravah- Understanding Copper Exploitation in the Longue Durée

6. Technology transfers over space and time

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Abstract text: The Timna Valley, located in the hyper-arid desert of the Aravah in southern Israel, is one of the best-preserved ancient copper mining regions in the world with archaeological evidence of minerals exploitation spanning at least 8000 years. The current study focuses on the spatial analysis of copper production and related sites in and around Timna from the Neolithic to modern times. Based on new archaeological data accumulated by the Central Timna Valley Project (CTV, https://www.tau.ac.il/~ebenyose/CTV/), and a reevaluation of previously published data by the Arabah Expedition and other teams, the current study provides new insights on mining and smelting sites distribution in the major copper production periods, transportation routes to the valley and inside it, as well as relationships between sites based on visibility. The study is accompanied by and based on a comprehensive database of regional archaeology, which currently includes more than 150 sites. The analysis is based on a Geographic Information System powered by Esri (ArcGIS). With the help of the GIS, the project is currently producing up-to-date maps and landscape models, which help visualize the phenomena mentioned above. More generally, this study explores the effects that the natural environment, technological developments, and socio-political conditions had on the spatial facet of metallurgical operations. It therefore aims to contribute to the broader discussion of patterns and trends in the quantity and quality of metallurgical activities in the local sphere of Timna, the regional sphere of the southern Aravah, and the broader sphere of the Near East.

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O97 - From unique to mass products – the ways of standardisation by the polychrome jewellery from the 5th-6th-century Carpathian Basin

6. Technology transfers over space and time

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Abstract text: The polychrome decoration of fine metalwork objects, and especially the use of red garnet as inlays was widespread during the Hellenistic, Roman and Early Medieval times representing an intercultural and supra-regional fashion in Europe (Arrhenius 1985; Adams 2000). In the archaeological material of the Carpathian Basin this polychromy was characteristic over around three centuries, from the Hunnic Period through the age of the Gepidic and Langobardic Kingdoms up until the Avar Period (Horváth 2012; Horváth 2013). Comparing with the 5th-century artworks rich in unique traits, the 6th-century artefacts are rather mass products with common features. Similarities are shown in the material, technological and stylistic details of the production, which are considered as the initial marks of the simplification or standardisation of the goldsmith work.

The question is, if it is possible to identify the scale, forms, and trends of standardisation and if we can assign its different stages to different chronological or regional groups. The 5th-6th-century fine metalwork of the Carpathian Basin is especially relevant in this question, providing examples from a dynamical period from political, cultural, social and economic sense and giving the opportunity to trace changes in the raw material supply, technological practice, and the evolution of the craft organisation to improve efficiency.

Since not a single goldsmith workshop or hardly any archaeological remains related to some sort of goldsmiths' activity are known in the region, the organisational background of the production is perceived indirectly, by the study of finished products. In our comparative analysis more than hundred objects from the collections of the Hungarian museums, generally made of gold, gilded silver or copper were investigated by non-destructive analytical methods: optical microscope observations were followed by handheld XRF, SEM-EDS and μ-XRD measurements. The performed analyses aimed at the reconstruction of the workflow of the manufacturing and decorative techniques, the identification of the chemical composition of metals, decorating inlays and coatings, and also the phase composition of niello. Differences in the material utilisation and the practice of metal alloying, garnet processing and niello making were studied in both space and time.

The results have shown the efficiency and productivity of the production and the optimisation of the workflow, revealing consciousness in both the material selection and the design of colour effect. The comparative, diachronic approaches presented in our contribution helped us to draw a systematic and regionally differentiated picture on the process of standardisation on polychrome jewellery.

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O98 - The study of clay shafts of bloomery furnaces

6. Technology transfers over space and time

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Abstract text: The study of largely clay-built shafts for prehistoric bloomery furnaces in Europe is most often severely hampered by the destruction through later activities leaving only small, scattered remains of the shafts. Despite this, the few, better preserved, finds have made it possible to establish some general types of furnaces and through various dating methods place them in a rough chronological order (Pleiner 2000, 149 & 172). There is, however, still a lot of work to be done, which is shown not least by the gradual change in interpretations of what was earlier thought to be pit-furnaces. Reexaminations of excavated furnaces and experiments have, in many cases, shown that these furnaces would have needed a shaft and have indeed had one (Dolan 2012).

The investment in gathering and processing of the raw material setts a high value on a successful process and encourages the formation of traditions in furnace construction to ensure the outcome. However, the basic technological requirements leave good room for personal/group variations on larger-scale traditions. What might seem to be an ad-hoc construction technique is rather a complex intersection of overarching traditions, local transcriptions based on skill and experience and adaptions to variations in raw materials. This complexity lends itself to studying questions ranging from the organization of the individual site to the interregional spread of the knowledge of furnace building and bloomery iron production. While the range of information in just a few remnants of fired clay from an excavated furnace is limited even these bits contain useful data on the raw material choice, the dimensions and the process.

The study of furnace construction in Sweden from the Iron Age (ca 500 BCE) through to the Medieval period (ca 1100 CE) has been evolving in a tight collaboration between ceramologists (KFL, Lund University & company SKEA) and archaeometallurgists at the company "The Archaeologists" (formerly the Geoarchaeological Lab, GAL). Through some examples from this research over the last 25 years (Stilborg 2023), I would like to point out the potential even in limited find materials and the overarching importance of developing research questions to the bloomery furnaces on all levels from the nerdiest to the structural.

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O99 - NIELLO THROUGH THE AGES – SCIENTIFIC ANALYSIS OF NIELLO-INLAID SILVER OBJECTS FROM ROMAN TO MEDIEVAL TIMES FROM THE CARPATHIAN BASIN

6. Technology transfers over space and time

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Abstract text: Niello is a blue-black, lustrous material, which was used to decorate silver-, gold- and copper-based alloy objects. Chemically, niello is composed of the sulphide of one or more metals, fused or inlaid into a recess carved into the metal surface. The composition of niello changed in the course of times depending on what type of metal it decorates. It has been widely accepted that during the Roman period niello was generally composed of the sulphide of only one metal, namely same as the metal it decorates: silver sulphide for silver objects and mixtures of copper sulphides for copper-based alloy objects. Intentional use of binary silver-copper sulphide niello was assumed to have started only at the end of the 5th century AD, whereas ternary silver-copper-lead sulphide niello was used from the 11th century AD. Niello became very popular from the first century in the Roman Empire and was used to decorate a wide range of objects. It remained fashionable in the Migration and early medieval period in Europe. No written sources are available for niello manufacturing from the Roman period. There are only a few sources from the early medieval period, which contain recipes and descriptions of silver sulphide and binary silver-copper sulphide niello, like al-Hamdānī (c. 942 AD) and Mappae Clavicula (late 12th century AD). Analyses of artefacts of the era and experimental studies are therefore necessary to trace the original niello technique.

During our study, we have analysed niello inlays in several Roman, Migration Period and medieval silver objects, which were found at various localities in the Carpathian Basin. The objects were analysed with non-destructive methods (handheld XRF, SEM-EDX and micro-XRD) in order to study the chemical and mineralogical composition and the microstructure of their niello inlays.

In addition to silver sulphide, silver-copper sulphide niello inlays were also detected on a Roman silver augur staff and a military belt set. The cause of the elevated copper content needs further investigation: two-metal sulphide (intentional use) or more debased silver (unintentional use) was used for making the niello. Niello inlays of the objects from the Migration period are very heterogeneous in composition: from pure silver sulphide, reflecting the Roman traditions, through various silver-copper sulphides, to pure copper sulphides. Niello inlays from the 13th century surprisingly also show a wide range in composition: from pure silver sulphide to ternary silver-copper lead sulphides.

O108 - Transmission of Iron Technology among Hunter-Gatherers in Ancient Arctic Europe

6. Technology transfers over space and time

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Abstract text: Exploring the origins and diffusion of iron is a key theme in European iron research, with particular emphasis on the global historical significance of steel. Often regarded as a catalyst for the advancement of societies towards industrialization, this viewpoint persists in contemporary discussions, especially in the context of achieving a climate-neutral society. In Arctic Europe, the emergence of iron technology has traditionally been considered peripheral, and its active phase is believed to have occurred much later than in central and northern Europe. The late transfer is typically attributed to the migration of Nordic farmers in the Viking Age/Early Middle Ages or the establishment of mining industries in the 16th-17th centuries, connecting the emergence of iron technology to social complexity and socio-economic change, mainly farming/sedentary lifestyles. On the contrary, the role of iron in ancient hunter-gatherer societies has been heavily underestimated, with metallurgical knowledge in such contexts often explained as anomalies and a result of long-distance trade.

Influenced by new directions in archaeological research incorporating innovative theories of transmission and an analytically integrated chaîne opératoire approach, we advocate for a broader understanding of the mechanisms underlying the transmission and adoption of iron technology, inclusive of non-agrarian societies. We delve into technological practices and associated social relations using archaeometallurgical analyses combined with a landscape/climate approach. From focusing on the importance of landscape and climate in the processes of transfer, adoption, and maintenance of iron technology, we can explore the *agency* of local societies at a much deeper level than traditional trade/exchange explanations.

Recent research carried out by the authors shows that iron technology was a widespread practice within the hunter-gatherer communities of ancient Arctic Europe more than 2000 years ago (ca 200 BC) (Bennerhag et al 2021). This encompassed not only the production of bloomery steel but also the mastery of complex smithing skills. A more expansive analysis, still in progress, reveals striking similarities across an even vaster geographical area, including large parts of northern Finland, Sweden, and Norway. This points to shared technological practices across a broad area, indicative of larger patterns of contact among these communities. Simultaneously, the ongoing research has brought to light variations in technological practices, particularly in raw material choices and curation strategies, suggesting diverse trajectories in the transmission of iron. In this context, we welcome a discussion on including more nuanced reflections on the complexity and regional variations in the transmission of iron technology.

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7. The long and historical perspective – mining and environmental impact

O116 - Reshaping the landscape: environmental and ecological impacts of historical mining and metallurgy in the Bergslagen region, Sweden

7. The long and historical perspective – mining and environmental impact
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Abstract text: Humans had already significantly altered many landscapes long before the emergence of 20th century environmental issues, e.g., acid rain, metal pollution, and biodiversity loss. As elsewhere in Europe, the introduction of agriculture during the Bronze/Iron Ages led to changes in forest cover, especially in southern Sweden. In central Sweden, it is instead the rise and rapid spread of ore mining and metallurgy during the 12th–13th centuries that led to a widespread reshaping of the landscape. The 89,000 km^2 Bergslagen region is littered with >5000 metallurgical sites (furnaces, smelters, foundries, forges) and >10000 mines, which influenced the environmental and ecological landscape.By studying >30 lake-sediment records using geochemical, diatom, and pollen analyses we can add important details on how early, poorly documented mining and metallurgy affected the environment in Bergslagen. Before the 12th century, pollen records show that cultivation and other land use were limited and discontinuous. This changes during the 12thcentury, when cereal pollen become a regular occurrence, charcoal particles increase, and concentrations of elements associated with erosion (Al, Ti) and mining/metallurgy (Cu, Zn, Pb) increase. From this time there is a gradual decline in forest cover that accelerated from the late 16th century when metal production expanded further. The increased demand for charcoal and increased agriculture, including transhumance, contributed to this decrease in forest cover. From the 16thcentury, charcoal became a limiting resource within Bergslagen, and metallurgy expanded to adjoining regions, leading to a more widespread decline in forest cover beyond Bergslagen. In association with the increase in land-use activities, there were also changes in water quality, such as a decline in lake-water organic carbon, hypothesized to result from a decrease in soil carbon stocks. In some lakes closely connected with blast furnaces, where the miners also lived and farmed, there was an increase in lake-water pH – similar to observed changes SW Sweden due to Iron Age land use. Some lakes surrounding the copper mines of Falun also experienced early acidification.While present-day rates of environmental change may be unprecedented, they are superimposed on an already drastically modified landscape. Because pre-industrial conditions, i.e., pre-19th century, are often used as a reference level, the scale of recent human-induced changes may be an underestimate of the full extent of ecosystem and environmental impacts.

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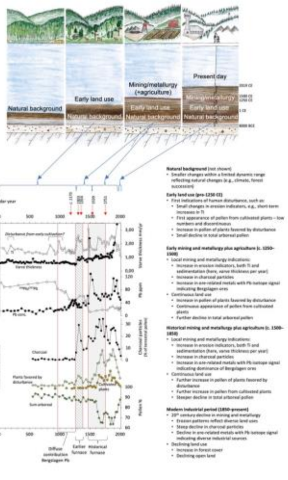
Natural background
Early land use
Mining/metallurgy (+agriculture)
Present day
Calendar year
Natural background (not shown)
Smaller changes within a limited dynamic range reflecting natural changes (e.g., climate, forest succession)
Early land use (pre-1250 CE)
First indications of human disturbance, such as:
Small changes in erosion indicators, e.g., short-term increases in Ti
First appearance of pollen from cultivated plants – low numbers and discontinuous
Increase in pollen of plants favored by disturbance
Small decline in total arboreal pollen
Early mining and metallurgy plus agriculture (c. 1250–1500)
Local mining and metallurgy indications:
Increase in erosion indicators, both Ti and sedimentation (here, varve thickness per year)
Increase in charcoal particles
Increase in ore-related metals with Pb isotope signal indicating Bergslagen ores
Continuous land use
Increase in pollen of plants favored by disturbance
Continuous appearance of pollen from cultivated plants
Further decline in total arboreal pollen
Historical mining and metallurgy plus agriculture (c. 1500–1850)
Local mining and metallurgy indications:
Increase in erosion indicators, both Ti and sedimentation (here, varve thickness per year)
Increase in charcoal particles
Increase in ore-related metals with Pb isotope signal indicating dominance of Bergslagen ores
Continuous land use
Further increase in pollen of plants favored by disturbance
Further increase in pollen from cultivated plants
Steeper decline in total arboreal pollen
Modern industrial period (1850–present)
20th century decline in mining and metallurgy
Erosion patterns reflect diverse land uses
Steep decline in charcoal particles
Decline in ore-related metals with Pb isotope signal indicating diverse industrial sources
Declining land use
Increase in forest cover
Declining open land
Diffuse contribution Bergslagen Pb
Earlier furnace
Historical furnace

O117 - Environmental responses and geomorphological consequences of ancient metallurgical activities since the Iron Age (Varenne watershed, Normandy, France)

7. The long and historical perspective – mining and environmental impact

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Abstract text: For at least 800 years, the Varenne watershed (200 km^2, Normandy, France) has been intensively involved in iron ore mining and iron production, both in blast furnaces (directly) and bloomery (indirectly). At the beginning of the 17th century, seven blast furnaces were operating in the watershed, six with a refining forge.

The research hypothesis is that these activities led to a profound transformation of the landscape, in particular the alluvial plains. On the one hand, the high demand for charcoal for the iron industry was at the expense of the region's forests, which may have led to soil erosion and accelerated the sedimentation in the valley bottoms. On the other hand, the installation of blast furnaces along rivers from the 16th century onwards led to the transformation of river systems, in particular through the construction of numerous hydraulic structures such as ponds, dams, dikes, weirs, diversion channels and other facilities. The aim of this research is to understand the evolution of landscapes, watercourses and alluvial plains before, during and after the iron industry.

One site in particular has been the subject of extensive research: the Forge Neuve site. It has the advantage of having been in operation for a relatively short period (1580-1670) and the traces left by the activity of this blast furnace/forge constitute a precise chronological marker. The second advantage is that the site has a well-developed alluvial plain, which is ideal for preserving sedimentary archives. Consequently, a geoarchaeological study was initiated. It was based on historical and field research: 18 cores drilled, five geophysical transects and a photogrammetric study were carried out. In the laboratory, grain-size, concentration of iron metallic spherules and microslag, magnetic susceptibility, ICP and EBX SEM geochemical analyses were performed and thirty radiocarbon dates were carried out.

These analyses have allowed us to reconstruct the evolution of the Varenne alluvial plain over the last 2kyrs. They allowed us to identify an ancient pond associated with the forge activities and to reconstruct the entire hydraulic layout. Finally, the use of iron metallic spherules in combination with topographic and stratigraphic analysis highlights the impact of a dam on the construction of the alluvial plain. These results demonstrate the importance of the transformations associated with the development of the blast furnace and, more generally, allow us to propose hypotheses on the consequences of metallurgical activities on the evolution of the alluvial plain.

O118 - The environmental legacy of medieval silver production in southern Morocco

7. The long and historical perspective – mining and environmental impact

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Abstract text: Historical sources and numismatic evidence indicate that medieval Morocco played a major role in the supply of silver for the expanding Islamic economy of the late first millennium CE. Archaeological evidence for this metallurgy is rare, however. Here, we present fieldwork evidence for large-scale sustained lead smelting in and around the site of Tamdult near Akka, southern Morocco. Tamdult was a major stop on the trans-Saharan trade route, and numerous coin mould fragments with traces of silver in them indicate the presence of a mint. Finds of itharge indicate the extraction of silver from argentiferous lead, which is evidenced by large slag heaps of lead-rich glassy slag in the immediate vicinity of the settlement.
In addition, using portable XRF analysis we identified a systematic and significant presence of lead in sediments and mud bricks of the site, and in the surrounding landscape. In this talk we explore the potential origin of this lead from either mining and ore beneficiation, or from lead smelting. We also explore the bio-availability of the lead (and copper) contamination, and its potential impact on modern populations. The result will have ramifications for any remedial action that may need to be done in this agricultural landscape, and are potentially of much wider significance for other major lead mining sites in Europe, and beyond.

O125 - State of knowledge, research prospects and revised dating of the so-called 'Celtic' gold panning mounds in the Belgian Ardennes

7. The long and historical perspective – mining and environmental impact

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Abstract text: The numerous gold-panning mounds of eastern Belgium were identified as such around 1875 by gold prospectors . This discovery gave rise to a local gold fever, but it was short-lived and of little interest due to the low gold content and inefficient gold panning techniques. Since then, dozens of other sites have been identified by geologists and amateur gold panners in other parts of the Ardennes massif. In recent years, airborne LIDAR data has also been used to identify stretches of river where gold panning had been carried out, to identify new sites and to measure their extent and characteristics. Numerous descriptions of the shapes, volumes, sizes and contents have been made as well as proposals for chronological attributions, mainly to the Celtic period, based on logical hypotheses rather than on empirical facts. As no mounds have been excavated using a methodology that allows them to be unequivocally dated, no periods of activity can yet be proposed. Only J.-M. Dumont carried out 14C dating from which he extracted those that could confirm the attribution of the gold panning activity to the Celtic period. These dates are questioned and a more objective and interdisciplinary methodology is proposed. Presently, it is not possible, on the basis of current data, to clearly attribute this exploitations to Iron Age, Roman or later period. Various geomorphological studies have provided significant information both on the impact of gold panning structures on the landscape and on the methods of exploitation of alluvial gold sites. For example, based on core sampling and analysis of the alluvial architecture of a headwater stream, a schematic history of the stages of gold panning and the geomorphological evolution of the river since the activity ceased has been proposed.

Selected references

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O126 - THE MATERIALITY OF SLAG. Socio-cultural relations to slag in central Scandinavia from prehistory until today

7. The long and historical perspective – mining and environmental impact

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Abstract text: Slag is often seen as a residual product of metal processing. When studies are carried out to gain deeper knowledge of slag, it usually takes place through various types of technical and metallurgical analyses. In these descriptive scientific analyses, the people who once handled the material disappear. People who work with different types of materials, such as wood, leather and concrete, have a special relationship with the material itself and its characteristics; this applies not least to metal and thus slag.

In this study I have explored how slag in different times have been used as an identity marker and how it affected people, both directly and indirectly. As case studies, I have used archaeological results from Late Iron Age (400-1100 CE) Gästrikland and the early modern and modern Falun. Both regions are located geographically close to each other in central Sweden. The Gästrikland region is well known in Scandinavian prehistory for an early iron production. The copper production in Falun is world-renowned and has made an enormous impact on culture as well as on the environment.

By reversing the perspective and instead recognising the slag as primary, it is possible to study how at different times and in different ways the material constituted an important social component in people's lives. I have used the theoretical framework of materiality where I do not see the slag as static, but instead follow it and its constant change through the creation of historical and cultural processes. The concept of materiality captures the field between material and human behaviour. Materiality is never constant but in constant change, a process that never ends. This is a description that can be directly transferred to slag. On several occasions throughout history, slag has been considered a waste product, but has regained its value with new technological advances. The slag still contains valuable metal, which will be spread over the world, while the slag remains in a new form. In this perspective, slag is performative.

The result of my study shows that slag is an active component of people’s material culture to the highest degree. Slag has produced and is producing opportunities and identities; it generates problems and makes people creative, from ceremonial contexts to filling masses, from inedible vegetables to beautiful pastries.

O127 - Defining ancient local mining and metallurgy combining metal palaeopollution and archaeological evidence at central Galicia (NW Spain)

7. The long and historical perspective – mining and environmental impact

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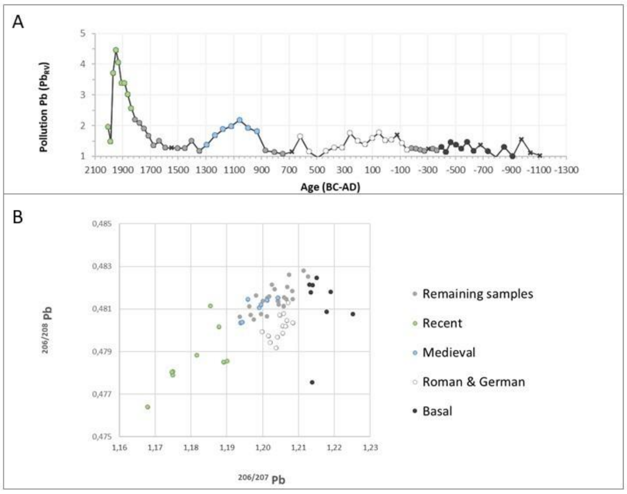
Abstract text: Northwest Spain has been an area of intense mining and metallurgical activity since prehistoric times. However, the apogee of Roman mining activities in the area has, to some extent, outshined the importance of metal extraction and production processes outside this period.

This study approaches the diachronic development of past mining and metallurgical activities at central Galicia through the combination of palaeoenvironmental, archaeological and historical approaches.

A peat core from a minerogenic peatland ('Cruz do Bocelo', NW Iberia), spanning the last 3000 years, was studied by integrating geochemical (XRF, Pb isotopes) and palynological evidence. The most remarkable peaks in the lead anthropogenic signal occurred during Roman, Medieval and Contemporaneous times. Although Roman and Contemporaneous signals could be related to regional processes, the high intensity of the medieval pollution peak, something relatively unusual for the Northwestern Iberian context, together with its lead isotope signature, were interpreted as evidence of local mining and metallurgical operations.

Catalogued mining and metallurgical evidence in the area (considering a radius of 30 km around the peatland) consists of 35 undated open pits, in areas with contrasted mineralogies, likely indicative of a variety of ores (probably gold, tin and iron), 8 references to lost remains related to iron metalworking (blacksmiths and hydraulic mills) and *'A Roxida'* iron slag heap. We will present the available information on all of them to evaluate their possible connection to the metal pollution detected in the peatland, although we will mainly focus on three particular cases: two sites that have been indirectly dated by their mention in medieval civil and ecclesiastical texts: i) a group of three open pits called *'As Grobas'* and ii) a production site known as *'A Granxa de Constantin'*; and iii) *'A Roxida'* iron slag heap, in which a preliminary analysis to characterise and date the slags is being performed.

This study highlights the value of small minerogenic peatlands, which usually have a small source area, as ideal contexts for the detection of local patterns of environmental change that may not be reflected in environmental archives with a higher source area and emphasises the importance of approaching past metal extraction and production from a multidisciplinary perspective.



Chronological evolution (A) and lead isotope fingerprint (B) of the lead pollution signal at 'Cruz do Bocelo' peatland fen.

8. Latest experiences of related archaeometric methods and technologies

O104 - Argaric Metallurgy: An Experimental Approach to Producing Tin Bronzes with Arsenic

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: The El Argar Culture developed in the southeast of the Iberian Peninsula during the Early and Middle Bronze Age (2200-1550 BC). It is characterised by a standardised material culture, mostly individual and double burials under the dwellings, and a settlement pattern with a predominance of high-rise sites, defensive elements, and an urban layout of terraced buildings with narrow streets, sometimes arranged in artificial terraces (Aranda *et al*. 2015).

Metallurgical production was dominated by copper and arsenical copper, with bronze items appearing later (from 1800 BC onwards). Silver was also commonly used, while gold is less frequently found (Murillo-Barroso, 2013). Most of the metal artefacts come from funerary contexts. Scarce remains of production have been found, with the most significant sites being El Argar (Antas, Almería) and Peñalosa (Baños de la Encina, Jaén), where the complete production sequence has been recovered.

The El Argar culture covered a vast territory, reaching up to 35,000 sq km at its peak (Villalba-Mouco *et al*. 2021). However, the available tin resources were scarce and inaccessible, which limited the possibilities for local bronze production. In contrast, copper resources were abundant and very often accompanied by high levels of arsenic which generated high arsenical copper objects (up to 10-12% As). However, the fact that two compositional patterns are detected in tin bronze objects (with and without arsenic) raises the possibility of two different productions, possibly local (tin bronzes with up to 2% arsenic) and imported (tin bronzes without arsenic) (Montero *et al*. 2019). Another possibility is that cassiterite hinders the ability of copper to fix arsenic during the smelting process therefore generating low to non arsenic tin bronzes.

To further investigate the bronze production processes, various experiments were conducted under technological conditions similar to the El Argar context. Arsenical copper ores known to be used by lead isotope analyses, were smelted with and without cassiterite to determine the behavior of tin and arsenic in the same metallurgical process.

The results of these experiments were combined with lead isotope and trace elements analysis of El Argar bronze objects, and their implications in the field of prehistoric metallurgy are presented.

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O105 - Crucible metallurgy field experiments: replicating prehistoric copper smelting, alloying and recycling to better understand the archaeological record

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: One of the most frequent aims of the analytical study of archaeological crucibles is to reconstruct the metallurgical operations for which each crucible was used. However, metallurgical remnants in the ceramic fabric and / or the crucible slag in the archaeological record are often inconclusive. During the analysis of crucibles from a Late Bronze Age workshop in the Carpathian Basin (Șagu, Romania) we were confronted with a similar question. Ot was not possible to determine whether tin oxides in crucible slag were leftover cassiterite from primary alloying or secondary products of tin oxidation (Orfanou et al., 2022).

To address the question of identifying primary alloying versus remelting of ready-made bronze, we designed a set of field experiments at the Centre for Experimental Archaeology and Material Culture at University College Dublin that took place over three days in September 2023 to evaluate the impact of various metallurgical operations on crucibles. We based the metallurgical set up on the well-documented archaeological evidence from the workshop at Șagu. We replicated a) smelting, b) remelting and c) alloying of copper and tin (metallic and minerals) in crucibles. Often, we repeated an experiment using a single crucible to evaluate the impact of one-off and repeated operations. Experiments included:

1. Alloying of copper and tin (metals) in 1 and 3 repeats (2 experiments)
2. Bronze remelting in 1 and 3 repeats (2 experiments)
3. Alloying of malachite and cassiterite
4. Reduction of malachite followed by 5 repeats of remelting
5. Cassiterite reduction

We collected samples from the crucibles used including crucible slag and the various metal charges resulting from the respective experiments. Examination of polished cross-sections under reflected light microscopy and SEM-EDS at the Department for Earth and Environmental Sciences at LMU Munich is currently ongoing. Preliminary results allow us to reverse engineer the metallurgical processes via the analysis of intermetallic phases in the metal charge and crucible slag, as well as to identify changes in the metal impurities upon repeated remelting cycles. We hope that our results will provide a possible road map for crucible analyses and help advance our understanding of prehistoric crucible metallurgy.

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O106 - Assessment of portable X-Ray Fluorescence for the characterization of medieval silver-copper coins

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Portable X-Ray Fluorescence (p-XRF) analysers are more and more widespread in research and especially in archaeometallurgy. Their low price, their ease of use and the high rate of analysis – in addition with their portability – explain this popularity. The number of research studies making use of p-XRF analysers is thus constantly growing. Nonetheless, these devices become available to users who are not trained neither in X-Ray spectrometry, nor in the knowledge of ancient materials characteristics, which can cause some errors or misinterpretations. P-XRF users should be trained to using these devices and their possibilities and limitations for different types of archaeomaterials have to be assessed by specialists.

Ancient silver coins are generally made of a silver-copper alloy, from nearly 'pure' silver to debased silver ('billon'). They are often affected by the so-called 'silver surface enrichment' phenomenon which is caused by the preferential oxidation of copper at their near surface during their making process as well as during their burial. As a result, a surface layer of variable thickness is depleted in copper and enriched in silver compared with the alloy that was initially prepared, entailing possible errors in the determination of the coins' compositions. This can be avoided by practicing abrasions at the surface, but the X-Ray beam of portable devices is generally 3 mm in diameter at the smallest. This entails that any cleaning would be visible with the naked eye and would generally not be accepted by collection curators.

In this study, we propose a comparison of the compositions of 28 ancient silver coins dating from the 10th to the 13th centuries containing various levels of silver, copper and trace elements. The results given by p-XRF without any preparation were compared with those obtained by laser ablation ICP-MS. This method used for ancient silver coins for nearly 20 years allows to avoid the silver surface enrichment phenomenon by the means of concentration profiles from the surface to the inside of the coins.

This comparison confirms the general oversestimation by p-XRF of the concentration of silver and associated elements (Au, Pb) in the coins, whilst copper and associated elements are underestimated. It also proposes limits of detection of this method for ancient silver-copper alloys. This study allows to evaluate the possibilities and limitations of p-XRF analysis of medieval silver coins and enables to undertake a reflection on its accuracy its accuracy for ancient coinages in a wider view.

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O107 - Multi-isotopic (Pb-Fe-Cu) and elemental characterization of Islamic gold coins (Fatimids): an insight into Trans-Saharan trade and chaîne opératoire

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Ancient gold provenance studies were thus far mostly carried out with elemental analyses, but they have limitations. Although they may allow to characterize metal stocks and highlight metal circulation in a given geographical space, notably with elements like platinum and palladium, it remains difficult to assign a geological and geographical origin to the gold objects studied. In contrast, isotope analysis offers a complementary and valuable insight into provenance studies. The radiogenic systems of lead isotopes provide insight on the age of the host mineralization. The more recently investigated stable iron and copper isotopes allow to characterize the ore type, e.g., magmatic, hydrothermal or supergene; primary vs secondary, etc.

A selection of eleven Islamic gold coins minted in Morocco, Tunisia and Libya and coming from a treasure of Fatimid dinars discovered in the medieval port of Caesarea (Israel) was studied. Elemental composition was determined using LA-ICP-MS and isotopes of Pb, Fe and Cu were measured using drill-sampling and wet MC-ICP-MS analysis. Medieval written sources tell us that Islamic gold originated in West Africa, but tangible proof has remained out of reach to this day.

Our lead isotope results from Fatimids gold coins gave much younger model ages (ca. 0-200 Ma; $^{206}Pb/^{204}Pb > 18.40$) compared to those of West African gold mineralizations (ca. 2000 Ma; $^{206}Pb/^{204}Pb \sim 15.00$). This suggests that Pb from these coins does not trace the gold ore source. Instead, we hypothesize it likely comes from pollution, perhaps at the very beginning of the *chaîne opératoire* or at the minting workshops place. In both cases, lead isotopes indicate that this pollution was produced by material located North of the Sahara. The Fe and Cu isotope results reveal signatures characteristic of supergene ores. $\partial^{57}Fe_{IRMM-14}$ values range between 0.0 and 1.8 ‰ (with an exception at -0.8 ‰) which correspond to the trend of marine and supergene sedimentary iron very abundant in West Africa in which gold can concentrate. $\delta^{65}Cu_{NIST976}$ of the Fatimid coins have a mean signature of 2.7 ± 1.2 ‰ (SD) which correspond to oxidative and/or carbonate deposit. Coupling elemental analyses with copper isotope suggests a supply via different (at least two) gold stocks.

Hence, these new isotopic analyses led to formulate hypotheses as to the origin and type of gold ore used, but it has also enabled us to understand more about the *chaîne opératoire* for these Fatimid dinars thanks to complement approaches.

O113 - New method of bulk slag analyses in archaeological semi-finished iron products via extraction of slag from a dissolved metallic matrix

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: The archaeological semi-finished iron products (blooms, ingots, bars) offer a great potential for gaining a major insight into past human societies who manufactured them. This potential can be especially effectively revealed through an application of a full-scale arsenal of modern analytical techniques including metallography to characterize production technology, direct ^{14}C dating of metal, and provenance via slag inclusion method to determine the ore sources. However, despite the major advantages of such sophisticated approaches, they often require cutting of a section from an object, which is not always allowed by museums where artefacts are stored. In contrast, taking of sample via drilling (using 3-5 mm drill) is sometimes regarded as less invasive and hence can be more readily accepted to compromise the damage to an object.

We have developed a new method for analysis of lithophile major and trace element composition of slag entrapped in the semi-finished iron products from metal chips extracted by drilling of an artefact. The procedure concludes in complete dissolution of 50 mg of drilled metallic chips in diluted HNO_3 to extract the slag inclusions from the metal matrix and analyze them via solution ICP MS. The data generated for most of major and trace elements proves consistent with the results of micro analyses of slag inclusions performed on polished section by LA ICP-MS, as tested on the hoard of Celtic ingots from Ay an der Iller (West Bavaria) and Schifferstadt (Upper Rhine). Although the method cannot fully replace analyses of sample sections (e.g., information about carbon content and presence/absence of welding lines is missing), it can nevertheless be regarded as an effective alternative for analyses of semi-finished iron products, especially when the strongly invasive approaches such as cutting are not permitted. The further potential of the method concludes in its combination with the analyses of siderophile element contents (via solution ICP MS) and Os-Re isotopic analyses, as both latter methods are performed on the fraction of the same metal chips. The combined application of all of these techniques allows to determine the key compatible parameters with the Os isotope composition of the smelted ores. These integrated approaches prove especially relevant in application to such artefacts as Iron Age iron ingots, of which more than 1300 pieces are known only in Germany.

O114 - Experimental extractive metallurgy of copper ores: new perspectives

8. Latest experiences of related archaeometric methods and technologies

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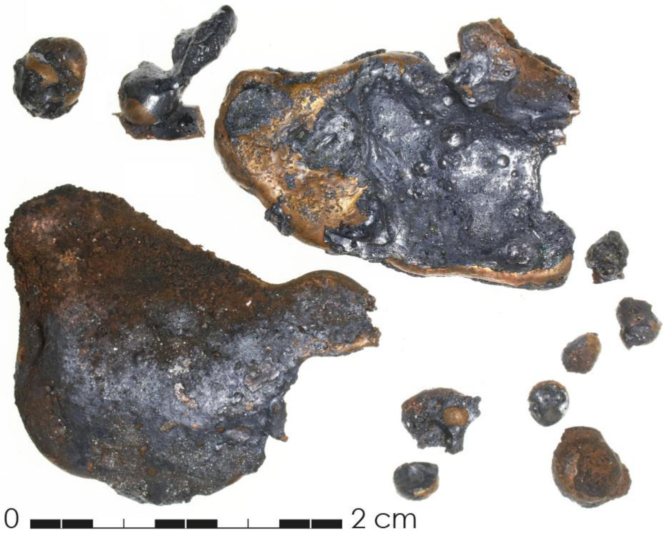
Abstract text: Experiments on copper ores smelting have been carried out since 2019 on the archaeometallurgical experimental platform at Melle (France). Those experiments were first related to the archaeology of the Iron Age in South-East Asia. After setting up a successful protocol, those experiments were continued and the questions were widened to other historical contexts: pre-Columbian Northwest of Argentina and the French Pyrenees mountains at the end of the Middle Ages, since the ores treated were of the same type. This simple process allows indeed continuous production, and can be applied to a variety of contexts.

In 2023, more than twenty copper ore smelting experiments were conducted on the platform. These operations were carried out using a copper carbonate (malachite), copper sulphides (chalcopyrite and chalcocite) and a lead and copper sulphoantimonide (bournonite). The cofusion of copper carbonates and sulphides (malachite and chalcopyrite) and the treatment of matte were also investigated.

These experiments conducted over several years have resulted in a significant gain in "savoir-faire", with an improvement in the protocol. This enhancement enables to repeat the smeltings and to produce metallic copper and matte almost each time whereas it is widely accepted that smelting involves at least two stages: the production of a matte followed by its desulphurization to obtain metallic copper. The matte was sometimes remelted with ore during the following experiments, with some mattes being more difficult to reprocess than others. At the same time, we are demonstrating the importance of reusing crucibles from one experiment to another, and the gains in production that this can bring.

By producing copper from known ores, compositional analyses (SEM-EDS and laser ablation ICP-MS) were performed on the metal obtained from the experiments for comparing their trace elements patterns with the characteristics of the ores. The results obtained by LA-ICP-MS show that the copper produced has very low levels of impurities regardless of the nature of the ore used. These observations indicate that the experimental smelting process developed enables the production of copper that can be considered "pure" from the point of view of ancient metallurgists.

These experiments have raised new questions, both regarding the processes used and the complexity of the smelting of some ores, which will need to be answered in future experiments. One further objective is to compare the particular compositions of the metallic copper obtained from different ores with the composition of ancient copper smelting products and finished objects.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O115 - Study of Ancient Japanese sword cross sections by neutron and comparison with metallography and micro-vickers hardness

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: The metallurgy of historic melee weapons (swords, in particular) is one of the most interesting topics in archaeometallurgy because these objects were manufactured, during the ages, by using the highest quality materials and the most advanced technology at the time. Japanese swords represent one of the most important topics in the field of historical metallurgy. It is since ancient times that Japanese swords are famous all over the world as the most effective in terms of hardness, resilience and, last but not least, aesthetics. Since late 19th century, the importance of Japanese arms and armors has been demonstrated by several studies conducted from a stylistic point of view and from an analytical scientific approach. Until recently, the largest part of scientific analyses was based on destructive traditional techniques for metallurgy, like metallography and scanning electron microscopy (SEM). However, these methods are unacceptable for well-preserved museum exhibits.

In recent times, we analyzed Japanese swords through non-destructive quantitative methods such as time of flight neutron diffraction (ToF-ND), neutron imaging (NI) and Bragg Edge Neutron Transmission (BENT).

ToF-ND is able to give quantitative phase concentration and micro-structural properties on large scale volumes. NI is able to give high spatial resolution attenuation coefficients that can be semi-quantitatively related to the microstructure and phase morphology.

Last but not least, BENT can provide amazing results on high spatial resolution, phase distribution, and microstructural properties such as microstructural state of welding areas as well as concentration and distribution of martensite in quenched areas. It is clear that all these methods offer important results about specific properties of historic metallurgy samples.

By applying neutron methods we aim to obtain an insight on the microstructural features to be compared with the results gathered through the usual characterization way: Optical Microscopy for metallographic analysis and Micro-Vickers Hardness testing. This approach allowed us to point out the sensitivity and limits of application of the neutron methods and the creation of a database more specifically suitable to the usage in the field of archaeometallurgy. We analyzed a group of seven metallographic cross sections extracted from a set of Japanese broken swords pertaining to Stibbert Museum (Florence-Italy). All swords are signed and judged as original by museum curators. Then it was possible to identify manufacturing period and style. The analytical approach included metallographic analysis, Vickers Hardness, Neutron Imaging and BENT analysis. We will show results related to comparison among such different analytical methods.

O122 - Reevaluating the Provenance of Late Bronze Age Copper Ingots using Lead Isotopic Data and a Mixing Model

8. Latest experiences of related archaeometric methods and technologies

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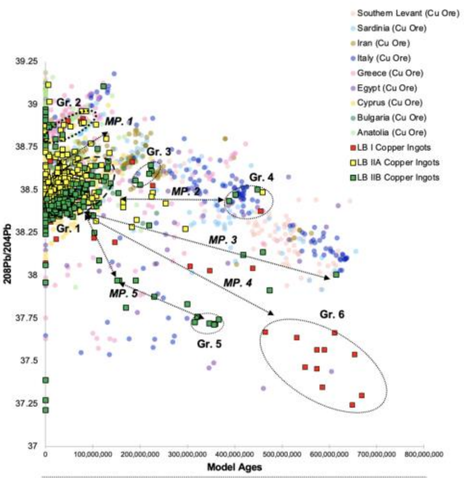
Abstract text: For the past four decades, lead isotope analysis of hundreds of copper ingots recovered from Late Bronze Age Mediterranean contexts have laid the groundwork to provenance copper-based objects. Recent advancements, including the use of innovative isotopic mixing models, call for a fresh examination of the origin of copper (and lead) utilized during this period. A robust legacy dataset, including 694 copper ingots and 781 lead isotope results, is used to identify major and minor copper and lead sources. The dataset, filtered based on secure archaeological contexts, employs a $^{208}Pb/^{204}Pb$ vs. *Model Age* plot and [Pb] vs $^{206}Pb/^{204}Pb$ mixing model to demonstrate that five different copper and lead sources, possibly more, were exploited. Mixing model results show that the majority of copper ingots group into broadly distinct clusters, each indicative of a single isotopic source. In accordance with earlier findings, the majority of Late Bronze Age copper ingots are consistent with geologically young copper ores from Cyprus. Nevertheless, small numbers of ingots overlap with Aegean and Aegean or Anatolian sources, in addition to a geologically very old source presented in new light. In select instances, mixing is indicated, particularly in the case of ingots recovered from 13th century BCE contexts. Such results have implications for regional interpretations of copper and lead sourcing, the development of complex trade networks in the Late Bronze Age Mediterranean, and future lead isotope studies.



Late Bronze Age Copper ingots plotted against Regional Copper Ores.
Circles Denote Groups of Ingots, Interpreted as Distinct Sources
Dotted lines Represent Potential Mixing Trajectories.

O123 - Archaeometric study of a broad collection of pre-Roman bronze fibulae from the center of the Iberian Peninsula

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Introduction

This work summarizes the results of an archaeometric study of pre-Roman bronze fibulae found at the Pintia site (Padilla de Duero/Peñafiel, Valladolid, Spain), located in the center of the Northern plateau of the Iberian Peninsula. Pintia was a large Vaccean city that developed in the second Iron Age, from the 5th century BC, overcoming the change of era in the Romanization process. At that time, it could house around 8 to 10 thousand people.[1] The archaeological research carried out on this site, over more than four decades, has provided important findings, among which it is worth highlighting the collection of fibulae with some 370 specimens, which places it in second place after Numancia (Soria). This large set is also relevant both for the diversity of models and for the perfect state of conservation of many of the pieces, constituting a magnificent testimony of the metallurgical activity of the Vaccean people (Figure 1). At the same time, there are a series of pieces that find their parallels among the finds of other bordering ethnic groups (Celtiberia, Vetonia and Autrigón world) and in more distant regions, such as Tras Os Montes, Gallaecia or even Central Europe.

Methods

With the aim of improving our knowledge about Vaccean metalwork and trying to look for evidence of its political and commercial relationships with other cultures, a selection of 126 fibulae from sixteen different archaeological sites assigned to various cultures has been studied by X-ray Fluorescence. Several parts of each fibula were studied, reaching a total number of 723 points analyzed, to ensure the representativeness of the obtained results and to identify differences between the pieces that make up the most complex specimens.

Results and conclusions

The obtained results allow for the identification of the main composition of the bronze alloys, generally presenting very low amounts of lead and a broad range of tin. However, a significant number of pieces with high lead contents are also found in this collection. In addition, it was possible to evaluate the effects of the patina on a representative selection of pieces that present polished areas, obtaining a good qualitative agreement between the results obtained from the patina and the polished surfaces in good agreement with previous results.[2] Finally, the hypotheses about a possible different provenance of some notable pieces have been reinforced by the detection of anomalous contents of some elements (e.g., silver, antimony, gold, etc.).

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O124 - Hydraulic hammer: new methods for the study of an archaeological object

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: The hydraulic hammer has been used as a production tool since the early 12th century. It has undergone various changes, particularly in terms of water supplies, the method of arm actuation and the head’s weight. 16th century technical literature provides relatively accurate descriptions of this object. Archaeologically, several of these tools have been excavated across Europe. Archaeometric researches have primarily concentrated on the iron production with such a hammerrather than the tool itself.

A new approach of the hydraulic hammer is proposed, based on modern remains and excavations recently carried out in the Pyrenees on a 19th-century forge. This approach aims to define the hammer's water requirements and working capacity, using both modelling and *in situ* experimentation.

Water power is an essential resource for forging and the conditions under which it is used, such as the available head and flow rate, are an essential criterion in choosing a steelmaking site. Hydraulic resources limit the size of the drop hammer and a quantitative approach to this system allows a better assessment of this constraint. A model of the drive mechanism, based on the equations of solid mechanics, calculates the minimum flow required, which is then compared with the available hydraulic power. Excavations of hydraulic forges in the Pyrenees provide many of the parameters required for modelling, but some of the data relating to the design of the hammer remain purely hypothetical. Modelling makes it possible to assess these hypotheses with the criterion of hydraulic power.

The hydraulic hammer's working capacity is determined by both the power developed at the hammer head and the force at the time of impact on the iron. To quantify these values, we conducted experimental measurements on an active hydraulic hammer (https://www.forges-de-pyrene.com/). An accelerometer was attached to the hammer's head for this purpose. The processed data were then used to estimate the machine's power. They are also used to define the force at the time of impact. This provides insight into their working capacity and allows comparisons between different types of hydraulic hammers.

This study of a hydraulic hammer from the 19th century demonstrate the interest of those new methods for studying mechanisms in an archaeological context. Those methods are applicable to other systems in the Pyrenees or elsewhere and for other periods. The ultimate aim is to integrate these studies into an overall model describing the production system.

Poster

1. Mines, Mining and Mining heritage

P1 - Rock and Heavy Metal in Medieval Oslo.

1. Mines, Mining and Mining heritage

Astrid Tvedte Kristoffersen[1]
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Abstract text: This presentation highlights key results from the recent PhD study *Rock and Heavy Metal: Mining and metal production in Eastern Norway in the Middle Ages* (Kristoffersen 2023).

The point of departure for the study was a single crystal of the mineral galena, from which lead and silver can be produced. The crystal was unearthed during archaeological investigations of a 12th–13th-century context in Oslo, Norway. Galena is relatively common in the geological Oslo Region. However, up until now there has been no confirmed evidence for the mining of rock mineral deposits in Norway before the end of the 15th century. Thus, the overarching question for the study was whether there is evidence for the exploitation of galena and the production of metallic lead or silver during the Middle Ages in eastern Norway.

In the study, methods from the natural sciences were combined with traditional archaeological artefact investigations to study lead and silver objects from the region. By lead isotope analysis and elemental analysis, the geological origin of the metals was discussed. The analyses revealed a large general spread in isotopic compositions and elemental compositions, which show that a variety of different metals and alloys were used during the Middle Ages. However, a significant group of artefacts of pure lead have a specific isotopic composition close to ore material from the Oslo Region. The analyses have thus made probable that galena was mined, and metallic lead produced in or close to the Old Town of Oslo in the period AD 1125–1325. The production was initiated by the end of the 12th century at the latest. The analyses suggest that the exploited galena ore was located in the central part of the geological Oslo Region. Furthermore, objects of local lead were distributed regionally, and to some extent mixed with imported lead.

It is argued that locally produced lead was used to craft a specific type of lead spindle whorl with a ribbed collar. Several of the spindle whorls show identical features and could therefore have been cast in the same mould. It is suggested that these spindle whorls were produced within an urban household or craft centre in the Old Town of Oslo. The study has thus deepened our understanding of technical advances and the utilisation of local resources, during the Middle Ages in Norway.

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2. Metals, metallurgy and societies

P2 - Characterization of tin-threads found on Saami Kirtle bags

2. Metals, metallurgy and societies

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Abstract text: Characterization of tin-threads found on Saami Kirtle bags

Saami tin thread embroidery, a distinctive cultural expression within the Saami people, has remained largely overlooked from a conservation research perspective, lacking comprehensive research on its chemical composition, manufacturing techniques, and preservation challenges. This study addresses these gaps, aiming to characterize the metallic components and fibrous core of spun tin threads used in Saami Kirtle bags.

Given the absence of comprehensive research on the chemical composition of Saami tin threads, this study employs chemical analysis, to bridge this knowledge gap. The investigation seeks to provide a systematic examination of the material, emphasizing the significance of understanding the specific metals and alloys utilized. This knowledge is crucial for developing effective preservation strategies and ensuring the longevity of Saami cultural heritage. Additionally, the analysis serves as a foundational step in exploring potential degradation patterns, a phenomenon largely undocumented in the literature.

The investigation primarily employs Scanning Electron Microscopy with Energy Dispersive X-ray Analysis (SEM-EDX) to gain comprehensive insights into the chemical composition and morphology of the tin threads present in the kirtle bags. In the event of observed signs of tin thread corrosion, X-ray Diffraction (XRD) will be employed to further characterize the crystal structure of affected areas.

Conducted in collaboration with Dalarnas Museum, Hälsinglandsmuseum, and Västernorrlandsmuseum, this study anticipates comprehensive outcomes. The study is expected to result in a more comprehensive understanding of Saami tin thread composition, preservation challenges, and manufacturing methods. Notably, as no previous study of this nature has been conducted (to the authors' knowledge), this research serves as a valuable pilot study, laying the groundwork for further exploration.

P3 - Decorated tools from Northern Italy

2. Metals, metallurgy and societies

Fabio Spagiari

Abstract text: During the Roman age, iron tools reached a high level of technological specialization that has kept them almost unchanged through the centuries up to the present day. In the territory of northern Italy, some categories of tools exhibit morphological peculiarities that give greater aesthetic value to the artifact and are difficult to explain other than as decorations.

A group of billhooks is characterized by a particular morphology of the handle, achieved by twisting the square-sectioned tang (*fig. 1, a-b*). This process probably makes it impossible to insert an additional handle made of perishable material, casting doubts on the functionality of the tool. The overall dimensions typically do not exceed 20 cm, making them suitable for small pruning actions and cutting elements of limited thickness, such as the detachment of grape clusters. These billhooks have been widespread since the late La Tène period, with a significant distribution in the Veneto region, in the necropolises of Baone (PD) (Gambacurta, Ruta Serafini 2019), Arquà Petrarca (PD) (Gamba 1987), Zevio (VR) (Salzani 1996), and Isola Rizza (VR) (Salzani 1998), with some sporadic finds during the Roman imperial age.

Another class of tools characterized by different peculiarities are shears. Between the 2nd and 1st century BC, there is the presence of two small spurs located on the handle on seven specimens, while on the heel of the specimen from Tomb L in Arquà Petrarca, a carved spout is attested (*fig. 1, c-d*). Two imperial-age shears found respectively in the "Tomb of the Verona Physician" (Bolla 2004) and in the urban excavation of Via Benzi in Como (Lambrugo 2005), instead, show two phytomorphic elements at the junction between the bronze spring and the iron blades.

The present work intends to examine the methods used to make these decorative elements by conducting an autopsy study using digital microscopy and the reproduction through experimental archaeology of some specific finds (billhook from Tomb 1 in Baone, shears from Tomb L in Arquà Petrarca and from Tomb 254 in Oleggio) (Spagiari 2023). The investigations carried out have confirmed that the morphological features under study do not have a specific function. The decorations show the desire of the craftsman to demonstrate his high metalworking skill also giving the artefact a greater value; this, especially in the late Iron age necropolises, seems to be linked to the wish to signal the social status of the deceased.

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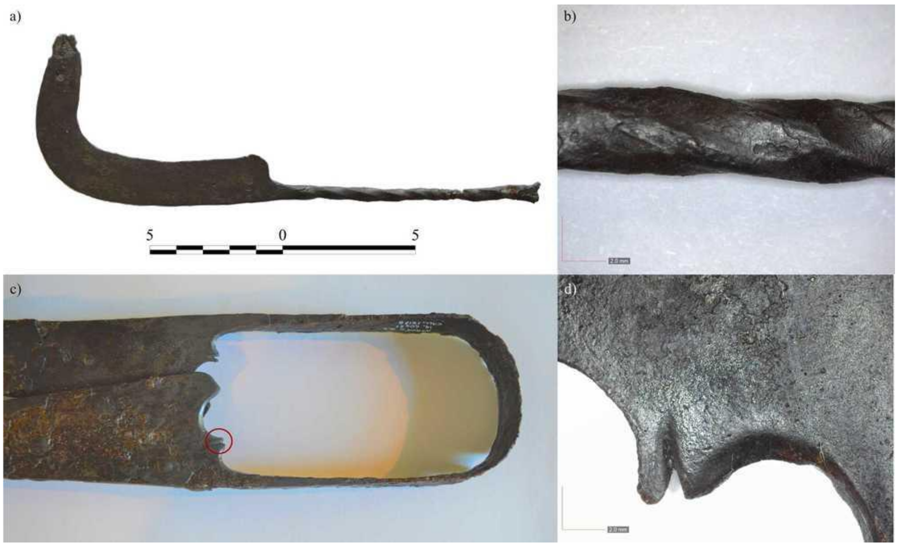
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P4 - Swords of Székesfehérvár – Technological analysis of two double edged swords from the 10th century Carpathian Basin

2. Metals, metallurgy and societies

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Abstract text: In 2020 a complex multiannual project has started in collaboration with the associates of the Pázmány Péter Catholic University (Budapest) and the Archaeometallurgical Research Group of the University of Miskolc (ARGUM). The primary objective of this research project has been the archaeological and archaeometrical examination of as many double-edged swords found in the 10th century Carpathian Basin as possible. In the frame of this interdisciplinary work 22 swords were examined by using archaeometrical-archeometallurgical methods. The main aim of this analytical study is to present the results of the archaeometallurgical investigations of two swords dated to 10th century, which were found in Székesfehérvár-Rádiótelep (Hungary) in 1923. We investigated the blades of the mentioned weapons for the purpose of mapping changes in the microstructure and the determination of the possible manufacturing methods. The microstructure of the blades were examined with optical microscopy (OM) and scanning electron microscopy equipped with energy dispersive spectroscopy (SEM-EDS). The whole process were completed with Vickers-microhardness test.

Summarizing the preliminary results of the two concerned swords, we could distinguish ferrite and pearlite in the microstructure of the blades but no martensit were observed in the samples. The metallographic investigations suggested that the blades were most likely made of two pieces of metal and it has shown a forgewelded constructions. The cores of the blades were made by folding however, the cutting edge of one of the swords were also made by folding technology. The latter construction is very unique among the examined weapons.

During our research project, we could observed similarities, differences and unique cases among the examined blades and it can be established that used manufacturing technologies are very diverse. In the light of this, the present study provides a depper insight into the current research precess of the double edged swords of the Carpathian Basin and, in wider aspects, its European context.

P5 - The wealth from Crucible and Anvil – Multimetality, Spatiality and Socio-economy in Iron Age south-east Scandinavia

2. Metals, metallurgy and societies

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Abstract text: The project 'From the Crucible and at the Anvil' examines the socio-economic implications of metalworking in Iron Age Scandinavia, focused on the spatiality, economic remits and technological repertoires of metal use. The connection between economy and metal use is central to the project and thus economic theory and spatial statistics are paired with archaeological and archaeometallurgical analyses to interpret the role och metal use and metalworking within Iron Age society. The project advocates an inclusive perspective with regards to metal use – covering the utilization of both ferrous and non-ferrous metals and analysing the differing and similar aspects connecting and separting them, technically and conceptually.

Within one case-study, metalworking sites have been analysed from a macro-level landscape perspective covering the wider south-east Scandinavian region throughout the Scandinavian Iron Age (500BCE-1100CE). The aim has been to infer the socio-economic implications of metal use through the macro-spatiality of metalworking sites.

In this paper, results from the case-study are presented and evaluated. The macro-spatial patterns of metal craftsmanship are used to infer the role of metal use in the overarching economic climate of the Scandinavian Iron Age. Employing a large data-set from both contract archaeology and large-scale inventory projects in southern Sweden, quantitative approaches and formal spatial statistics have been both necessary and fruitful. Using a macro-level approach, the site-information analysed was reduced, with general spatial location, primary metal use and coarse chronology forming key attributes.

This method differs significantly from the more high-resolution and qualitative approaches normally favoured when countering questions concerning the societal implications of metal use. The benefits and limitations of macro-level landscape perspectives are thoroughly discussed in the paper and methods for how such methods can be fruitfully integrated in the economic analyses of the Scandinavian Iron Age are suggested.

A qualitative landscape analysis of a sub-region of the study area forms the basis of another case-study within the project. The focus in this regard has been to elucidate the spatiality of commodity-chains of metal use, and to contrast those patterns to the general Iron Age landscape. Comparing the two case studies provides the opportunity to gauge the use of both sets of approaches, highlighting their pros and cons. Arguments for utilizing an inclusive toolbox with regards to method and theory when interpreting the societal implications of metal use will in this way be advanced in the paper.

Keywords: Metal use, Landscape analysis, Multimetality, Socio-economy, Commodity-chains

3. Archaeometallurgy of copper and copper-based alloys

P6 - Beyond the Surface: Examination of Late Bronze Age Bowl Production Techniques in Cyprus

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Cyprus has been an attractive position throughout history due to its location in the Eastern Mediterranean. Karpaz peninsula, located in the north-east of Cyprus, was a key with its advantageous location in terms of sea currents and wind directions, which were vital for maritime transportation in prehistoric times. The village of Kaleburnu in the southeast of the Karpaz peninsula is located opposite Ugarit in the Late Bronze Age has gained a special importance with its location. Discovered in 2004 with the first hoard[1] found in Kaleburnu village, Kral Tepesi settlement has unique property of harboring the most extensive hordes ever unearthed in Cyprus with the second hoard[2] discovered in 2014.

The discovery of second hoard in the same archaeological site, the variety of artifacts and the quantity of finds have raised many scientific questions.Finding out how these metal-based objects were made is one of the most exciting questions, among many other archaeological questions. In this context, the similarities and differences in the production process of 3 handled bowls with the same bowl typology and free handle, which were found nested in the hoard discovered in 2014, constitute a scientific question worthy of research.. Within the scope of this study, X-Ray Fluorescence (XRF) analyses were carried out to determine the chemical content of the bowls with handles. In the light of the data obtained, it was determined that two bowls were made of copper-tin alloy and the third bowl (Fig 1) was made entirely of copper. The fact that one of the 3 bowls of the same typology is made entirely of copper strengthens the possibility that the production processes went through different stages, and detailed analyses have begun to characterize the production processes.

For this purpose, to investigate the surface morphology, shape, size, and distribution of the fragments, Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM-EDS) will be utilized. X-ray Diffraction (XRD) will be carried out to investigate crystalline structure and Optical Microscopy (OM) will be used to examine microstructural properties. The main aim of the research is to understand the production techniques of each type of bowl and to present a comparative study of bowls with different chemical contents by identifying the differences in production techniques. Through the results in hand, findings obtained can be used in similar material analyses by providing new perspectives in the fields of archaeology, archaeometallurgy, chemistry and can guide similar studies in the future.

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P7 - Complex Deities. The British Museum's (Department of Greece and Rome) collection of Roman Copper-Alloy statuettes: an integrated approach

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: The British Museum's Department of Greece and Rome holds over 1,800 copper-alloy figural statuettes. Having received limited sustained attention previously, these items have great untapped potential for both art historical and chemical analysis, particularly when these approaches are integrated together. Most of the statuette collection has no confirmed archaeological provenance but was donated by a series of major collectors in the 18th and 19th century who were known to have operated around Naples, such as Sir William Hamilton, British Envoy to Naples. Thus it is likely a significant number of these items have a Campanian provenance linked to the 79 AD Vesuvian eruption and were excavated from Pompeii and Herculaneum, the 'cities of Vesuvius', from the 18th century onwards. This research aims to develop a uniquely integrated approach to this item type, combining chemical analysis with stylistic study, alongside collection history and archival research. Individual object histories are traced for each item, while as a whole the collection is situated within a broader Roman societal and economic context, considering factors of manufacture, recycling, repair and religious display.

This paper specifically presents the results of the analysis of the surface composition of 410 statuettes of deities using portable X-ray fluorescence (pXRF). Readings were taken from different parts of each statuette with the aim of creating a picture of the true appearance of these items, detecting different decorative surface treatments and previously un-recorded historic restorations. Alongside the pXRF, qualitative descriptions of each item, including stylistic and typological categorisation were undertaken.

This wide-scale analysis work allows comparison between the 13 different types of deities, considering major and minor alloy components. Initial conclusions suggest preference for specific alloys for certain deities, likely to achieve a particular surface appearance, such as greater use of zinc within statuettes of Cupid and Mercury. The proportion of statuettes with additional decorative elements (for example silvering of the eyes) was shown as much higher than previously visible by the naked eye (c.16% of items). This work also showed the varied restoration processes used to curate this collection since the 18th century. The challenges of analysing museum collections not available to sample in large numbers are considered, as well as those collections with previously insecure provenance. This paper illustrates how an integrated analytical program can illuminate complex statuette assemblages.

P8 - Compositional and provenance variability of copper alloys produced by Únětice culture based on analysis of the EBA hoard from Tursko, Central Bohemia

3. Archaeometallurgy of copper and copper-based alloys

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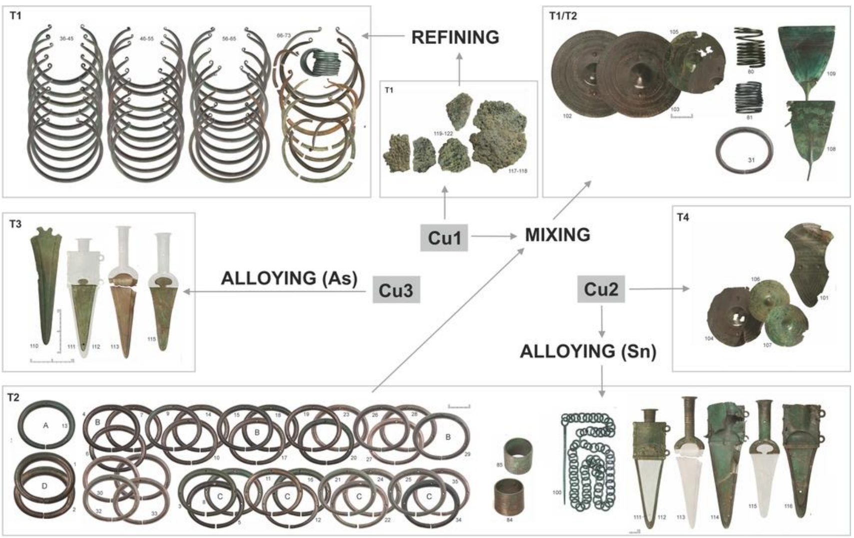
Abstract text: The bronze hoard from Tursko, Central Bohemia, Czech Republic, is one of the largest, most varied and most important EBA hoards ever. The collection of ~130 artefacts (weapons, ornaments, copper ingots and casting cakes) made of ~28 kg of bronze, and five gold nop-rings, was deposited during the Early Bronze Age (EBA) Únětice Culture period (ca. 2000–1800 BCE) in a quite large vessel near the today´s Central Bohemian village Tursko, not far away to north from Prague, and re-found in 2015.

General chemical composition of 111 sampled artefacts or their parts and microstructural features of casting cakes were determined using SEM/EDS. Selected 35 artefacts were further analysed by INAA and ICP–MS in order to determine the content of minor and trace elements. Using HR–MC–ICP–MS were analysed lead isotope ratios of such representative selection of artefacts.

This detailed analytical examination of the artefacts enables us to document products of several stages of the processing of the copper material ranging from primary metallurgical operations (casting cakes) to material in the form of solid neck rings, in which copper was transported, to final products. At least three sources of copper ore used to produce the artefacts were identified in the analysed assemblage. The origin of fahlore copper with the Cu–As–Sb–Ag chemical signature is presumably in the Tyrolean Alps, in the Innsbruck region. Raw material of this provenance is represented in the Tursko hoard by casting cakes and solid neck rings. Most of the final artefacts represented in the analysed hoard were made of fahlore copper with the chemical signature Cu–As–Sb–Ag–Ni with the proposed provenance at Lower Tatras region in central Slovakia. These objects were subsequently alloyed with various concentrations of tin. The provenance of arsenical copper used for production the dagger blades and the halberd blade points to the local sources of arsenopyrite from Bohemian sites. Analyses have proved the mixing of copper material of various origins during the production of the final items and, therefore, the use of various source materials in one metallurgical workshop.



P9 - Copper and copper alloys of the Industrial Revolution

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Analyses of copper and copper alloy objects from the time of the Industrial Revolution (here defined as the two centuries leading up to the availability of electricity as a bulk energy supply and the Hall-Héroult process) form only a small proportion of the vast number of analyses from the archaeological record as a whole. Even so, the number of analyses runs into the thousands, and it begins to be possible to identify regional and chronological trends in alloy compsotion and alloy selection. At present the results tend to come from particular sectors such as ordnance, marine engineering, furniture, and sculpture but there are, still too few data from everday objects. A key point to emphasise is that the range of alloys used expands as the range of uses expands, and we have documentary evidence, from patents to litigation, of the research undertaken at the time to design new alloys, not always successfully.

The first part of the paper will discuss examples of these experimental alloys designed before the emergence of physical metallurgy as a science. Using larger datasets, the second part will demonstrate regional trends in alloy use. At the first AIE meeting in Milano a paper explored the evolution and distribution of bronze and other copper alloys for ordnance (Northover and Gilmour 2003).To avoid repetiton a similar exploration will be made of the brasses used for furniture mounts, ornaments, and lighting in the 18th and 19th centuries. It begins to be possible to identify historically useful trends. The last part looks at the demands of new technology, such as the components of steam locomotives. Here it is necessary to find sample material in original condition and this exists in the form of locomotives lost at sea on their delivery voyages. Here we see a diverse range of alloys and also newly introduced technology, such as brass boiler tubes. Very fortunately in this last project it has been possible to take metallographic samples from most components studied. The conclusions will consider where these studies might progress next.

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P10 - Copper circulation in the southern Levant during the EBIIIA: Tell el-Hesi as a case study

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Several copper-based artifacts were uncovered in the EBIIIA city at Tell el-Hesi (~28th c. BCE) by the different expeditions that excavated the site (PEF, 1890-92; Joint Expedition, 1970-1983; and Michigan/Mississippi State University, 2023). In this study, we analyzed several artifacts by ICP-MS/AES for elemental along with lead isotope composition (Nu-HR-MC-ICP-MS) to better understand the quality of the metal/alloy used and to identify the geological source of the copper. Our results provide preliminary insights on metal circulation in the southern Levant during the peak in the first period of urbanization in the region (EBII-III), including the role of the Aravah copper mines vis-à-vis northern sources. In addition, comparing our results to the report of Gladstone from 1894 enabled us to examine and discuss the development of the archaeo-metallurgical discipline over the past 130 years.

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P11 - Cu3As surface layer on archaeological bronzes: human-induced formation or natural corrosion phenomena?

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Some of the Late Bronze Age daggers found in the cemeteries in Koban and Chmi and today held in the Natural History Museum of Vienna, Austria, show some very peculiar surface features: though made of tin-bronze (blade) and arsenical bronze (hilt), the hilts often have a silvery surface, which cannot be traced back to any form of silvering. Similar features were noted also on other arsenical bronzes, mainly daggers and swords, from the Iberian Peninsula and, rarely, from elsewhere in Europe. It was usually assumed that this phenomena is related to the long deposition in the ground and/or to “inverse segregation”, i.e. arsenic sweat during casting. However, the reason for the silvery color lays in a specific treatment of the bronze after deformation and polishing, which will be presented. The observed treatment is the oldest known proof of alteration of an alloy’s surface in order to change its color apart from intentional patination.

P12 - Exploring Copper Production in 1st Millennium BC Cyprus: Insights from Asgata-Kalavasos mining region

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Introduction
Cyprus' economy and prosperity have diachronically depended on the exploitation of its mineral wealth, particularly copper deposits. However, the intensity of production varied over the centuries. During the Late Bronze Age (LBA) (1650 – 1050 BCE), Cyprus gained widespread recognition as the primary copper producer in the eastern Mediterranean (Muhly 1989; Kassianidou 2013). The island flourished during the Roman period (1^{st} c. BCE – 4^{rd} c. CE) and, more significantly, during the Late Antique period (4^{th} – 7^{th} c. CE), primarily due to copper production reaching industrial levels (Georgakopoulou and Kassianidou 2013; Kassianidou 2022). Nevertheless, limited knowledge exists regarding the exploitation, production and trade of copper by the Cypriot Kingdoms in the 1^{st} millennium BCE. Here, we present the results of chemical, microscopic and radiocarbon dating analyses of archaeometallurgical remains collected from various slag heaps, in the Asgata – Kalavasos mining area, in the southern foothills of Troodos (Fig. 1). This mining district is the third most important on the island and one of the less-studied areas.

Method
Slag samples were collected from all documented slag heaps in the Asgata-Kalavasos mining district. Initial examination involved HHXRF, followed by studying a sub-set under the Optical Microscope, and detailed analysis using SEM-EDS.

Results
^{14}C dating revealed that the majority of the slag heaps date to the 1^{st} mil. BCE, with one dating to the Roman period. Analytical examination of slags indicated their derivation from smelting copper sulphide ore. Importantly, the 1^{st} mil. BCE material demonstrated significant chemical and microtextural homogeneity, while Roman period samples stood out with elevated magnesium and silica content at the expense of iron. This was reflected in a more glassy texture and limited occurrence of free iron oxides and copper sulphide inclusions. A slag heap without a ^{14}C date is characterised by both manganese- and iron-rich slags, suggesting the presence of two contemporary smelting technologies and/or the use of different ore sources. The presence of Mn-rich slags could serve as a proxy for dating the slag heap to the Roman/Late Roman period.

Conclusions
The chemical and microscopic analysis of archaeometallurgical remains from the Asgata-Kalavasos mining region has enabled a diachronic study of copper production in the area. Based on the current data, the earliest and most extensive evidence of exploitation dates to the 1^{st} mil. BCE. This study lays the groundwork for achieving a better understanding of copper production on the island during the age of the Cypriot kingdoms.

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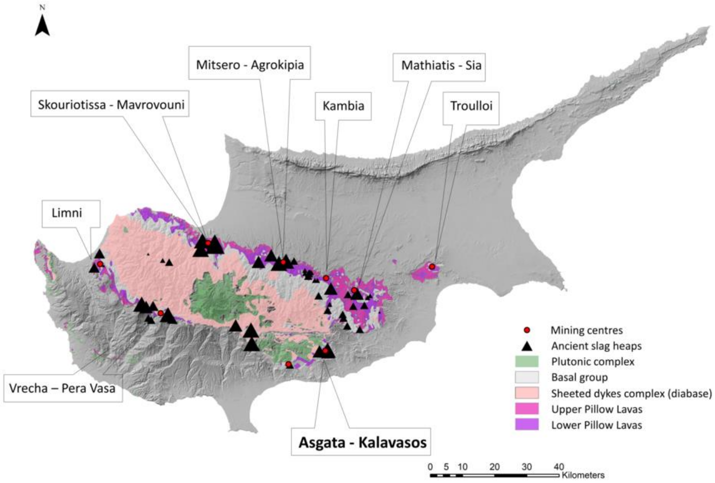

Map of Cyprus showing the location of mining districts and ancient slag heaps (produced by V. Kassianidou based on digital geological data provided by the Cyprus geological Survey)

P13 - First Metallographic and Compositional Study of Hercules Votive Statuettes from Ancient Samnium: Production Techniques and Conservation Strategies

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: In ancient Samnium, located in the area that includes Molise, Abruzzo, and Campania between the 6^{th} and 1^{st} centuries BC, the cult of the demigod Hercules was very common. The myth of the hero arrived from Greece and spread through the influence of both Magna Graecia and Etruria. The Samnites were highly influenced by Etruscan iconography of Hercules with leontè ad club. This led to a close connection between religious cult and the production of bronze votive statuettes. Furthermore, the production and techniques of metal casting became a distinctive feature of the Samnites from the Archaic age until late Hellenism. The Hercules statuettes preserved at the Samnite Museum in Campobasso fall within this context and belong in part to the provincial collection, and the rest are occasional or decontextualized finds in the 1990s. Because of that, archaeologist have dated them solely based on stylistic criteria placing them between the 5^{th} and 2^{nd} centuries BC. This work proposes a first in-depth compositional and metallographic study of the alloys of some Hercules in the collection of the Samnite Museum of Campobasso and the methods of their production by reproducing the original alloys. Metals and metal alloys are indeed an endless source of information, allowing us to trace a history of the material from extraction to processing, thermal treatments, and mechanical deformation to which they were subjected, but also eventual wear. By studying the reproductions, metallographic and chemical characterization (XRF, LOM, SEM) it is possible, for example, to infer the cooling rate and to establish a correlation with the materials used for casting (e.g. sand, clay, or stone), as well as with the processing and production techniques of the finished object through observation of the microstructure. Furthermore, both metallographic characterization and reproduction can come in support of researchers to understand the conservation status of the collection, improve, and implement musealization strategies. In addition, an initial patina analysis is proposed to determine whether natural or artificial patinas are present. This study, in fact, attempts to make a hypothesis on a possible tinning of some specimens belonging to the 5^{th} and 4^{th} centuries BC. Having an established protocol of metallographic study, reproduction, and preservation of objects to prevent deterioration of materials will also be useful for the study of objects other than statuary, such as weapons. Specifically, preliminary analyses have also been conducted on spearheads, as well preserved at the Samnite Museum.

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P14 - Introduction and establishment of brass coins in Eastern Gaul at the end of the Iron Age

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: As far as we can see today, brass was entirely unknown to the population in Eastern Gaul before the Roman conquest. There are a few late Iron Age zinc-bearing scabbards of so-called Noric type swords appearing from the territory of the tribe of the Treveri in the Moselle region at the same time as the Gallic Wars, or a little later. Nearly all objects made of brass in this region date after the Gallic Wars or are chiefly believed to be imports. There is currently no evidence that brass has been used regularly before Roman administration has been established after revolts. One of the first group of objects made regularly of brass are the so-called Germanus Indutilli L coins minted from 15 BC, presumably by the Treveri on the initiative of the Roman authorities.

Within a joint program between the IRAMAT – Centre Ernest-Babelon at Orléans and the Leibniz-Zentrum für Archäologie in Mayence, LA-ICP-MS and µXRF analyses of Germanus Indutilli L coins from French and German collections are performed to discuss the metallurgical practices used on a regional scale to manufacture objects and mint coins, which are possibly the first series issued in brass on the territory in present-day Germany, Eastern France, Luxembourg and southeastern Belgium.

P15 - Middle Chalcolithic Small Copper Objects in the Southern Levant

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Early metallurgy in the southern Levant is commonly related to the late fifth millennium BCE, during the Late Chalcolithic period, when there is multiple evidence for local production and utilization of copper, of both local and Anatolian/northern origin. A singular copper awl was reported a decade ago from the Middle Chalcolithic site of Tel Tsaf in the Jordan Valley (Israel), dated to the late sixth millennium BCE, where it was found in a granary that was used for the burial of a woman. XRF analysis indicated copper corrosion with 6% tin (Sn) and 0.8% arsenic (As) and low traces of lead (Pb) and Iron (Fe). While the excavators suggested the Caucasus as a possible origin for the artifact, others questioned its dating to the Middle Chalcolithic period. Since then, two other small copper objects, a spatula and an awl were found in a Middle Chalcolithic temple, at the site of Motza, near Jerusalem. In the framework of this study, all three objects were analyzed for their chemical and lead isotopic composition. The results revealed diverse chemical and lead isotopic signatures, suggesting both the possible use of local copper ore sources and the arrival of such small copper objects from remote origins via trade.

P16 - New developments on the metallurgy of Peñalosa in Baños de la Encina, Jaén, SE Iberian Peninsula

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Peñalosa is situated in the municipality of Baños de la Encina, in the northern part of the province of Jaén. It has provided significant information on metallurgical production during the Early and Middle Bronze Age (approximately 1850-1450 BC).

The site belongs to the El Argar cultural area, which spans over 30,000 km2 in the southeast of the peninsula. It is situated at the northwestern edge of this cultural complex, that is characterized by a standardized material culture, mostly individual and double burials under the dwellings, and a settlement pattern with a predominance of high-rise sites, defensive elements, and an urban layout of terraced buildings with narrow streets, sometimes arranged in artificial terraces, like the site of Peñalosa.

This site exhibits all phases of copper metallurgical production, from the extractive phase to finished products. A significant amount of ores, slag, metallurgical ceramics, moulds, ingots, and finished pieces have been recovered (Contreras and Moreno, 2015).

Linares-La Carolina area has abundant copper and lead mineral resources that were exploited from prehistory until the mid-20th century. Evidence from Peñalosa suggests that the settlers exploited at least two of the copper seams, as demonstrated by the LIA data obtained from the site and one of the excavated mines.

The new information on the c*haîne opératoire* of some finished pieces recovered from the site is presented in order to improve our understanding of the last step in the metallurgical production process. Drawing on metallographic and microhardness analyses, this piece approximates the functionality and technological complexity of metallurgical activity at Peñalosa and within the broader Argaric cultural sphere.

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P17 - Oxidic and sulphidic copper ore smelting in Early Bronze Arge Iberia (2250-1800 cal BC)

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: El Argar society (2250-1550 cal BC) is one of the best known cultures in Bronze Age Iberia and Western Europe whose development leaded to significant changes in the archaeological record. Settlements were mostly located on high and terraced hills and individuals were not commonly buried in collective monumental tombs, but mostly inhumated in individual graves under the houses. Another feature which has also been used to define the El Argar society since it was first described by the Siret brothers in the 19th century, is its metallurgical assemblage, including extensive use of silver, the inception of tin-bronze objects from 1800 cal BC onwards and some distinctive types such as silver diadems, spiral ornaments, halberds, riveted daggers or swords.

Nonetheless, up to now, little is known on the technological aspects of copper-based metallurgy in El Argar society. Smelting remains have been reported in some sites, but archaeometallurgical analyses have only been conducted in one site, Peñalosa (Jaén), which stands out due to the high amount of metallurgical remains (20 k of slag and 13 k of copper ores known so far), although its main phase dates from 1750-1550 cal BC.

In this paper we present metallurgical evidence of copper smelting in the El Argar site of Laderas del Castillo (Alicante), where copper prills, slagged pottery, slag fragments and metal objects have been recovered in recent archaeological excavations. Metallurgical remains date from 2250-1800 cal BC, including some earlier evidence, therefore providing data on the earliest phases of the El Argar society and allowing evaluation on continuity and/or innovation if compared with previous Copper Age metallurgical traditions.

In order to reconstruct the metallurgical process, a batch of samples of production remains and metal objects were selected for Scanning Electron Microscopy (SEM), as well as for trace elements composition by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) and lead isotope analyses by Multi-Collector Inductively Coupled Plasma-Mass Spectrometry (MC-ICP-MS).

Results evidenced the use of different resources and the smelting of both oxidic and sulphidic ores (possibly *fahlore* type) without previous roasting. This is not common on Iberian prehistoric metallurgy although some examples are also known. Results are evaluated on the light of the known Copper Age and El Argar metallurgical evidences in order to assess technological changes and continuities.

P18 - Preliminary study and characterization of some of the metal statues found at San Casciano dei Bagni (Siena).

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Archaeological excavations conducted since 2019 at San Casciano dei Bagni (Siena) have uncovered a monumental sacred complex dating from Etruscan and Roman times, closely linked to the presence of thermo-mineral water (39 -42°C). The Roman temple was erected on pre-existing Etruscan structures and has different architectural phases from the early Tiberian period until the early 5th century CE, when the entire sanctuary was decommissioned. As of 2022, excavations within the sacred uncovered a significant number of votive artifacts, including several bronze statues. In this Etruscan and Roman thermo-mineral sanctuary, archaeologists have found evidence of centuries of history that can further enrich historical, sacred-cultural, and manufacturing knowledge along these long periods, providing new evidence for archaeometallurgy. This not only allows for an understanding that can enhance the field of materials science, but also ensures optimal approach for conservative studies, needed interventions, museum display, and accessibility of the artifacts.

This paper presents the metallurgical and electrochemical characterization of some the bronze statues found at Bagno Grande. Understanding the technology and composition of the materials used, as well as studying and evaluating the alteration layers created over time and their response to corrosion, is an important initial phase of our investigation. Preliminary non-destructive analyses were conducted by XRF (X-Ray Fluorescence) spectroscopy for preliminary characterization of the alloys, which were then compared with SEM-EDS (Scanning Electron Microscopy-Energy Dispersion Spectroscopy) analyses. After micro-sampling, optical microscope observations were carried out for a more in-depth understanding of the structure of the various alloys under investigation.

For the study of the alteration layers and their corrosion response, electrochemical tests were conducted using techniques such as LSV (linear sweep voltammetry) and EIS (electrical impedance spectroscopy). These techniques were used to study the kinetics and rate of electrochemical reactions at the interface. In addition, electrochemical parameters such as corrosion potential and current density provide crucial information on the current state of the artifacts.

The integration of this information with data obtained from the previously mentioned analytical techniques allows for a comprehensive preliminary view of the metallurgical characteristics and degree of preservation of the statues of San Casciano dei Bagni. This multidisciplinary approach is essential to evaluating the state of conservation of the artworks and to planning conservation interventions aimed at preserving this cultural heritage for future generations.

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P19 - Production of arsenical bronze using speiss on the Elephantine Island (Aswan, Egypt) during the Middle Kingdom (Middle Bronze Age)

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: We would like to present in this paper the first direct evidence of the copper alloying by arsenic in Ancient Egypt, i.e. the evidence for the production of arsenical bronze. The material in question comes from a well-stratified and well-dated context of the Middle Kingdom settlement on the Elephantine Island, located in the Nile in contemporary city of Aswan. Several excavation seasons of the Realities of Life project, led by Johanna Sigl, focused on a small part of the Middle Kingdom settlement on this island. The main deposits are datable from the Eleventh to Thirteenth Dynasty. Almost 500 stratified metallurgical remains (slags, fragments of crucibles, casting prills), minerals and finished produced artefacts were documented and analysed using the pXRF in the site magazines. Selected 48 metallurgical by-products were studied in more detail using metallographic methods (at the laboratory of the Institut français d'archéologie orientale du Caire, pôle Archéométrie) and the SEM/EDX (Desert Research Center), with the research supported overall by the Ministry of Tourism and Antiquities. Secondary metallurgical operations (including melting, casting, alloying and possible recycling), processing unalloyed copper, mostly arsenical copper, and also ternary alloy of copper, arsenic and tin were recorded within this extensive analytical research. Evidence of the copper alloying by arsenic and intentional production of arsenical bronze at the site is supported by the finding of speiss fragment, coming from the remains of House 175, datable to the advanced Twelfth Dynasty (18th Century BC). This artificially produced iron-arsenic alloy is relatively well-known from several EBA and LBA copper workshops, especially located in Iran, suggesting that speiss was widely used and traded (Thornton et al. 2009, Rehren et al. 2012). This newly studied material makes the corpus from the Elephantine Island a crucial contribution to the understanding of the processes of Middle Kingdom copper metallurgy in Egypt.

P20 - REFLECTING THE PAST – MATERIAL STUDY OF HIGH-TIN BRONZE MIRRORS FROM THE MIGRATION PERIOD CARPATHIAN BASIN

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Bronze mirrors from different localities (Maglód, Üllő, Csongrád, and Tiszaug) from the Carpathian Basin were analysed by using handheld XRF and SEM-EDX methods in order to determine their chemical composition and microstructure. The specimens presented here are dated to the 5th century AD belong to the so-called nomadic mirrors, including the Berezovka and Čmi-Brigetio type with their radial decoration. The shape and use of these grave goods go back to the Sarmatian culture of the steppe. The spread of the nomadic mirrors coincides with the migration of the tribal confederation led by the Huns, from the Caucasus through the Black Sea region to the Tisza and Central Danube regions. In the Carpathian Basin, this type appears as early as the late 4th century AD. It became most fashionable in the 5th century, continued to live in the Gepidic period and, although sporadic, its presence can be counted in the Avar period. The pattern on the back is similar, but in each case, it is a unique piece. Up to now, the material of these mirrors has been undetermined, mentioned in the publications as “white metal” or “mirror metal”.

The surface of the mirrors was cleaned from corrosion products before measurements. Each mirror is characterised by elevated tin and lead contents (> 20 wt% Sn; > 3 wt% Pb), therefore, their alloy can be described as high tin bronze. This special alloy composition was commonly used in India, China and the Roman Empire, in contrast with the Greek and Etruscan mirrors that were manufactured from low tin bronzes. In the Roman Empire, mirrors made of low tin bronzes were later tinned. No tinning was observed on the surface of the analysed mirrors. There are several advantageous properties of high tin bronze alloys compared to low tin ones: (i) higher reflectivity, better polishability; (ii) due to the rising amount of $\alpha+\delta$ eutectoid (silverish white intermetallic compound) the alloy is silverish white, greyish white, whereas low tin bronzes are generally reddish brown in colour. However, the higher the tin content of a copper-based alloy is, the more brittle and rigid and the more hardly workable it becomes. This can be compensated by adding lead to the alloy. Lead reduces brittleness and rigidity, and increases castability, as it decreases melting point and enhances fluidity. However, the disadvantage of too much lead is that it reduces reflectivity, as it forms dark grey, opaque compounds.

P21 - Slag Vitrification as a Proxy for Smelting Technology - Tracking 7,000 years of copper production in Timna

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: Since the late 1950s, the Timna Valley in southern Israel has served as a "field laboratory" for the study of archaeometallurgy in a hyper-arid zone. It is one of the best-preserved ancient copper mining and smelting regions in the world, with evidence of metallurgical activity spanning 7000 years. As part of the Central Timna Valley Project (CTV, https://www.tau.ac.il/~ebenyose/CTV/) we attempt to assess major technological developments from the *longue-durée* perspective, focusing on smelting activities and its most common byproduct, slag. In the current study, we test the hypothesis that the proportion of the slag's glassy phase (amorphous non-crystalline solids) constitutes an additional proxy for different smelting technologies, assuming that in more advanced technologies the percentage of glass would be higher, due to higher temperatures, improved reducing conditions, lower viscosity and more efficient tapping. We, therefore, applied a systematic chemical and mineralogical analysis of slag samples from five smelting sites corresponding to five distinct copper production periods. These were classified as distinct technological phases, characterized by variables such as slag typology, furnace structure, heating methods, and fluxing agents. In relative chronological terms, the sites correspond to the Early Bronze Age, Late Bronze Age, Iron Age I, Iron Age IIA, and Early Islamic Period. The absolute datings of the sites were established by Carbon-14 analysis and archaeomagnetic dating. To specifically characterize the quantity and quality of glass within the slag samples, our research applied X-ray fluorescence, X-ray diffraction, X-ray computed tomography, scanning electron microscopy with energy dispersive spectroscopy and other analytical methods at Vanderbilt University, the Pacific Northwest National Laboratory, and Tel Aviv University. Preliminary results, produced during the summer and autumn of 2023, have so far supported our hypothesis regarding the glassy phase, with a clear difference between non-tapping and tapping technologies. The research is still ongoing with further analyses, observations, and conclusions expected in the coming months.

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P22 - The colour of bronze

3. Archaeometallurgy of copper and copper-based alloys

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Abstract text: This presentation explores a study of the use of colors in bronze jewelry and decorative ornaments from Denmark's late bronze age (around 1100-500 BC). Based on previous research, on possible colors of tin-bronzes, the colors are divided into five groups: red, orange, golden, silver, and tinned. XRF analyses are used to determine the chemical composition of the chosen artifacts, thus making it possible to estimate the original colors of the bronzes used. The analyses show the use of all five colors in the different types of jewelry and decoration artifacts. On the basis of this, it is possible to recognize certain tendencies in specific types of artifacts, such as the tutuli, which have mostly been produced in a golden color, and within a different range of 3% in tin content. Furthermore, by applying pre-existing theories about the bronzesmith and her/his skills and knowledge to these artefacts, we get a glimpse into the intentional choosing of colors in the late bronze age. This study shows the perspective of future research on the colors in bronze artifacts from the bronze age.

4. Archaeometallurgy of iron

P23 - 500 kg for a bloom dated to the Antiquity? The example of the crude mass of iron from Orcines (Puy-de-Dôme -France)

4. Archaeometallurgy of iron

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Abstract text: The roman sanctuary dedicated to Mercury, located at the top of the Puy de Dôme volcano (1465 m asl), was studied in the late 19th and early 20th centuries. In 1901, a very large piece of iron was excavated in a trench situated at the east of the temple, associated with architectural elements. Its imposing dimensions (around 85 cm in diameter and 48 cm high) and mass (470 kg) immediately raised the question of its interpretation. Was it an agglomerate of ferrous products welded together following a fire? Or a meteorite? Long forgotten in the reserves of the Archaeological Museum of Clermont-Ferrand (Bargoin museum), it is only recently that this object was submitted to a multi-scale analysis with the objective to determine its nature.

In addition to the macroscopic approach, photogrammetric acquisitions were used to calculate its volume. Chemical analysis of major elements was carried out on the metallic matrix, ruling out the hypothesis of meteoritic iron. Optical microscopy of two peripheral samples revealed the structure and composition of the metal, characteristic of its formation by the direct process. Several radiocarbon measurements were performed, on fragments of charcoal trapped in the peripheral oxides, and by extraction of the cementite present in the metal. Taken together, dating results show that this object is not an agglomerate of heterogeneous products, but a mass of raw metal produced in a low furnace, during Antiquity.

This bloom is a testimony of the exceptional skills of the craftsmen of this period. This type of metal product, intended to be transformed into an object, is rarely documented by archaeology. Is this example a unicum, or could such masses of metal have been produced regularly during Antiquity? A number of hypotheses will be put forward, based on available archaeological documentation, taking into account, in particular, the architecture of contemporary low furnaces. The aim of this poster is also to bring the attention of the archaeometallurgists community upon this exceptional object, in order to permit comparisons.

The iron bloom from Orcines (France)

P24 - A NOVEL APPROACH TO DIFFERENTIATE ICELANDIC IRON PRODUCTION SLAGS FROM OTHER VIKING SOURCES COMBINING SR ISOTOPES AND TRACE ELEMENTS

4. Archaeometallurgy of iron

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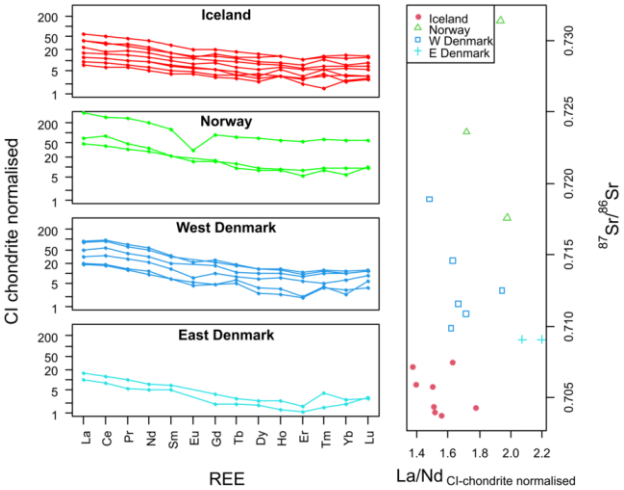
Abstract text: Throughout the Viking Age, Norway was a main producer of iron. When Norwegian Vikings settled in Iceland during the 9th century, they brought the tradition of ironmaking with them. In this project, it is investigated whether they also brought iron with them from Norway. This was done by comparing trace elements and strontium isotopic composition of Viking Age Icelandic slag with Danish and Norwegian slag. The analysis is based on 9 slags from Iceland, 6 from West Denmark, 2 from East Denmark, and 3 from Norway. Selected trace elements and Sr isotope data are shown in the figure. The Icelandic samples shows a fairly flat chondrite normalized light rare earth element (LREE) signature, whereas the Norwegian and Danish samples have more elevated LREE values consistent with their respective geologies. The Icelandic slags have low Sr isotope values consistent with Iceland's volcanic geology. The Norwegian slags have comparatively higher and varied Sr isotopic values, whilst the Danish samples are intermediate between Norway and Iceland. This again is consistent with geology. There is a small but significant difference between the values of eastern and western Denmark, with the values from western Denmark being higher and more variable than those from Eastern Denmark. This is due to the presence of limestone in the soils in eastern Denmark.

The trace element results are further analyzed using different quantitative statistical methods, e.g., principal component analysis. The results show a clear differentiation between the Icelandic slag and the Danish and Norwegian slag. This almost certainly means that iron was sourced locally in Iceland and not imported from Norway. Moreover, the trace elements and the $^{87}Sr/^{86}Sr$ values differentiate between Norway, East-, and West Denmark.

The results show that Icelandic iron production slags can clearly be distinguished from other Viking iron production sources, showing great potential for future iron provenancing studies in the North Atlantic.

This project is based on a B.Sc. project by Kristine Urhøj Møller at the Department of Geoscience, Aarhus University. We are grateful for the support by our partner institutions in Iceland for samples. We also thank the Medieval Archaeology Society and the Historical Metallurgy Society for their support.



Iceland
Norway
West Denmark
East Denmark
CI chondrite normalised
REE
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Iceland
Norway
W Denmark
E Denmark
La/Nd CI-chondrite normalised
87Sr/86Sr

P25 - Evidence for Steel Making at Naikund and its Relationship with Dhamna Linga and Dhaulameti in Maharashtra. India

4. Archaeometallurgy of iron

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Abstract text: The Early Iron Age Megalithic Culture of Vidarbha dated to (700 B.C – 555 +/- 100 B.C) has brought to light the evidences of earliest iron working especially smelting in India, from a site named Naikund. Naikund has brought to light 12 types of iron artefacts out of 32 total types of artefacts reported from the megalithic sites in the vicinity. Naikund is the only site that has reported iron smelting workshop from the Early Iron Age Megalithic level. This probably suggests the existence of centralised producton unit. However to prove the existence of a centralised production unit a typo-technological analysis of the artefacts recovered coupled with ethnographic survey is required. The typological analysis of the objects show a degree of standardisation based on usage pattern. Wet chemical analysis aids in understanding the chemical composition of the ore utilized. Micro - structural analysis gives us a clear insight to the existing technical knowledge of iron working. Therefore the comparative analysis of objects from the excavated megalithic sites (Naikund, Dhaulameti and Dhamna Linga), would aid in proving or negating the possibility of a centralised administrative unit, if negated then the possibility of dispersed administrative units and their probable locations.

P26 - One of Europe's largest excavated Early Medieval ironmaking areas from the Carpathian Basin - Latest results of the research of Avar bloomery centres.

4. Archaeometallurgy of iron

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Abstract text: In 2001, the excavation at Kaposvár-Fészerlak unearthed more than 400 Avar Age features associated
with ironworking across a total of 17500 m2 area. This is the second largest known Avar ironmaking site in Europe, featuring the most characteristic structures recorded on iron reduction sites of this period.
At Zamárdi, on the southern bank of Lake Balaton, four sites were excavated in 2005 and 2012. The nearly 1500 archaeological features recovered from a total area of 27700 m2 date to six periods. The Avar 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. The excavations revealed an ironworking centre and settlements of outstanding importance in the Avar Age that stretched more than 1 km in length. The complex of bloomery workshops and settlements, were in use from the middle of the 6th century to the end of the 9th century (a much longer period than that of Kaposvár), ranging from the Langobard period to the Hungarian conquest.
In 2022, a huge area in Kaposvár-Ipari Park was excavated. Evidence of Late Avar ironworking was scattered over an area of more than 5 hectares. The different stages of ironworking, as well as the preparatory, supplementary and finishing phases (rectangular pits with iron slag, wells, reheating fireplaces), were observed. Roughly five workshop areas can be distinguished in the excavated area. Workshop areas 1 to 3 are dominated by roofed bloomery furnaces and their service units, while workshop areas 4 and 5 are dominated by reheaters, which makes them reheating centres. In the latter workshops, the iron blooms were probably compacted to the desired size and density. Then, the intermediate products (compacted blooms, bars, etc.) were distributed by a system of the period to the Avar smithy workshops, even to remote parts of the Avar Kaganate. The ironmaking centre may have been in operation from the second half of the 7th century until the 9th century.

P27 - Petrochemical Analysis of Ancient Metallurgical Residues in Puisaye, France : Unraveling Manganese Enrichment Patterns

4. Archaeometallurgy of iron

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Abstract text: The Puisaye natural region, situated in the Yonne department of France, boasts a centuries-old history of iron and steel production. Since the 1980s, extensive prospecting, survey, and excavation efforts focused on cataloging ancient metallurgical sites in north-eastern and central-eastern France have revealed over 2,500 sites within the Puisaye region alone. Among the diverse metallurgical artifacts unearthed, ancient slags have emerged as a focal point due to their glassy appearance and striking similarities, both petrographically and chemically, to slags from historic blast furnaces.

This ongoing study seeks to deepen our understanding of these vitreous materials and characterize them comprehensively. Initial analyses, in agreement with earlier observations by the iron and steel industry, confirm the intense reexploitation of ancient slag heaps during the 19th century, highlighting significant manganese concentrations.

The study's dual objectives involve elucidating the origin of these high manganese levels and comprehending various petrological structures, correlating them with chemical compositions. To address these objectives, a diverse corpus of approximately thirty slags samples and twenty ores samples from distinct locations underwent scrutiny via multiple analytical methods, including SEM EDS, WDXRF, and XRD.

Preliminary findings are indicative of a conspicuous manganese enrichment in the ancient slags, coupled with an unexpected abundance of Rare Earth Elements (REE) surpassing 1000 ppm. Conversely, the ores exhibit relatively low manganese content (below 1.5 wt. %), yet demonstrate comparable REE concentrations, prompting inquiry into the possibility of deliberate manganese additions. The ongoing investigation aims to unravel the intricate relationships between vitreous and crystalline textures and chemical compositions.

This comprehensive exploration into the metallurgical history of the Puisaye region not only sheds light on ancient industrial practices but also contributes valuable insights into the utilization of manganese in metallurgical processes. The findings presented herein contribute to the broader understanding of historical metallurgy, with implications for both archaeological and geological research. This research paves the way for further investigations into the technological choices and environmental impacts of ancient metallurgical activities in the Puisaye natural region.

P28 - Reconstructing the production volumes of smelting workshops, from Antiquity to Middle Ages. A comparative approach of Puisaye and Morvan-Auxois areas.

4. Archaeometallurgy of iron

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Abstract text: This presentation will focus on some aspects of the results of a doctoral thesis concerning the analysis and modelisation of the organization of smelting activities in northeastern France. The main objective of this work is to propose a multi-method characterization of the territories in which concentrations of smelting sites are located. The approach adopted for the Bourgogne-Franche-Comté region has the advantage of enabling diachronic comparisons between several production areas (previous work has shown the continuity of activities from the Iron Age to the Middle Ages).

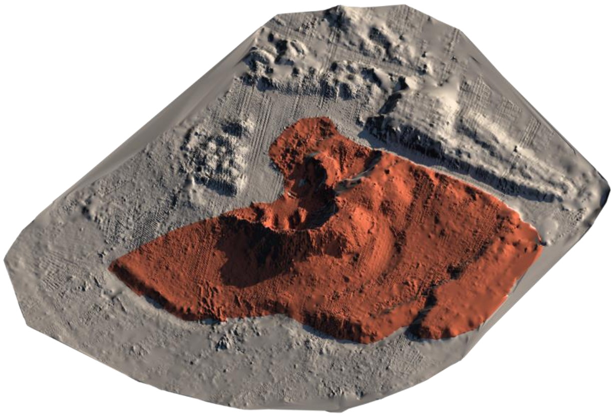
In particular, this comparative study will enable us to compare two production areas situated in Burgundy (The Puisaye and the Morvan-Auxois) that differ in terms of chronology, access to raw materials, concentration of sites and volumes of slag heaps. This presentation will focus upon the input based on LiDAR acquisition, archaeological fielwork and chemical analyses in order to better estimate the volume of production and of iron produced, for each zone of production studied.

The first step is to interpret the LiDAR datas in order to reconstruct the spatial organization of the workshops and calculate the volume of the slag heaps.

Archaeological fieldwork is also being carried out to understand the stratigraphy of the slag heaps and to realise volumetric sampling that will provide information on the concentration of siderurgical waste in a given volume. Boreholes are also drilled to probe the "buried" part of the slag heap, which sometimes reaches depths of up to 2 meters. This volume is modelized in 3D using topographical data from the geological terrain, and is taken into account in the volume calculations.

Finally, the use of pXRF enables material balances to be calculated, taking into account the dosage of Si-Al-Fe-Mn-Ca-K-Ti-P elements present in ores, bloomery furnace walls and slag. These data are used to establish a theoretical yield for a reduction operation at the site studied.

The combination of data on the volume of slag heaps, the concentration of slag in the heaps and the results of the material balances makes it possible to assess the scale of production in these workshops by estimating the quantities of metal produced and exchanged. Throw the study of a selection of the best-documented sites in Puisaye and Morvan, this work aims to demonstrate the potential of an interdisciplinary approach to contribute to a deeper understanding of the spatio-temporal evolution of smelting techniques, their organization and their economic dynamics.



3D model extracted from LiDAR acquisitions representing Montholon's slag heaps n° 1 (Puisaye, Burgundy).
Processing software : CloudCompare, Blender.

P29 - Retrieval of Archaeological Insights from Ferrous Artefacts: An X-ray Diffraction Investigation on Medieval Armors

4. Archaeometallurgy of iron

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Abstract text: Metallurgical investigations of medieval armors offers crucial insights into ancient manufacturing techniques [1]. Metal nature and heat treatment significantly affect mechanical properties, impacting armor effectiveness. This approach has enriched the study of medieval armaments. However, metallographic studies require to invasively collect samples, a practice rarely allowed on museum artefacts. Moreover, it only provides localized informations, possibly overlooking the armor's diverse microstructure.

For this reason, the development of non-invasive approaches is required. X-ray diffraction (XRD) using Synchrotron Radiation (SR) is well suited for the identification of phases, commonly found in ancient ferrous alloys, like cementite, ferrite and martensite [2]. The high flux, the good collimation and monochromaticity of the photon beam favor the detection of minor phases with low volume fraction (such as cementite) and can provide information on residual strain and texture. Combined with the fast diffractograms acquisition, it allows to multiply the analysis over extended regions of the samples to assess the heterogeneity of the metal on large museum artefact.

The aim of the present study is to set up a dedicated experimental approach for the analysis of armour pieces. To do so, we first prepared Fe-C model alloys at targeted carbon concentration ([C] < 0.8 wt%) in order to obtain typical microstructure found in ancient ferrous alloys such as perlite, ferrite, martensite and bainite. Secondly, we applied different thermal treatments and cooling rates all monitored by quenching dilatometry to obtain these microstructure. Finally, we carried out a combination of characterization techniques, such as Optical Microscopy, Secondary Electron (SE) imaging using Scanning Electron Microscopy (SEM) and microhardness measurements, which enabled us to identify and attest the obtained microstructures.

We carried out SR-XRD measurements on our model alloys on the DiffAbs beamline at SOLEIL Synchrotron. The acquisition of these reference diagrams in the first instance were used to interpret the diffractrograms also obtained on armour pieces.The selected armours for this study date back to the medieval period and are part of the collection of the “Musée de l’Armée” in Paris, France (Inv. n°679.2 PO, n°679 PO and n°679.1 PO). First Examinations unveiled microstructural variations across different regions of the armor, suggesting the armorer's deliberate choice to reinforce specific sections over others.

The data collected from model alloys and medieval armours will play a key role in developing a reference database. This will bring fresh perspectives on the manufacturing processes, ultimately paving the way for broad interdisciplinary exploration in this field.

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P30 - The archaeometry of the remains of metallurgic activities from the church of S. Paragorio at Noli (Savona, Liguria, Northern Italy).

4. Archaeometallurgy of iron

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Abstract text: During the archaeological excavations in the ground of the ancient church of Saint Paragorio at Noli traces of metallurgic activities were discovered.
They belong to an early phase dated to the 6th century AD and to a later phase dated to the 7th-8th century AD. Both phases were characterized by the presence of plano-convex forge slags and the second phase also by traces of copper alloys working. All these remains are deeply weathered by the action of the chlorides from the very close seashore and by the organic acids seeping from the church burial ground.
The study of the 6th century finds suggests that for the making of the forges' hearths some of the kaolin from a not far deposit was used, the slags were left cooling of the forges' hearths which were not cleaned on a regular basis. The metal phases globular shaped suggest that they were in a liquid state which vouches for a high working temperature. The specimens of the 7th-8th century are not homogeneous. Also, in this phase the smiths did not clean the hearth frequently in order to avoid a fast cooling of the forge. These later slags show a less proficient technology and a loss of a high percentage of metal. The chemical compositions of their amorphous phases show that the 6th century slags are grouped close to the eutectic at a temperature of 1250° C, within the range of 1300° C and 1550° C, while the slags of the later period are in the range of 1350-1650 ° C. The chemical analyses of the iron prills within the slags has shown that they contain Sb and As. The remains of copper alloys are very rare and are dated to the 7th-8th century AD only. They have been interpreted as coming from the re-smelting of bronze scrap.

P31 - The ore sources and production techniques of iron catapult bolts as indicators of Roman iron supply networks along the Germanic Limes

4. Archaeometallurgy of iron

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Abstract text: An extensive archaeometric investigation was conducted on eighteen Roman iron projectiles (bolts) retrieved from the Saalburg Limes fort (Hesse) and a Roman-Germanic battlefield at Harzhorn (Lower Saxony), dating back to the Imperial period (1st-3rd c. AD). This multidisciplinary study encompassed paleobotanic analysis to identify the wood types used in the shafts, metallography to examine manufacturing techniques, and an integrated provenance approach incorporating trace element analyses of slag inclusions (LA ICP-MS), metal matrices (ICP-MS) and osmium isotopic composition of the metal (NTIMS). The combination of these methods analyses majorly enhance the precision of determining the provenance of the iron artefacts. According to preliminary results, the bolts were manufactured via simple blacksmithing techniques, which align with their function as mass-produced items intended for a single-use. Surprisingly, despite the considerable distance between Saalburg and Harzhorn, the majority of projectiles from both sites can be preliminarily sourced from the iron ore deposits associated with Jurassic limestones, such as those occurring in southern Germany, Switzerland, and northeastern France. This suggests that iron used for the bolts was produced in the core of the Roman Empire rather than directly at the Limes border. Furthermore, at least three artefacts exhibit a signature consistent with the Roman iron mines at Noricum, famous for production of steel.

P32 - The use of iron and steel in pre-roman weapons from North-Eastern Iberian Peninsula. Technological implications and methodological challenges.

4. Archaeometallurgy of iron

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Abstract text: A collection of weapons made of iron and steel from the North-Eastern area of the Iberian Peninsula have been extensively studied with metallography. The specimens are associated to the archaeological site of Mianes (Santa Bàrbara-Tortosa, Tarragona, Spain), largely a pre-roman burial site of the Iberian culture, but were recovered without proper archaeological context. They were provided by a private part and known to have been accidentally found during an alteration episode of the site by public works in the last part of the 20th c. These circumstances notwithstanding the artefacts can be confidently attributed to the Iberian culture, dated to 6th-5th bce on typological grounds and considered as part of the grave goods from incineration burials.

These conditions allowed for the extensive sampling of the weapons in order to extract additional archaeometric information, resulting in a rare chance to study to a greater extent than usual the distribution of carbon in weapons. This includes analysing the full cross -sections of weapons blades or the study in different points, also in full cross-section, of a complete *soliferreum* all-metal javelin.

The results have provided new insight into the technological processes, technical choices and control of materials involved in the manufacture of weapons in pre-roman times in this territory, and afforded comparisons with results from differentiated cultural communities from the rest of the Iberian Peninsula. They also highlighted the methodological challenges involved in the study of ferrous objects subjected to peridepositional high temperature processes, in this case associated to pre-burial incineration and/or ritual destruction, something widely prevalent in the pre-roman societies of the Iberian Peninsula. This strongly affects the approach to the study of all metallic objects coming from funeral contexts in this period, which are a significant percentage of the total (Gener, 2017), and the associated distorting effects are reported and discussed.

Evidence of technological choices related to the use of iron and steel in order to take advantage of their mechanical properties was also observed in the results. These choices and their implications on the degree of control over materials and technical parameters are discussed, as well as their ramifications on the availability of their sources and of the specialized production and transformation knowledge. Magnetite coatings are also observed in some cases, and their possible intentional or accidental nature as part of the extended *chaîne opératoire* of these weapons is debated.

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5. Archaeometallurgy of precious metals and other non-ferrous metals

P33 - A Golden Legacy from Persia: Non-Invasive Analysis of the Achaemenian Gold Rhyton from the Metropolitan Museum of Art

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Precious metals have been often employed to manufacture various decorative artefacts at pre-Islamic Iranian Plateau. One of the most outstanding occurrences from this period of Iran was the large use of gold to create and decorate objects. Indeed, the use of gold and its alloys was extended for making different vessels and other decorative and royal objects in ancient Persia, especially in the Achaemenid empire (ca. 550-330 BCE). The technology of manufacturing of gold objects and the alloys used are subject of interest for art historians as well as heritage scientists. A vessel terminating in the forepart of a fantastic leonine creature, also known as lion Rhyton, in the collection of the Department of Ancient Near Eastern Art, at the Metropolitan Museum of Art, was studied by means of non-invasive analytical techniques, including quantitative micro-XRF and X-ray radiography. Results of micro-XRF showed that the Rhyton is made of a ternary Au-Ag-Cu alloy with average of 96:3:1 percent. Also, the X-radiography imaging showed that the object has been made of various forged parts to shape the hollow vessel as well as the front sculptural part. Some gold brazing made of ternary alloy with more copper concentration are used to join the rear horn-shaped vessel to the front leonine creature.

P34 - Bracteates and beloks- The composition of Iron Age Gold

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: It is often assumed that the Iron Age gold objects in Scandinavia were made from Roman coins, and thus were of relatively high purity. In general, Roman gold coins maintained their gold content, unlike silver coins, which were at times severely debased by the addition of copper.

Analyzes of a large number of bracteates show, however, that the composition changes systematically according to the type of bracteate, so that A bracteate has the highest gold content, and the contents of silver and copper increase in B, C and to D bracteate. The composition therefore seems to be strongly controlled, as is also known from some types of coins, and follows exactly the same course as seen, for example, in Merovingian and Visigothic coins from the period between approx. 450 and 650 AD. The changes in composition seem to have caused certain technical problems for the artisans who made the bracteates.

Gold Berlocks from the 1st to 2nd centuries, on the other hand, seem to have made a choice between two different types of alloys. One with a relatively high purity (about 70-80 % gold) and the other made of about equal parts gold and silver. It thus appears to be the relatively rare type of alloy "electrum". These Berlockes often have a very pale yellow color, and in some cases can be mistaken for silver. The choice of this particular composition must, however, be assumed to have been deliberate. Here, too, the different compositions of the base metal have meant that varying solders have been used.

P35 - Interdisciplinary research in an ancient ore-washery in the Greek Laurion mining region: re-examining models of operation

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: During a joint Greek-German interdisciplinary research project (cooperation between the antiquities administration of East Attica and the University of Bochum) at Ari in the famous mining region of Laurion, an ancient ore-washery was partly excavated.

Numerous ore-washeries dated to the Classical period have been preserved there, but most of them were unearthed during the resumption of the exploitation of ancient metallurgical residues and mining in the 19th century. Only a small number of them have been documented by archaeological excavations and, to an even lesser extent, excavations have been accompanied by specialists in archaeometallury. Therefore, the excavation at Ari was conducted in close cooperation with specialists from the NCSR Demokritos, in order to better understand the washing process, i.e. density separation, of ore components. Thus, we were able to identify, examine in-situ, and sample a unique layer of metallurgy-related precipitate, present in excavated water bearing parts of the flatbed washery.

According to the long accepted view, density separation of finely ground ore particles was achieved on sluices, wooden gutters with small hollows, in which the denser material remained, while lighter particles were washed away. Another interesting opinion suggested that the ceramic bowls found in the workshops may have been used for panning. These views have been challenged in recent studies by proposing a so-called plain table or buddle process, on which the ground ore was separated by density on its washing surface, using a water film and scrubbers, and no sluices.

In order to review these different theories, further scientific analyses were carried out at the NCSR Demokritos. Polished sections of samples from the aforementioned metallurgy-related precipitate layer, regarded as probable washing residues (tailings) during excavation, were analyzed with an optical microscope, a scanning electron microscope and an X-ray spectrometer device (SEM-EDS).

The results of this study, are assessed trying to resolve three interrelated problems:

(a) Understand the post-depositional taphonomic processes that led to the formation of the layer in question, cross-examining contextual archaeological stratigraphy and spatial variability of the sampled layer.

(b) Define whether the precipitate could be direct washing residues (tailings) left behind after the last ore-washing operation or whether it is material that was subsequently washed in over a period of abandonment.

(c) Link identified quantified chemical compounds (in the layer samples) to certain metallurgical processes.

The combination of answers or of questions rephrased as to the above triptych could provide detailed insight about the washing process.

P36 - Jewellery artefacts of tin and lead alloys in Vilnius (late 14th–early 15th centuries)

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: Jewellery artefacts made of tin and lead alloys were rare and they were typical of the late 14th–early 15th centuries in Vilnius. Some of them were undoubtedly cast by local jewellers in moulds in the workshops in the territory of Vilnius Lower Castle.

The artefacts found in Vilnius (rings, pendants, earrings / temple, beads, brooches, mounts) were mainly made of alloys of three elements (tin-lead-copper)[1]. Some of the jewellery artefacts were also made of almost pure tin (with a tin content of 94,8–99%).

The rings that may have been cast in stone moulds found in Vilnius Lower Castle should also be mentioned. The only pieces of moulded artefacts were two moulds (made of different stones: dolomite and limestone) with two rings cast at the same time, and 11 rings possibly cast in these moulds. The rings were made of tin-lead-copper or tin-lead alloys and one ring was made of pure tin.The dominant element is tin, in one case – lead. So different alloys were used to cast the same type of rings.

A two-sided mould made of lava is special and could be used to cast three mount pieces at the same time and 21 small pieces – possibly pins - on the other side. Tin was also identified on the surface of this mould.

Tin, zinc, silver and copper were recorded on the crucibles from the 14th–15th centuries in the territory of Vilnius Lower Castle. A fragment made of lead (99%) and several formless fragments of lead (98,63–98,89%) were also found in Vilnius.

In summary, it is likely that tin and lead were used to cast the artefacts in Vilnius.

[1] The XRF method was most often used for the study of metal alloys in archaeological artefacts. SEM-EDX method was used to study metal alloys and composition of metal droplets in crucibles.

P38 - Silver Production in the Feudal Lordship of Molina de Aragón (Guadalajara, Spain): ¿A Possible Case of Licuation in the Middle Ages?

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: In this poster, we present the archaeometallurgical results obtained from the analysis of some metallurgical residues related to silver production within the framework of the "MEDGREENREV project" (ERC SyG project Ref. 101071726). In addition to some slags related to iron smithing, these were excavated in the craft area of the Jewish quarter of the medieval town of Molina de Aragón (Guadalajara, Spain), head of a feudal lordship located in the northeast of the Iberian Peninsula.

In addition to establishing historical questions related to the agencies of metal craftsmen in the Iberian Middle Ages, in particular the role that Jewish silversmiths and blacksmiths played in craft specialisation and the maintenance of feudal societies, the results of their analysis have made it possible to generate a novel hypothesis regarding the exploitation of mining resources and the technology used in silver metallurgy in the 12th-13th centuries.

Thus, their SEM-EDX examination reveals compositions and microstructures similar to those related to the cupellation process ─silver extraction from lead-argentiferous minerals such as galena─. However, the abundant CuO phases, with considerable contents of other heavy metals such as Sb_2O_3 or As_2O_3 seem to refer to a stage of the operational chain close to the ore, to the raw material. This, together with the discovery in the same stratigraphy of argentiferous copper ores from the surrounding mines ─which we demonstrated by means of lead isotope analysis─ would suggest that we are in fact dealing with a possible case of liquation of argentiferous copper ores from which the silver was being extracted.

Such a hypothesis would represent the first archaeological evidence of the liquation process in medieval Iberia, as well as one of the earliest testimonies of the use of such technology, usually associated with the late Middle Ages in the scarce literature.

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P39 - The knowledge and application of gilding techniques in the Kingdom of Hungary during the Árpádian Era

5. Archaeometallurgy of precious metals and other non-ferrous metals

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The knowledge and application of gilding techniques in the Kingdom of Hungary during the Árpádian Era

One of the most frequently used decorative surface treatments in the history of metalworking was gilding which has several types, furthermore most of these techniques had been known since the age of antiquity. Numerous publications have been written about the technical history and methods of gilding, but relatively less work has been done regarding the Middle Ages compared to antiquity. Moreover, as far as we know no such research was made about metal artefacts from the Árpádian Era (1000-1301 AD). In addition, the selected group of finds which includes imports can give us new information not only for local, but also to the international researches. The technological study is based on non-destructive analysis of twenty-one different items. The chosen artefacts has been selected to cover as a wide range as possible in terms of the main material composition (copper or copper-based alloys and silver or silver-based alloys), technological processes, and the range of size, complemented by some samples with surface decoration processes requiring further heat treatment (enamel and niello), in order to obtain as complex results as possible of the correlation between the main technological process of the artefacts and the gilding as part of the final work phases. Besides the objects of local or unidentifiable origin, there are a few imports from some of the main European metalworking centres of the period, such as enamels of Limoges and 12th-century bronzes probably from Lower Saxony, which both represent highly developed and specialised workshops with their own traditions. Finally, by comparing the results of the study with international researches and medieval narrative sources about gilding, further details of the traditions of medieval metalworking and the continued existence of gilding techniques with antique origins could be revealed.

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P40 - The Treasure of Como (Northern Italy) and the gold metallurgy in Roman mints during the late Empire.

5. Archaeometallurgy of precious metals and other non-ferrous metals

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Abstract text: The so-called Treasure of Como was discovered in 2018. It was formed by 1000 gold coins of the 5th century AD and it was buried between the end of 472 and the beginning of 473 AD. Its study was the starting point of multidisciplinary research aimed at the analysis of this complex, which presently is the most substantial and entirely preserved find of late antique gold *solidi* in Italy.

This Treasure includes coins made both in the Eastern (96) and Western (904) Empire. The latter is represented by the mints of Rome, Ravenna, Milan and Arles, with a very clear prevalence of the Milanese atelier (639). The numismatic study has also allowed to identify the different dies used to strike the coins and to recognize the exceptional occurrence of groups of coins struck with the same pair of dies, mostly in the mint of Milan.

The Roman State had to warrant the absolute purity of gold in the coins. The presence of some tiny iron fragments visible to the naked eye on some coins was the input for a complete reconsideration of the gold metallurgy in the imperial mints during the late Empire. It was then possible to reconstruct their manufacturing chain: the gold purification, its partition from silver, its smelting, the making of the roundels and their minting. The ancient sources, such as the metallurgy treaties of the Medieval and Roman-Hellenistic tradition, were re-examined. Optical microscopy (OM) was employed in the examination of a first group of these *solidi* and their manufacturing defects allowed to outline the technology used in their minting.

Preliminary archaeometric analyses showed that most of the examined coins were made with Au up to 99.5%, with an average of 99.87%. Only two coins attributed to the Emperor Maioriano are composed of an alloy of Au and Ag (92.8-94.5% and 6.5-5%, respectively). A selection of *solidi* was characterized using a multi-scale approach and non-invasive procedures based on the Energy Dispersive X-ray fluorescence (ED-XRF) and by SEM-EDS. The elemental abundance patterns of nine selected *solidi* were traced also by in-vacuum synchrotron-based X-ray fluorescence (SR-XRF) at the XRF beamline of the Elettra Synchrotron in Trieste (Italy).

6. Technology transfers over space and time

P41 - Scientific study of early medieval “gombiky” from Mosaburg / Zalavár (Hungary), the seat of the easternmost county of the Carolingian Empire

6. Technology transfers over space and time

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Abstract text: Hollow, spherical pendants termed *gombiky* are considered as ornaments and clothing fasteners typically worn by members of the Moravian and Bohemian ruling elite in the 9th-10th centuries AD, recovered as prestigious grave goods from early medieval cemeteries of Mikulčice and Prague Castle (Czech Republic) (Krupičková 2020; Ottenwelter 2022). However, as it is recently revealed, this type of ornament forms an integral part of the elite garments in further territories as well, such as the province of *Pannonia inferior* (Szőke 2021, 446, Fig. 102). This paper presents the archaeological context, typology, material and technological study of eighteen *gombiky*, unearthed from elite graves next to the early medieval churches of *Mosaburg* / Zalavár (Church of the Virgin Mary and Church of Saint Adrian), the easternmost political, ecclesiastical and economic centre of the Carolingian Empire, located in the territory of the present-day Hungary (Szőke 2014; 2021).

The archaeometric investigation of the *gombiky* from *Mosaburg civitas,* dating from the 9th century AD, was carried out by non-destructive analytical methods. Optical microscope observations were followed by handheld XRF and SEM-EDS measurements in order to characterise the metal composition, to reconstruct the workflow of the manufacturing and decorating processes as well as to determine the quality of workmanship. The eighteen items, similar to their closest analogies in Great Moravia, show various form and design, made of gold, (gilded) silver and bronze, decorated by chasing and repoussé, but also with granulation and filigree work. The results have evidenced the use of different types of alloys and gilding techniques, different technical solutions for fitting the construction elements, as well as specific sketch marks. The research provided a better understanding of the relationships among the production of these ornaments and the analogous objects, even tracing possible workshop affinities.

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8. Latest experiences of related archaeometric methods and technologies

P42 - From bloomery to blast furnace– a project aimed to understand what led to the rise of the blast furnace in Sweden II

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Lapphyttan in Norberg municipality, may be regarded as the type site for the Medieval Blast Furnace. Its date is probably between 1150 and 1250. Before that Sweden had been exporting bloomery made steel since hundreds of years. It is believed that customers in particular appreciated its good hardenability, which was caused by its low phosphorus content. The introduction of the BF was a question of productivity and brought parts of Sweden into a kind of protoindustrial mode with large consequences This presentation will focus on the theoretical considerations that have so far led to practical studies in a replica of an excavated bloomery. The objective has been to find the variables that came to support the transition to the blast furnace. The basic hypothesis is this: Iron is formed at the beginning of the reduction of iron ore. The metal melts when the dissolved carbon content in the metal has risen sufficiently (by decomposition of CO, I e 2CO= CO2+C(%)). These drops flow down the shaft and hit other drops and thus become larger. That is the main cause that the loupe (bloom) is formed. However, it also gets warmer further down. The consequence of this is that the fayalitic (=2FeOSiO2) slag reduces carbon out of the metal, whereby the melting point of the metal rises. The loupe grows in size during the entire time ore is charged. For this to happen, you need to have a certain amount of slag including components (as CaO or MnO) that will keep the slag fluid as its FeO-content is decreased through the reaction with dissolved carbon. Iron droplets passing close to the furnace wall, where the temperature ia lower will be affected to a lesser extent and not integrated in the loupe. In fact they are the reason for the existence of iron metal in the furnace bottom slag It is expected that at a sufficient increased temperature the carbon dissolution will be faster than the slag reaction, whereas no loupe will form, just molten high carbon iron. Until 2023 we have carried out some twenty experiments with the aim of increasing the shaft temperature in order to get molten high carbon metal in the shaft bottom.

P43 - Every quest needs a map. Characterisation of heterogeneous archaeometallurgical samples by p-XRF

8. Latest experiences of related archaeometric methods and technologies

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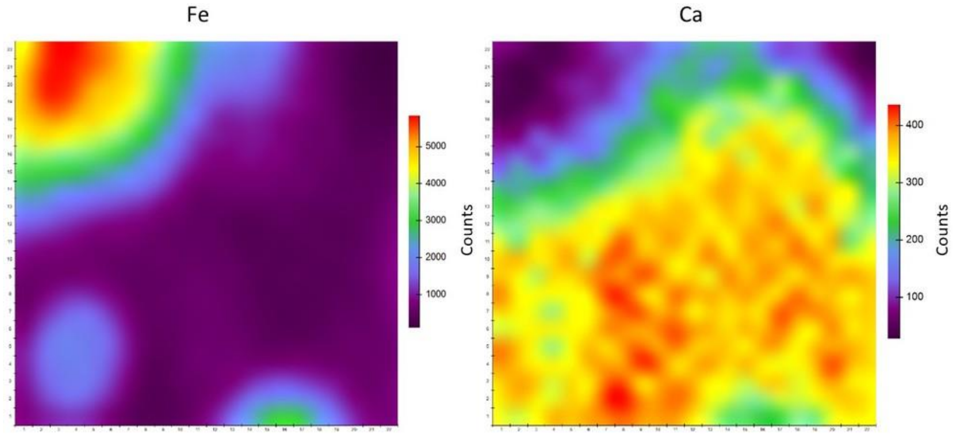
Abstract text: It is well known that the use of portable XRF spectrometry in archaeometallurgy has increased significantly in the past decades, both for the analysis of slags and other metalworking debris and for onsite surveys. As the accuracy and reliability of instrumental measures keep growing, archaeologists and archaeometrists are exploring more possible ways to fully exploit the potential of this analytical technique.

The case study presented here is part of a wider research project on archaeological mining landscapes. Surface surveys in an area known to have housed iron mining and ore processing activities for several centuries led to the collection of a fair amount of heterogeneous samples, such as ore (raw and roasted), smelting slags (both direct and indirect process), refining and smithing slags from a wider area. Thus, researchers were in need of a convenient analytical tool to carry out a preliminary screening of the samples, prior to more in-depth analyses such as SEM-EDS.

For this purpose, micro-XRF 2D mapping (Bruker Elio) was used to identify the composition and spatial distribution of the elements. The analysis was performed with a He purging system to further extend the range of detectable elements. The investigated area was about 4 mm^2.

The main advantages of this technique are:

- It is non-invasive and requires little sample preparation, allowing the screening of a larger number of samples in order to choose which ones will undergo deeper investigation.
- While knowing the bulk chemical composition is of little avail in this case, the elemental map of relatively large areas of the sample allows a quick assessment of its microstructure combined with the distribution of the main elements. These data enable the identification of the nature of the sample, i.e. to which step of the technological process the sample belongs.



Spatial distribution of Fe and Ca in roasted ore sample PI-MF_02

P44 - From bloomery furnace technic to blast furnace technic - an antempt to understand the knowledge and know-how that led to the rise of the blast furnace

8. Latest experiences of related archaeometric methods and technologies

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Sven Ekerot[1]
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Abstract text: Introduction
I Sweden the bloomery technic was introduced somewhere between 1000-900BC. This means that there was about 2000 years of practies using the bloomery technic when the blast furnace technic was introduced to Sweden. This paper will conentrate on the part of the project that concerns the bloomery experiments, the construction and the building of the furnace, roasting of the ore and the running of the reconstructed furnace.

Method
The background is as follows: In the Iron Age we know that mostly different kind of limonite ores were used in the bloomery process but there are some rare examples that rock ores of the type magnetite was used. I Sweden the blast furnace run on different kind of rock ores like magnetite and hematite. The bloomery experiments are therefore run both on limonite and rock ores, and in this project, we have chosen a limonite ore called red earth and a magnetite rock ore that does not need any addition like for example lime.

The roasting of the magnetite ore is done on a rectangular pile of wood as fuel (like the ones we find on bloomery sites).The ore pieces are 15-18mm. The magnetite is roasted twice. The limonite red earth ore is roated once on a iron plate over wood as fuel. The read earth has a grainsize of 0-3mm and the magnetite is downsized to the same size.

When most of the find of charcoal in mid Sweden, in connetion with the bloommery proces, is pine we therefore use charcoal of pine.

For the reconstruction of the bloomery furnace, we have used a furnace found at an iron production site in the vicinity of early blast furnaces, among them Lapphyttan. We have used both the geometric as well as the building materials as model.

We have charged the furnace with 15kg of ore, red earth alternatively magnetite. The ratio in weight between ore and charcoal is 1:1 in both cases. We are measuring the temperature intermittent within the furnace from preheating to the opening when taking out the bloom.

Results
In total 22 experiments have so far been performed with limonite and rock ore. We have achieve blooms and slag close to the shape, structure and chemical composition to blooms and slag from archaeological iron productions sites. In this way we can ensure that we have blooms which can be refined and forged into malleable steel.

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P45 - GlobaLID: A sustainable data infrastructure for Pb isotope data

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Lead isotopes are currently the most powerful method for the reconstruction of the raw material provenance of non-ferrous metals. Crucial for the successful application of the Pb isotope method are reference data from all potential ore deposits or other qualified materials with a known production location such as slag or ingots. The first open-access database with such data was OXALID, and many more followed since. They all have two major drawbacks: They are static, i.e., either not maintained anymore or published as spreadsheets, e.g., in supporting information of articles. They each follow their own approach in the description of the data, sometimes resulting in ambiguous or missing information. Consequently, Pb isotope data currently lack interoperability, and duplicated work is required in their compilation, making this strategy obsolete.

These limitations can be overcome by a community-driven digital data infrastructure, which allows for storing, curating, and accessing Pb isotope data. Complemented by a metadata scheme, workflows, and guidelines for the publication of Pb isotope data, such an infrastructure can leverage the power of Pb isotope data by making them vastly interoperable. Cleverly designed, such a data infrastructure renders the expansion of the database to other methods, material or isotope systems easily possible. In addition, the participatory design helps constructing a truly global picture of available Pb isotope data, making gaps in data coverage visible and bringing the global Pb isotope community closer together. Crucial for the successful acceptance of such an infrastructure will be its development as close to the needs and expectations of the user community as possible.

GlobaLID (Global Lead Isotope Database, https://archmetaldbm.github.io/Globalid/) is already on the path to becoming this data infrastructure. Early prototypes have been made available by us since 2021 (Klein et al. 2022) and already gathered data from four continents. Based on them, we already reached out to the community with a questionnaire and a synergising workshop, where the project received overwhelmingly positive feedback and support. However, only with recently acquired funding did the full implementation of the data infrastructure become possible.

This contribution will present the roadmap for the implementation of the GlobaLID data infrastructure and how it is envisioned to make everyone’s work with Pb isotope data easier. The contribution will focus on the inclusion of the community in the process, where and how we will reach out for input and feedback from the community and how interested colleagues can become actively engaged.

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P46 - Mott-Schottky analysis from impedance data as archaeometric tool

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: This work describes the application of Mott-Schottky (M-S) analysis of impedance data of sub-microsamples extracted from the corrosion patina of copper, bronze, and brass archaeological artifacts attached to graphite electrodes. Studied samples include Renaissance statues from the Hofkirche in Innsbruck and a variety of objects from museums and Archaeological Heritage Office (soprintendenza) in Austria (Bad Aussee, Johanneum Graz and the Tyrolean State Museums), and Italy (Genoa and San Remo), dating from the Bronze Age to the 18th century. The theoretical approach developed exploits the semiconducting nature of cuprite and tenorite, the main copper corrosion products formed under 'ordinary' atmospheric attack and moderate corrosion conditions.

Impedance measurements were carried out at sample-modified graphite electrodes in contact with 0.10 M Na2SO4 (pH 6.28) aqueous solution and plots of (capacitance)-2 vs. applied potential (Mott-Schottky plots) were obtained, whose slopes and intercepts can be related with the semiconducting properties of the metal patina in turn related to the composition, compaction, thickness, porosity, roughness and other textural features. The results obtained enable the classification of the studied archaeological samples, providing information on their composition, manufacturing technique, and age.

P47 - New Approaches in the Analysis of Archaeological Iron Samples: The Case of the Celtic Iron Bars from Ay an der Iller

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: In the case of the 12 iron bars from the iron mass find at Ay an der Iller, an attempt was made to exhaust all available analytical methods to learn more about the nature of the mass find, its origin, and age. The iron ingots from Ay were discovered in 1935 south of Neu-Ulm during dredging operations in the Iller. There is no contextual information that allows for a more precise interpretation of the find (origin, reason for deposition, etc.). Bipyramidal iron ingots are widespread in northeastern France, Switzerland, and southwestern Germany. The circulation of these bars is indicated by Berranger (2014) to be from the 9th to the 4th century BC. The bipyramidal iron bars consist of one or more consolidated blooms that have been forged together. They are the first semi-finished products made in Central Europe to appear in large quantities. The significant informational potential of these iron bars is clear, but for a long time, the analytical capabilities were not advanced enough to utilize this potential fully. Furthermore, the acquisition of samples (by sawing or drilling) is not desired in every museum. Therefore, we have tried to develop methods that cause minimal damage to the archaeological objects while still providing all the necessary information. The analysis data presented here include the analysis of Re and Os, Os isotope compositions, the chemical composition of slag inclusions, and the analysis of siderophile trace elements in the metal.

P48 - Pilot study of provenance analysis in Estonia

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: Previously not much research has been done in Estonia considering provenancing. Lithic and Sr isotopes in human bones have been explored but not much beyond that. The methods have been improved drastically since the inception of them and many more statistical analyses have been implied to determine the composition with more accuracy and prowess. One of the more important revelations has been the usage of LA-ICP-MS for trace elements which has also been integrated in the latest analyses. Since then the use of macro- and trace elements has been essential for the success of the method. Beyond slags, the research material incorporated currency blooms which have a history of being one of many tradeable materials in the north. Since they were used for trade there is a possibility that some of the currency bars were brought in from neighbouring lands. Since the eastern trading way, Austrvegr, runs from the northern coast of Estonia, the possibility of a long distance trade for iron goods isn't too far fetched.

The results of the dual analysis of SEM and LA-ICP-MS were successful. The baseline PCA was done with multiple variables in mind – firstly the geological bedrock system, secondly the bedrock stage and thirdly the counties. Only iron smelting slags were used for the baseline so information of chemical composition would most certainly be only local. Three different groups with many similarities and some differences appeared – Ordovician, Silurian and Devonian. Ordovician was chemically most heterogenous and Devonian most homogenous. The geological bedrock stages provided much needed compaction of the groups, especially Silurian and helped to be more precise about the localization.

The discussion dwells into the possible interpretations of local and foreign trade, trading- and even production centres. The possibility of local trade is shown by multiple currency blooms which were found from Praaga, Ollepa, Maalasti and Kuremaa. The chemical composition is indicative of slags from different bedrock zones. Most likely the blooms were traded for example from Ida-Virumaa. There was also the question of currency bar from Sürgavere which had completely different chemical composition compared to the baseline and other currency blooms, which could be an indicator of foreign trade of currency blooms. Another hypothesis was that there have been centres for making currency blooms. For example the blooms found from Metsamägara, Alulinna and Varja share similar chemical consistency.

P49 - Quantifying slag cooling rates – re-melting fayalitic slag under controlled conditions

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: The literature on fayalitic slags often refers to the shape and size of fayalite crystals as an indicator for the speed of cooling of the slag, which in turn informs on aspects of the furnace and smelting technology such as slag tapping vs. pit furnaces. Blocky fayalite is known to represent relatively slow cooling, while more rapid cooling leads to increasingly elongated and finally skeletal and then feathery habits. However, there is no quantified timescale linked to these estimates, making them entirely subjective and qualitative. The key reference for this phenomenon of cooling-speed related olivine shape is Donaldson (1976), which is based on geological olivine and covers timescales of cooling that are several orders of magnitude different from archaeological furnaces slags.

We conducted a series of controlled cooling experiments, remelting fayalitic iron slag in mullite crucibles under strongly reducing conditions and allowing them to cool at different rates. Following solidification and mounting as polished blocks we used Optical and Scanning Electron Microscopy to document the development of different fayalite shapes as a function of the speed of cooling. The results for the first time allow us to systematically assign (semi-)quantitative values to cooling rates based on the size and habit of fayalite, and the relative proportions of fayalite and glass matrix in real-world archaeological slags.

Further experiments are needed to test these values for related slag systems, such as magnetite-rich fayalitic copper smelting slags or alumina-rich slags rich in hercynite, to explore the suitability of fayalite shape and size as a more widely applicable measure in slag descriptions and interpretation.

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P50 - X-ray microtomography to study a closed crucible from the Roman fort of Aquis Querquennis (Porto Quintela-Bande, NW Spain)

8. Latest experiences of related archaeometric methods and technologies

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Abstract text: *Aquis Querquennis* is a permanent Roman fortification located in the northwest of the Iberian Peninsula, between the villages of Porto Quintela and O Baño, in the municipality of Bande, in the south of the province of Ourense.

It is a stone fortification with an area of 2.6 hectares, surrounded by a 3-metres-wide-wall, measuring 176 metres by 146 metres. At present, 75% of the internal area has been excavated, including 6 barracks (*centuriae*), the hospital (*valetudinarium*), the granary (*horrea*), the latrines (*letrinae*), the headquarters (*principia*), the four gates (*Decumana, Praetoria*, *Pincipalis dextra* and *sinistra*), part of the *praetoria*, various sewers, about 50% of the length of the wall and the corresponding section of the *intervalum*, including several ovens, several sections of the V-shaped ditch (*fossa fatigata*), and a large, unbuilt area in front of the *Porta Decumana* (the southern gate).

The excavations carried out since 1975 have made it possible to establish that this fortification housed a *cohors quingenaria equitata*, specifically the *Cohors III*, dependent on the *Legio VII Gemina*. Its presence would have been linked to the construction of the Via Nova, which linked *Braca Augusta* to *Asturica Augusta*. The first inauguration of the *Via Nova* took place in the middle of the reign of Vespasian (79-80 AD), marking the beginning of the occupation of the site. The abandonment of the site occurred in the early years of Hadrian's reign (ca. 120 AD), with the transfer of the cohors to Pomet Hill in *Porolissum*, in the northwest of *Dacia*.

In the large open space in front of the *Porta Decumana*, several pits have been excavated, which were used as waste dumps and in which by-products of metallurgical production were recovered, whose analysis, characterisation and discussion are presented here, including X-ray microtomography to study a closed crucible.

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