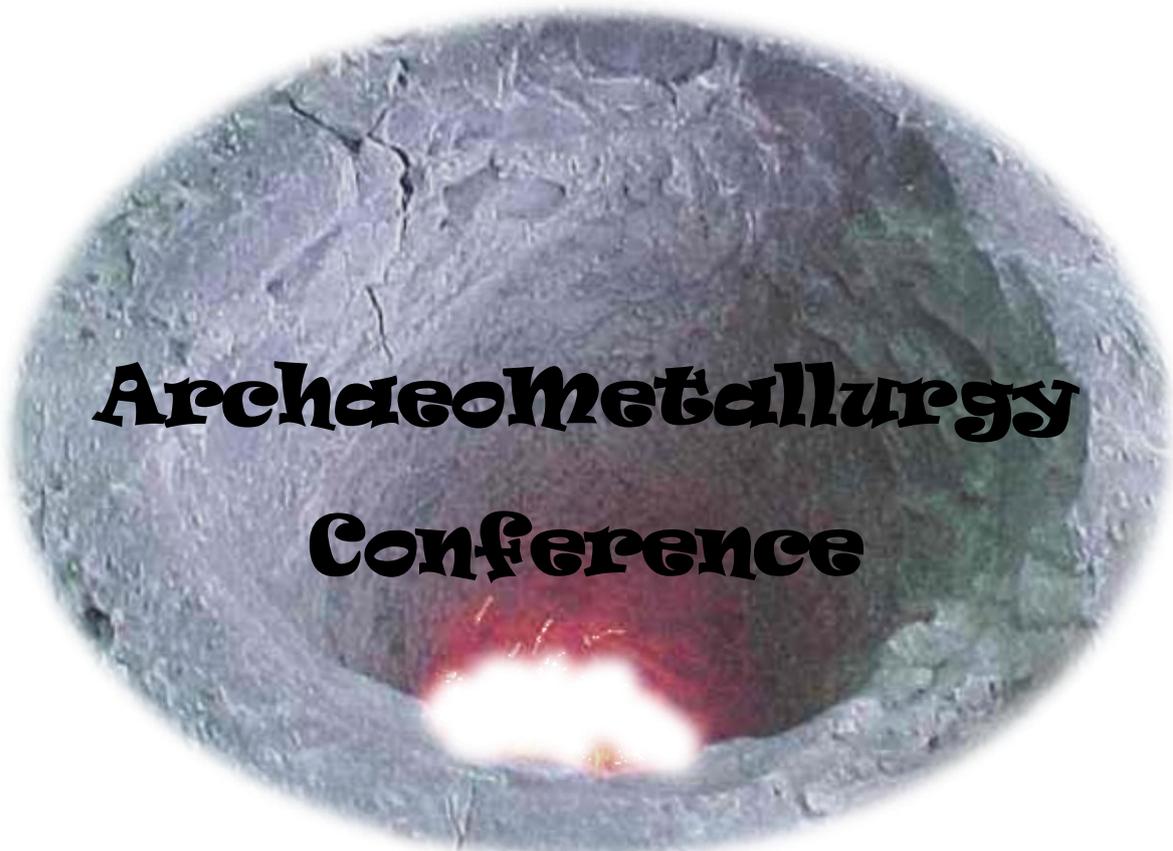




 UNIVERSITY OF
BRADFORD
MAKING KNOWLEDGE WORK

A large circular image showing the interior of a furnace or crucible. The walls are dark and textured, and a bright, glowing fire is visible at the bottom center.

Archaeometallurgy Conference

10th-12th November 2009

University of Bradford

Abstracts



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Detailed Schedule

Tuesday 10th of November		
8:30-10:30	Registration & Coffee	
10:30-10:40	Welcome & Safety	
10:40-11:00	Introduction	
Chair Tim Taylor		
11:00-11:20	Allan Daoust	One Man's Garbage is Another Man's Obsession: A Theoretical View of the Role of Slags Within Archaeometallurgical Research
11:20-11:40	Jui-lien Fang	Colour Change in Copper Alloys through Alloying
11:40-12:00	Jane Cowgill	Iron Age Greys: Druids or travelling salesmen
12:00-12:20	Jim Brophy	Nidderdale Iron Project
12:20-12:40	Ed Kendal	A study of wear in Roman and Early Medieval knives.
12:40-14:00	Lunch & Posters	
Chair David Crossley		
14:00-14:20	Samantha Rubinson	Metallurgical Comparison of Early Medieval Utilitarian Iron Artefacts with Specialized Craft Tools
14:20-14:40	Tim Young	Characterisation of early medieval smithing slags from Ireland
14:40-15:00	Susan La Niece	The Asante Ewer and the casting technology of large Medieval Bronze Jugs
15:00-15:30 (30 minutes)	Rachel Cubitt & David Starley	Tudor arrowheads: battlefield finds under the microscope
15:30-16:00	Coffee Break	
Chair Tim Young		
16:00-16:20	Jane Wheeler	The impact of the medieval and early modern iron industry on the woodlands of Rievaulx and Bilsdale, North Yorkshire, UK
16:20-16:40	Janis Heward	Kiln hunting! In search of the definitive earthwork evidence for chop-wood/white coal production
16:40-17:00	Derek Barker	The other side of the melt; Bradford's fire-brick industry
17:00-17:10	Gerry McDonnell	
Continued Discussion at a pub selling real ale.		

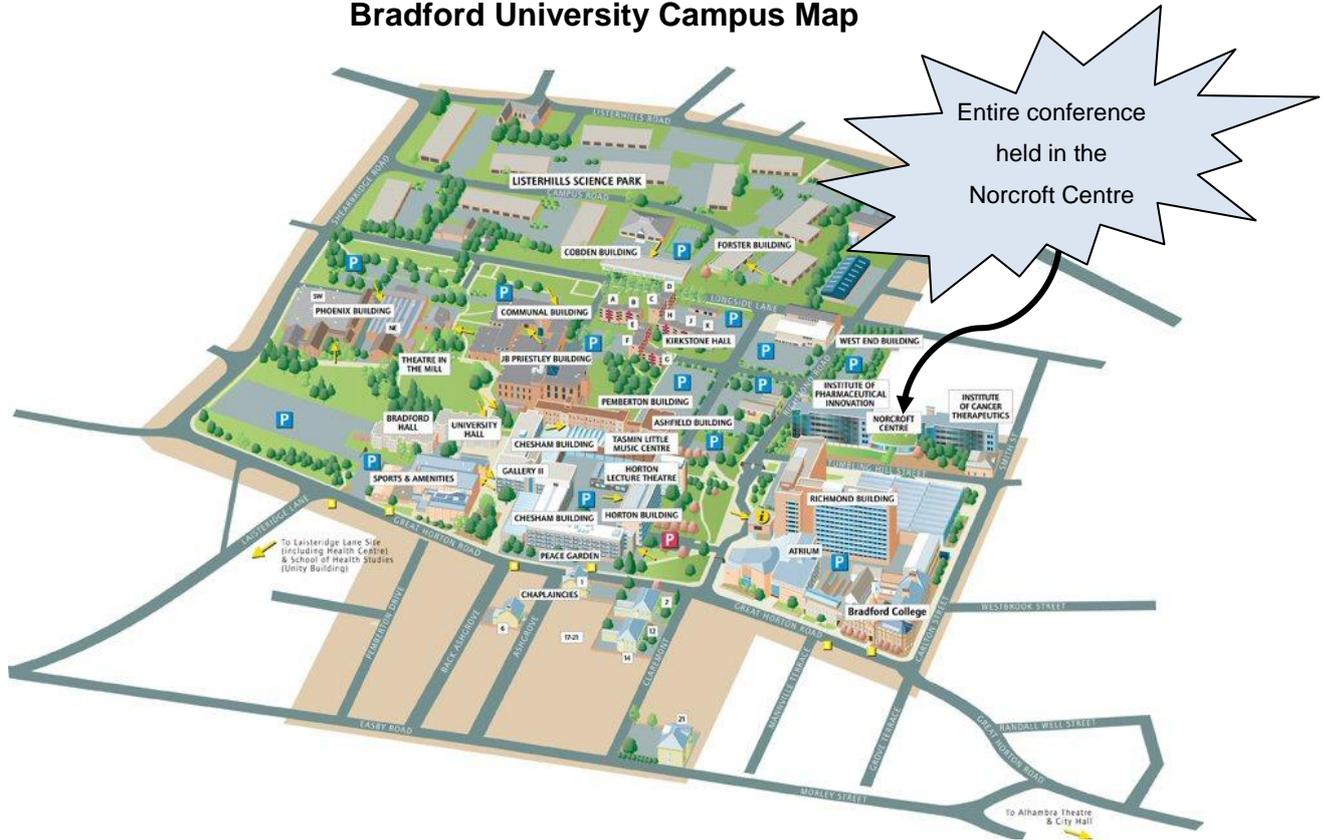
Wednesday 11th of November		
8:30-9:10	Registration & Coffee	
Chair Roger Doonan		
9:10-9:30	Tim Taylor	Metals, evaluation and materiality
9:30-9:50	Miljana Radivojević	Assessing skills of the first European metalworkers: metallographic analysis of copper implements from Plocnik, a Vinca culture site in south Serbia
9:50-10:10	Christina Clarke-Nilsen	Identification of raised vessel manufacturing workshops in Late Minoan Crete
10:10-10:30	Giovanna Fregni	From Bronze to Copper: The Effect of Recycling on Copper Alloys in prehistory.
10:30-11:00	Coffee Break	
Chair Justine Bayley		
11:00-11:20	Burkart Ullrich	Geophysical prospecting on iron slags in Hamadab/ Northern Sudan
11:20-11:40	Roger Doonan	Forging, Texts, and Identity: Understanding iron and iron workers in EIA Greece.
11:40-12:00	David Dungworth	Who's afraid of the bowl furnace?
12:00-12:30	<i>2 minute poster presentations</i>	
12:30-13:30	Lunch & Posters	
13:30-15:00	Poster Session with Coffee	
Chair David Dungworth		
15:00-15:20	Peter Halkon	Iron and the Parisi
15:20-15:40	Janet Lang	Iron Cart Tyres from Wetwang: a brief metallographic examination
15:40-16:00	Arne Jouttijärvi	Smithies and ironworking in Denmark
16:00-16:20	Arne Espelund	Roman age ironmaking in Mid-Norway
16:20-16:40	Christine Elgy	Ironworking in Roman Worcestershire and surrounding areas: can we compare data across commercially excavated sites?
18:00	Evening Buffet at Omar Khans	

Thursday 12th of November		
8:45-9:30	Registration & Coffee	
Chair Tim Young		
9:30-9:50	Maxime L'Héritier	How to part silver from copper. Understanding <i>Saigerprozess</i> through experimental liquation and drying
9:50-10:10	Marie-Pierre Guirado	Silver refining in Medieval times
10:10-10:30	Peter Claughton	Slag? What slag? In search of evidence for medieval lead/silver smelting
10:30-10:50	Justine Bayley	Understanding Lithage Cakes
10:50-11:20	Coffee Break	
Chair David Starley		
11:20-11:40	Patrice de Rijk	Interim results of the Stanley Grange Medieval Iron Project
11:40-12:00	Peter King	Experimental ironmaking processes of the 1720s
12:00-12:20	Joan Unwin	Steel blades: made in Sheffield 1624-1924
12:20-12:40	David Cranstone	Packaging the iron industry: Is the technological package a useful concept?
12:40-14:00	Lunch & Posters	
Chair David Cranstone		
14:00-14:20	Eleanor Blakelock	Craft specialisation and the manufacture and use of iron knives in Viking Dublin, Ireland
14:20-14:40	Arne Espelund	Carbon Control prior to Bessemer
14:40-15:00	Tim Young	Some analytical observations and the origin of spheroidal hammerscale
15:00-15:15	Thanks for Coming & HMS Student Prize	
15:15-15:45	Coffee	
15:45-17:00	Packing Up	
16:00-onwards	Continued Discussion at a pub selling real ale.	

Poster Schedule

David Dungworth	Hammerscale: high speed digital video and scanning electron microscope
Donald B. Wagner	Iron Cupola Furnaces in China and Europe
Samantha Rubinson	Investigating the Effects of Phosphorus on the Iron Microstructure and its Implications on the Identification of the Alloy in Archaeological Artefacts
Eleanor Blakelock	Reconstructing the blacksmithing landscape: Results from a comprehensive and integrated analytical program
Sarah Jane Clelland	A geochemical investigation towards discriminating between lava and ironworking slags from Iceland.
Sarah Jane Clelland	Craft Specialisation in Iron Age Orkney
Rod Mackenzie	Cementation Steelmaking 'Slags'
Janis Heward	Kilns: Chopwood or Potash
Janis Heward	Chopwood Kilns
Thomas Birch	The Gresham shipwreck: An archaeometallurgical investigation into the Iron bars
Lynn Biggs	Iron Technology in peninsular Thailand: evidence from 2 nd century BC sites at Khao Sam Keao and Phu Khao Thong.
Núria Morell I Cortés	Lead in Iron Age in Iberian Peninsula: Use and Practical Applications
Ny Björn Gustafsson	Beyond deposition: Workshop strategies and non-ferrous metal-working on Gotland in the early middle ages.
Jim Brophy	Nidderdale Project Poster

Bradford University Campus Map



Evening Venues



Evening Drinks

The Thirsty Scholar

Tuesday 10th & Thursday 12th



Conference Dinner

Omar Khans

Wednesday 11th

Fieldtrip Information

Trip to the Royal Armouries in Leeds.
Sign up sheet on reception.

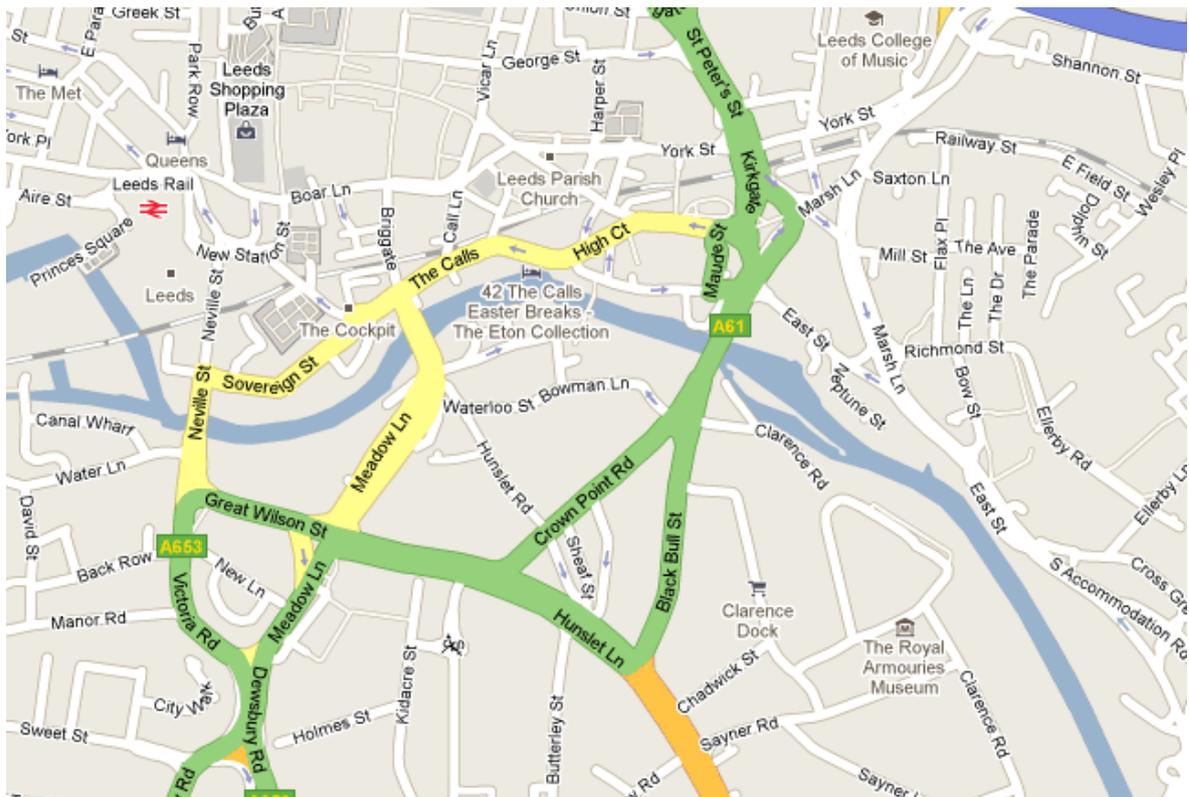
I will meet people at Bradford Foster Sq Railway station at 9:10AM

We will catch the 9:31AM train to Leeds

There will be a 20 minute walk from Leeds station to the Royal Armouries.
If extreme weather we will take the 28 bus.

For those of you wishing to drive to the museum, after getting on to the M62 east bound head on to the M621. Exit the M621 at junction 3 and follow the brown tourism signs with the 'horned helmet' Royal Armouries logo. There is ample parking in a privately operated multi-storey secure car parking is located only 100 metres from the museum entrance. Please aim to arrive at 10:20AM.

The museum has free entry although special exhibitions and displays can be charged.



One Man's Garbage is Another Man's Obsession: A Theoretical View of the Role of Slags within Archaeometallurgical Research

Allan B Daoust

Since archaeometallurgy essentially originated from the unplanned union of two widely disparate fields of study, this new sub-field of archaeology was left without a clearly defined framework or research agenda beyond the study of past metallurgy and its associated remains. While the virgin territory that this field encompassed allowed for tremendous progress to be made, this progress has not been even or equal across the various areas of research, a situation which is particularly clear amongst the field of ferrous slag research. Smelting slags have received the lion's share of research dedication and thus have provided numerous insights in the nature of this process, while "smithing slags have received little attention" (McDonnell 1991: 23) as there is no clear indication of the potential information which these materials may provide or their broader function within the blacksmithing process. This paper attempts to address this situation by establishing a clear theoretical framework and a specific model in order to expand the current parameters of archaeometallurgical research. Such a model shall demonstrate the role of archaeometallurgical remains such as ferrous smithing and smelting slags within a broader techno-industrial and socio-technological context, while elucidating the various relationships which exist amongst technological processes and their products. Although such a model has not been *explicitly* utilized within archaeometallurgical research, various aspects of this model have been *implicitly* and *indirectly* employed for the study of smelting slags with great success. In order to demonstrate the potential value of such a theoretically-based model for the study of past metallurgical systems within a broader socio-cultural framework, this model shall be considered within the context of previous iron smelting slag research. This model shall then be applied to the study of smithing slags, demonstrating the nature and role of this material within the smithing process while outlining their value as a viable source of archaeometallurgical information. These examples shall serve to illustrate the need for the adoption of such a theoretical model within archaeometallurgy, thus furthering the potential of this field to make significant contributions within a wider archaeological context, beyond the parameters of the metallurgical processes and their associated products and materials.

Reference

McDonnell, G. 1991. A model for the formation of smithing slags. *Materialy Archeologiczne*. 26: 23-26.

Colour Change in Copper Alloys through Alloying

Jui-Lien Fang

Division of Archaeological, Geographical, and Environmental Sciences, Bradford University

The origin of the use of metal in human history could be dated back 11,000 years. The reason that metals were noticed by ancient people was their bright and shiny colours which made them used for decoration purposes. Following the invention and development of technologies for the production of copper, copper alloys, iron and steel and other metals, the function of metals was expanded from decoration purpose to weapon, agricultural purpose, construction and domestic tools, etc.

While the popularity of iron technology rapidly pushed the growth of civilisation, some range of copper alloys, such as tin bronze and brass were still in use for different purposes. The advantage of copper alloys is that their properties could be effectively modified through controlling of addition of alloying elements and heat treatments. One of the important properties of copper alloys which could be changed through alloying is colour. A famous example is the use of high-tin bronzes. Some researchers suggested the use of high-tin bronzes should be due to their colours, which resemble the precious metals gold and silver.

A series of copper alloys containing different alloying elements and percentages were made in laboratory. Their colour properties were measured by a spectrophotometer. The results show that alloying does change the colour of copper and the colour of tin bronzes containing 18%-33% tin was changed from gold-like to silver-like as tin percentage increased.

Iron Age Greys: Druids or travelling salesmen

Jane Cowgill

Freelance Archaeologist

Iron Age Grey slags are common finds on Iron Age sites and even though Gerry first identified and named them in the 1980s, their existence is seldom recognised. This talk is an attempt to bring their existence to a wider audience and renew the debate of why and how.

Nidderdale Iron
Jim Brophy
Nidderdale Iron-Age Project

Nidderdale is rightly famous for its lead extraction and smelting, activities which often obscure the fact that there has been an abundance of iron smelting in the area from the Iron Age to the 17th Century. Iron-Age (Nidderdale) is a community archaeology project that is working to remedy this situation by exploring and recording the archaeological evidence for historic iron smelting and related activities.

Evidence has been revealed of pre-historic iron smelting and smithing on the edge of an Iron Age settlement at Dacre. This metal working site is known to us (and more widely too) as the Dacre Iron Age Smithy, a name suggested by Gerry McDonnell whose advice enabled us to properly identify the feature. The initial indicator was a find of slag and hammer scale but bloomery furnaces and smithing hearths have been added to the list over the last two years.

There is also abundant evidence of medieval iron smelting from the time when Dacre was a grange of the Cistercian abbey of Fountains. This evidence includes an extensive water management system, numerous bloomery furnaces, charcoal preparation areas, ore roasting hearths and water powered forges. Many bloomery furnaces appear as single entities but there is at least one that has three platforms adjacent to it and another complex of three furnaces and several platforms that have clearly formed a single production unit.

The post-monastic period is represented by a "Smelthouse" that seems to have reached the end of its active life in 1611. The smelt house is recorded on an accurately surveyed map of that date and the remains of a wheel pit are visible although a little effort is required because they are now covered by top stones to make a bridge. The exact form of the smelt house is yet to be determined but it seems likely to have been a blast furnace.

In addition to these remnants of known periods there are other bloomery furnaces and related features of unknown date that raise the intriguing possibility of more or less continuous iron manufacture on the site from the Iron Age to Tudor times.

In the same area as the Iron Age smithy evidence recently came to light of small scale lead smelting that is probably from the same period. The lead smelting is of particular interest because it was unexpected since this site is on millstone grit and is approximately five miles from Greenhow, the nearest known source of lead ore. The main evidence of the smelting is lead dross and some small pieces of galena suggesting local processing of ore brought from Greenhow or elsewhere.

Iron-Age (Nidderdale) is in the second year of a four year project financed by the Heritage Lottery Fund and it has good reason to be grateful for the support of Bradford University and a number of individual staff and students who have acted well beyond the call of duty, prominent among this number is Doctor Gerry McDonnell. Thank you Bradford University and thank you Gerry.

A study of wear in Roman and Early Medieval knives

Edward Kendal

Division of Archaeological, Geographical, and Environmental Sciences, Bradford University

Archaeological wear is an area that has had little attention in the past by archaeologists and has only ever been mentioned in passing comments regarding artefacts. This study looks at wear as an indicator of usage in iron knives from the Romano-British and Early Medieval periods and a method of quantifying wear and expressing it as a percentage was created prior to the study. 240 knives from 20 sites were examined with both metallographic data existing from some of them. Initial results show that there is a clear link between percentage wear and manufacturing type and also the type of site.

Metallurgical Comparison of Early Medieval Utilitarian Iron Artefacts with Specialized Craft Tools

Samantha Rubinson¹ & Gerry McDonnell²

1) Division of Archaeological, Geographical, and Environmental Sciences, Bradford University

2) Gerry McDonnell Archaeometals

This paper reviews the use of specialized iron alloys and treatments in both utilitarian artefacts and specialized craft tools from sites throughout Early Medieval Britain as an indication of alloy availability and the technological knowledge during this period. Previous studies of post-roman iron artifacts have concentrated on edge tools (Tylecote, 1986; McDonnell, 1989) making it difficult to gauge the actual extent of the use of specialized alloys. Through the examination of one hundred and forty artefacts, ranging from knives, edged tools, weapons, locks, nails, building materials, currency bars, and un-worked bloom fragments, from eight different sites across Britain, an assessment of the regional variations in technology and alloy availability became possible. These artefacts were examined through the use of optical analysis and micro-hardness testing, with elemental composition analysis obtained by SEM-EDS to establish the presence of different alloys, addresses their use within specific artefact types, and elucidates their elemental compositions. This data was subjected to several levels of comparison. Firstly, a comparison alloy usage between utilitarian artefacts, such as building materials and nails, with both specialized tools, including clothing accessories, knives, edged tools, and locks, and pre-smithy iron, such as currency bars, and un-worked blooms. Secondly, the data from the eight sites examined here was examined first as a collective whole then divided site status in order to establish patterns of iron alloy usage amongst the various types of settlement. Finally, a cultural comparison between the use and distribution of iron alloys amongst Saxon and Viking assemblages was conducted. Ultimately a synthesis of the iron alloy technologies available for this period and an increased understanding of the availability of smithing technologies will facilitate the development of a picture of the post-Roman iron industry within Britain.

References

McDonnell, J. G. 1989. Iron and its alloys in the fifth to eleventh centuries AD in England. *Archaeometallurgy*, **20**, 373-381.

Tylecote, R. F. and Gilmour, B. J. 1986. *The metallography of early ferrous edge tools and edged weapons.*, B.A.R., Oxford.

Characterisation of early medieval smithing slags from Ireland

Dr Tim Young

GeoArch, Unit 6, Western Industrial Estate, Caerphilly, CF83 1BQ.

Irish early medieval smithing assemblages show a continuum of size, morphology and texture between small smithing hearth cakes (SHCs) of conventional appearance and large cakes weighing up to 11kg.

Some assemblages of SHCs are size restricted, with the majority of the SHC assemblage weighing less than 500g. These assemblages can be attributed to end-use blacksmithing with a high degree of confidence. Investigation of the chemical composition of these small SHCs (both in assemblages where they dominate and in assemblages with a high proportion of much larger cakes) shows that they may be modelled broadly as a mixture of tuyère-derived ceramic with iron.

SHCs weighing above 2000g, in contrast, show a significant contribution to their chemical composition from material derived from the smelting process. Despite previous assumptions that these large cakes were furnace bottoms, recent clarification of contemporary smelting assemblages has allowed their recognition as residues from smithing, broadly, if not precisely, equivalent to conventional SHCs. The influence of smelting materials suggests that these cakes are associated with bloom refining. Supporting evidence for association of the large SHCs with bloom refining comes from the occurrence of the largest cakes on a site at monastic Clonfad where particularly large blooms were being worked down into iron sheet for the forging of Type 1 ecclesiastical handbells; each bell requiring an iron sheet weighing approximately 5kg.

SHCs of an intermediate size between 500 and 2000g may show chemical compositions linking them to either of the two compositional classes. Even on sites which do not appear to be directly related to the processes of iron production, there is a small proportion of SHCs ranging up to 2500-3000g in weight. These cakes suggest an element of the bloom refining process occurred, even in assemblages which appear to be dominantly from blacksmithing. It is suggested that this phenomenon, associated with the lack of recognised “trade-iron” in Ireland, indicates that incompletely refined blooms were supplied to the end-user smiths, a practice that can be paralleled elsewhere in Europe.

The early medieval smithing was undertaken in floor-level hearths, blown through ceramic tuyères. This technological “package” appears in the early medieval period (perhaps c. AD500) replacing an Iron Age tradition apparently of clay-walled hearths, producing much more modestly-sized SHCs. The use of ceramic tuyères persists through the medieval period (although large assemblages of this period have not been examined) and into relatively recent times, perhaps as late as the 19th Century.

The Asante Ewer and the Casting Technology of Large Medieval Bronze Jugs

Susan La Niece

Scientific Research, The British Museum, London WC1B 3DG

The so-called Asante ewer is a very large bronze jug in the collections of the British Museum. It is 62 cm high with its lid, weighing 18.6 kg when empty and is a rare survival of a Medieval English lidded jug. On the heraldic shield under the spout are the royal arms of England that were current from AD 1340 to 1405 and the devices of a lion and of a stag on the lid place the manufacture of the jug in the last years of the reign of Richard II. Two other similar large metal jugs are known. One is in the collections of the Victoria and Albert Museum and the other has more recently been acquired by Luton museum.

This paper will present the results of a study of the three – their metal composition and the casting features, both those visible on the surface and those revealed by radiography. All the jugs were cast in two-part moulds and have inscriptions in raised lettering around their body similar to that seen on castings of bells. Radiography showed unusual features which link all three jugs. There are several squarish shapes in the radiographs of the jug walls. These are interpreted as the spacers which separated the core and cope during the casting process. These spacers are made of very porous metal, of slightly different composition to the jugs but showing the same signature of a high antimony content. This distinctive feature would seem to link these jugs quite closely, perhaps to the same foundry.

Tudor arrowheads: battlefield finds under the microscope

David Starley¹ & Rachel Cubitt²

1) Freelance Archaeometallurgist

2) York Archaeological Trust

Whilst typological studies provide a useful framework for classifying medieval arrowheads and can give some indication of dates and function, our understanding of these artefacts, produced in hundreds of thousands, relies on too few stratified and provenanced finds. Within the typologies, the value of certain types in defeating armour is far from universally accepted. Archaeometallurgical research provides an alternative insight into the quality and likely effectiveness of these weapons. Examination of arrowheads from one certain and one putative War of the Roses battlefield assemblage; Towton (1461) and Holm Hill, Tewkesbury (1471), have provided a unique and unexpected insight into the manufacture of these projectiles. This shows a demand for quantity over quality, which led to new construction methods, and suggests that the majority of troops were only poorly protected by armour.

The impact of the medieval and early modern iron industry on the woodlands of Rievaulx and Bilsdale, North Yorkshire, UK

Jane Wheeler

School of Geosciences, Department of Geography & Environment, University of Aberdeen

The arrival of the Cistercian community at Rievaulx in the twelfth century has been associated with the development of the monastic estate and the expansion of pastoralism and subsequent deforestation. The results of this multi-disciplinary doctoral research project focus on the impact of iron-working on woodland resources at Rievaulx within the valley of Ryedale and Bilsdale, to the immediate north, which originally formed the proximate estate of Rievaulx Abbey.

Results challenge historical orthodoxy in respect of the environmental impact of the arrival of the monastic community in 1132/33, indicating that the area prior to the Cistercian influx was already a populated and managed landscape with a legacy of iron-working. Palaeoecological data demonstrate that woodland management was practised and wood stocks were not exploited to the point of exhaustion as industrial activity intensified, but management strategies changed in accordance with consecutive phases of production, the acceleration of output in respect of technological innovation and associated economy of scale, and market fluctuations.

The long history and continuity of iron-smelting in Bilsdale and within the environs of Rievaulx until the mid-sixteenth century, and the subsequent transfer and centralisation of the process at Rievaulx, provides a rare opportunity to examine the environmental history and archaeology of a valley site in direct response to one metallurgical process. The results presented in this paper reveal the relationship between the iron industry and its management of local wood stocks through time until the eventual demise of the industry in the mid-seventeenth century.

Keywords: iron-working, archaeology, pollen, charcoal, woodland management, fuelwood, Cistercian, medieval, early modern, Yorkshire

Kiln hunting! In search of the definitive earthwork evidence for chop-wood / white coal production.

Janis Heward

This presentation addresses the archaeology of woodland fuel production for the ore-hearth lead smelting process. From the late 16th century into the 18th century kiln dried wood, chop-wood, or white coal, was the principal fuel used for lead smelting. Its use was superseded by peat in many of the ore-hearth smelt mills in the Pennine uplands; it was also supplemented and, in many areas, the ore-hearth was replaced entirely by coal fired reverberatory furnace; but many small ore-hearth mills continued to use wood well into the 18th century.

Only a few of the kilns used to dry the wood survive as definitive structures which can be associated with ore-hearth smelting sites, most are found as earthwork features in woodland locations, often quite remote from the smelt mills. The author will explain her interest in their archaeology, from its beginnings as an undergraduate at Bradford, through the use of documentary evidence to identify new sites and to interpret working practices, to the problems of differentiating the field evidence from that of other woodland industries such as potash production.

The other side of the melt; Bradford's fire-brick industry

Derek Barker

Bradford Industrial Museum

A combination of geological resources, and technological developments, favoured the development of an iron smelting industry in late 18th century Bradford. Lower Coal Measures underlie the City of Bradford containing seams of commercially valuable fireclay, coal, iron ore and ganister. The refractory properties of fireclay were of value for furnace linings, a fact that had been recognised by Abraham Darby I. By 1888 there were 15 producers of firebrick in the Bradford area. The manufacture of refractory bricks is discussed, and in particular the works of J.R. Fyfe in Shipley. Massive amounts of firebrick fragments and foundry waste were produced by the iron industry; the subsequent use of this material will be described. The conservatism of the iron smelters, and the exhaustion of available coal and iron ore seams, resulted in the rapid decline of Bradford iron smelting in the early 20th century. Firebrick manufacture soon followed the iron works into oblivion.

Metals, envaluation and materiality

Tim Taylor

Division of Archaeological, Geographical, and Environmental Sciences, Bradford University

Modelling the first appearance of metals and their subsequent (pre)history almost inevitably takes a technological standpoint as primary - the identification of elements, alloys, techniques - despite the fact that these are categories/concepta that have crystallized out from a process of epistemic development within academe over just the past two or three centuries. This paper considers the challenge of constructing understandings from the opposite direction, so that the processes by which ancient metals first came to be recognized (or not) can be more sensitively investigated.

Accessing skills of the first European metalworkers: metallographic analysis of copper implements from Pločnik, a Vinča culture site in south Serbia

Miljana Radivojević¹, Prof. Thilo Rehren¹, Dušan Šljivar² & Dr John Merkel¹

1) Institute of Archaeology, University College London, UK

2) Department for Prehistory, National Museum Belgrade, Serbia

The early metallurgy in the Balkans has attracted scholarly attention for decades, particularly in regards to the findings of massive copper implements circulating in this area in the late 6th and early 5th millennium BC (cf. Pernicka, 1990). Four assemblages (44 artefacts) of copper implements from Pločnik, a Vinča culture site in South Serbia, display exceptional testimony of metallurgical activities in the Early Chalcolithic period in the Balkans. These assemblages consist of a distinctive type of copper hammer-axes, then chisels, armbands and a needle; however, they represent chance findings within the settlement of Pločnik and hence their Vinča culture provenience has been disputed by some (Garašanin, 1979).

The most recent scientific excavations at Pločnik yielded several more implements that typologically relate to the implements in the assemblages, strengthening the argument of the Vinča culture origins of their production. Hence, in order to explore the technological relation between these groups of implements, we undertook metallographic and chemical examination of two samples: a chisel coming from the Vinča culture context and an ingot originating from one of the four assemblages. The physical and chemical characteristics of these samples were assessed using optical microscopy, micro-hardness testing and SEM-EDS. We examined the properties of early copper tools and skills employed in their making and working. These aspects contribute to our understanding on the technology and organization of copper production in the early metallurgical societies.

References

- Garašanin, M. 1979 Centralnobalkanska zona. IN BENAC, A. (Ed.) *Praistorija Jugoslavenskih Zemalja (Prehistory of Yugoslav Countries, in Serbian)*. 79-212. Sarajevo, Svjetlost.
- Pernicka, E. 1990 Gewinnung und Verbreitung der Metalle in prähistorischer Zeit. *Jahrbuch des Römisch- Germanischen Zentralmuseums Mainz* 37, 21-129.

Identification of raised vessel manufacturing workshops in Minoan Crete.

Christina Clarke-Nilsen

Australian National University School of Art.

The identification of the site of a metallurgical workshop in Late Bronze Age (Minoan) layers in Crete is inevitably tied to the process of casting. The remains of casting are relatively easy to identify – metal spill, evidence of a high-temperature hearth, the remains of moulds, crucibles and tuyères – and allow for certainty in the identification of a workshop. Such remains have helped in the identification of workshops at Kommos, Knossos, Mochlos, Gournia and others. However, the range of metallurgical techniques used in Minoan Crete was much broader than casting, and includes forging, raising, repoussé, soldering, granulation, engraving and sheet punching. There should be remains which indicate these other processes, although they may be subtle and easily overlooked. By presenting a model for a Bronze Age vessel raising process, this paper aims to identify what equipment may have been used for the process and how a site at which raising occurred may be identified.

From Bronze to Copper: The Effect of Recycling on Copper Alloys in prehistory.

Giovanna Fregni & Roger C P Doonan
Dept of Archaeology, University of Sheffield

It is accepted knowledge that when re-melting alloys some of the metal with a lower melting temperature is lost and more metal must be added in order to maintain a consistent alloy composition (Untracht 1985: 349). To better understand the process of recycling, a campaign of experimental remelting was undertaken for a range of copper alloys similar to those known to have been used in prehistory. Experimentation explored the effects of technical choice on furnace environment and alloy composition. Combined analytical studies of the results of these experiments have demonstrated some compositional trends associated with recycling. Results also indicate that the effects of technological choice need to be clearly understood before making any broad inferences about compositional change and recycling. This paper concludes with a cultural analysis of the role of recycling and how this can inform biographical studies of copper alloy artefacts.

Geophysical prospection of iron slag heaps at Hamadab/ Northern Sudan.

Burkart Ullrich¹ & Pawel Wolf²

- 1) Free University of Berlin, Institute of Geological Sciences, Geophysics / Eastern Atlas – Geophysical Prospection, Germany
- 2) DAI – German Archaeological Institute

Since 2001, a joint Sudanese-German team has excavated the Meroitic settlement of Hamadab, located three kilometres south of Meroe City, the capital of one of the ancient Sudanese Kingdoms. Two mounds rising about four meters above the surrounding fertile plain of the river Nile characterize the site. Main focus of the archaeological research is the fortified settlement at the northern hill with densely built brick masonry buildings and streets. Several slag heaps indicate local iron production near the settlement. A small-scale excavation in 2002 at one of these heaps (H100) revealed a tightly packed slag layer containing *tuyère* fragments of iron smelting furnaces, coarse pottery and pieces of iron slag with large inclusions of charcoal, indicating that the iron smelting furnaces must have been situated next to the heap.

In spring 2009 a geophysical field survey using Ground Penetrating Radar (GPR) and Induced Polarisation (IP) electrical measurements was carried out at slag heaps H100/200 and H800. Conventional steel electrodes with an electrode distance of 0.5 or 0.8 m were used for electrical measurements at five profiles. The quality of the measured apparent complex resistivity data was good for the resistivity values and acceptable for the phase shift values according to the difficult conditions for resistance measurements in arid areas. Using the BERT package (Boundless Electrical Resistivity Tomography), 3D-models of the complex resistivity were reconstructed associated with surface topography of the slag heaps. The models of the electrical parameters show a great variety of both, resistivity and phase shift, possibly indicating a heterogeneous composition of the heaps: furnaces and slag as well as waste and ashy layers in greater depth. The GPR measurements with a 500-MHz-antenna were executed at three resistivity profiles of heap H800 and on parallel profiles at H100/200 to achieve a 3D-data set. The data was processed and corrected with regard to the topography. The GPR-sections show stratified reflections, which indicate the expansion of the heap to areas, where slags were tilted. Furthermore, areas of low reflection indicate pits, holes, or loose sediments within the heap. These parts might be remains of eroded or destroyed furnaces.

This example shows the potential of geophysical prospecting techniques, which allows to prospect slag heaps even in aride climate. On the other hand, there is a gap of knowledge and experience on the petrophysical response of archaeometallurgical targets in archaeogeophysics. Both excavation on these medium scale slag heaps and more fundamental laboratory analysis may fill this gap in the future.

Keywords: archaeometallurgy, meroitic studies, sudan archaeology, iron slag, geophysics, ground penetrating radar, geoelectrics, induced polarisation

Forging, Texts, and Identity: Understanding iron and iron workers in EIA Greece.

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The study of Iron Age metallurgy in the Eastern Mediterranean has focused on the distribution and chronology of particular artefact types in an attempt to understand the origins of iron and its role in the dramatic social transformations which occur at the end of the Bronze Age. Scholarly attitudes to the inception of iron have varied from it being a potent agent of social change to it being an inconsequential outcome of wider societal processes. Whilst such studies have focused on early iron artefacts, often in combination with textual evidence, there have been very few studies which have addressed the actual contexts of iron working, either in the early phases of its uptake or during its wider adoption.

This paper presents a contextual analysis of iron working in Early Iron Age Greece. Particular attention is paid to the relationship between excavation strategies for excavating iron working sites, such as those advocated by Gerry McDonnell, and the kind of histories which can be written. It is suggested that our focus on technological origins has guided much research at the expense of attempting to understand how iron metallurgy is accommodated within the new social practices which emerge at this time. Significantly and somewhat surprisingly it is argued that our understanding of smiths in Iron Age Greece is often structured more by later historical documents than primary archaeological deposits.

Who's afraid of the Bowl Furnace?

David Dungworth

English Heritage

For over a century archaeologists have categorised smelting furnaces as bowls (essentially those which are wider than they are tall) or shafts (taller than they are wide). The idea of the bowl furnace, however, has been in decline for several years (in particular as it applies to the smelting of iron), and some archaeometallurgists would now deny that any such thing ever existed. In this talk I would like to review the history of the idea of the bowl furnace. I will further explore some archaeological, scientific and ethnographic evidence which might allow us to rehabilitate the idea of the bowl furnace for iron smelting. In part my motivation for exploring the changing fortunes of the bowl furnace in archaeometallurgy is the light which this sheds on the nature of our discipline. How do we decide what constitutes reliable evidence? How do we formulate models of past (metallurgical) activity to explain such archaeological evidence? How do we make, and react to, paradigm shifts?

Iron and the Parisi

Peter Halkon

Department of History, University of Hull

This paper will examine the development of iron production within the supposed tribal territory of East Yorkshire from the beginning of the Iron Age to the end of the Roman period. Research undertaken since 1980 in which Bradford University has been involved, particularly with Geophysical Survey at Hasholme Hall and Bursea House in the Foulness Valley, has demonstrated the presence of one of Britain's largest prehistoric iron industries contemporary with the Arras Culture with its chariot burials. The region's first currency bar has been identified at Gransmoor in the Hull Valley. Discoveries such as the South Cave weapons cache in 2003, probably buried during the Roman conquest of this region, confirm the continuation of a high level of expertise in metalworking within the region at the beginning of the Roman period. The right natural resources and continued expertise in furnace based industries led to the development of a Roman pottery industry which seems to have overtaken that of iron in importance, though iron working and production continued. There are slag inclusions in the fabric some pottery types and at Hasholme an anvil typologically dated to the 3rdC AD was excavated.

More recently further evidence for iron production has been located elsewhere in the Vale of York during the Iron Age and Roman periods and in 2009 a small furnace thought to be of Roman date has been discovered at Thearne in the lower Hull Valley. It is not surprising therefore that small votive tools and pots adorned with the head of the god Vulcan and smith's tools clustering in the region provides evidence for the veneration of the smith god.

Iron Age Cart Tyres from Wetwang, Yorkshire

Janet Lang

Emeritus Researcher, The British Museum

In 1985 John Dent published a paper in *Antiquity* outlining the finding and excavation of three cart burials at Wetwang, in Yorkshire. The finds were conserved in the British Museum and while they were there a small sample was removed from each tyre for metallographic examination. The results were reported at the time, but are still awaiting publication so last year it was decided to revisit the work with the intention of publishing the data as a short note. The paper presented by Swiss, Hunter and McDonnell at the Hüttenberg Conference in 2008 gave encouragement to this project, even though the availability of a single sample from each tyre is not ideal, as Swiss *et al* showed. The metallographic results will be discussed in the presentation, but in brief the samples from Wetwang burials 1 and 3 were found to be wrought iron, with phosphorus in both the metal and inclusions, while the sample from burial 2 contained up to 0.8 carbon, distributed very inhomogeneously.

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Smithies and Ironworking in Denmark, an ongoing project

Arne Jouttijärvi
Heimdal-archaeometry

The paper presents an ongoing research project on smiting workshops in Scandinavia. The focus is on the Iron Age, but a number of Smithies dated from the Viking period and until the 18th century will also be included. Different approaches can be used in the investigation of the archaeological remains of workshops.

The physical distribution of slag, hammerscale, charcoal vitrified clay and other types of debris from ironworking can yield information about the structure of the Smithy and the organization of the work within it, whereas the chemical characteristics of slag, hammerscale and slag spheres will tell about the processes used in the workshop.

The work of the blacksmith consisted basically of three different processes: cleaning of bloom iron, welding together pieces of iron and/or steel and the forming of the object. Although superficially similar, the hammerscale from these processes will have different chemical composition. It is therefore possible, on the basis of chemical analysis, to establish which processes took place within a given workshop.

Analyses of excavated workshops have shown that they can be divided into different categories. One type only showed slight signs of bloom-cleaning and welding. They probably represented farm-smithies where simple tools and fittings were made from available pieces of iron. Other workshops was somewhat more advanced, employing both the bloom cleaning and the smiting of finished objects, although not using welding to any significant extent. A third type of workshop seemingly produced more advanced tools or weapons needing the welding of pieces of iron or steel. Apparently the raw material for these smithies was bar iron, as they only occasionally performed the cleaning of blooms.

The composition of refining slag and especially the slag inclusions in iron makes it possible to estimate the origin of the iron cleaned or worked in a smithy. The origin can probably not be traced to a single production site, but only to broader areas. The slags from cleaning of blooms are essentially smelting slag, and will therefore resemble the slags from smelting sites, although they will show a reaction with ashes from the charcoal. Slag inclusions in iron artefacts will resemble the bloomery slags even more, as they have to a large degree been shielded from reaction with the surroundings by the iron. Within Scandinavia and the northern part of Continental Europe a number of slag types can be distinguished based on differences in the local geology.

Bloomery Ironmaking during the Roman Iron Age in Mid-Norway

Arne Espelund

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Dating by the ^{14}C -method and archaeometallurgical studies have revealed that a period of large-scale bloomery ironmaking in Norway started about 300 BC. A type of shaft furnace with a well preserved slag pit, often in batteries numbering about 4 furnaces has been registered at some 400 sites in Mid-Norway including neighbouring Swedish Jämtland. They are invariably placed at the end of terraces facing water. The cylindrical stone-lined slag pit measuring some 80 cm in diameter was equipped with a vertical slot, so that the resulting slag (about 150 kg) could be removed and the furnace therefore be used repeatedly. The moderate amount of broken pieces of burnt clay from the shaft expresses that also the shaft could be used several times.

The furnaces were operated by induced draft, created as a chimney fire by insertion of split wood to the shaft. It was invariably resin-rich pine. Air was sucked in through five openings measuring 8 cm. In full agreement with normal firing, a cyclic pattern was established. It is revealed by ripples on pieces of slag, which solidified onto the cold wall of the slag pit, Each ripple may represent some 10 kg.

When idle, there was a small hot zone in front of every opening, which probably was closed with a sod. It is assumed that there was a "dead zone" with only partial reduction from Fe_2O_3 to FeO between every opening. When wood was added on top and the sod removed, the hot zone would be enlarged, thereby supplying half reduced, FeO -rich ore to the slag, ensuring carbon control of the resulting metal and fluxing of the slag. This principle, named *volume zone* control, has much in common with the Catalan process in the Pyrenees-Basque country.

It appears that the furnaces were operated by groups of serfs led by a chieftain from one of the large farms near the Trondheim fjord. No place representing experimentation leading to this process of a uniform character has been found, so that the author is eager to find a parallel to the method in some other country.

The resulting iron was a split bloom weighing some 18 kg, of which several are found in our museums. A slag-free, compact bloom of an excellent quality with some 0.2% C has been studied by the author.

Around year 200 AD the annual production was around 40 tons, of which only some 1/10 was needed in the area. The rest was probably exported. Boat sheds found at about 15 m.a.s.l. express the land rise during some 2000 years. Behind the production and the trade one must expect to find an interesting infrastructure.

The large find from the same period in Illerup-Ådal in Denmark contains weapons, which may have been made from iron produced north of Kattegat. This is revealed because of the low content of phosphorus and a certain amount of cobalt, found by microprobe analysis. This study has recently been initiated by the author.

Ironmaking by this process was discontinued around year 600. It is postulated that this is due to major changes on the Continent in the wake of the Migration period, such as a famine and a plague. The export market was lost.

Ironworking in Roman Worcestershire and surrounding areas: Can we compare data across commercially excavated sites?

Christine Elgy

Worcestershire Historic Environment and Archaeology Service

Slag, a primary product of iron smelting, is chemically stable and was not re-worked in Roman times so retains many of the chemical characteristics of the original ore. It is an ideal material for comparing metal production at various Roman sites as it is often present in large quantities and, unlike more highly valued metal objects, can be subjected to destructive analysis.

In commercial archaeology, chemical data from analysis of iron ores and slags on various sites are available in separate specialist reports, but comparisons are not made. This is because the information from different sites is not always easy to interpret without further specialist support.

This work compares chemical data for ores and slags from different Roman sites in Worcestershire and surrounding areas, from specialist reports by Dr. Gerry McDonnell and others, and asks what conclusions can be drawn. Information on ores and slags from industrial sites, including the Forest of Dean, are used to address questions of provenancing, and the data which raised questions of additions of minerals during the smelting process is revisited.

How to part silver from copper, understanding SAIGERPROZESS through experimental liquation and drying

Maxime L'Héritier, Florian Téreygeol, Eddy Foy, Vincent Detalle, Annick Texier & Bernard Gratuze

Institut de Recherches sur les Archéomatériaux

Liquation and drying process also known as *saigerprozess*, its German name, is a metallurgical process used to separate silver from copper, which spread in Europe at least from the 14th century onwards. At that time, many great silver-rich lead mines in Central Europe entered depletion though the demand in silver was stable and that in copper was increasing; thus making use of argentiferous copper ores containing less than 2w% silver became profitable.

The principle of *saigerprozess* relies on the strong affinity of silver for lead. The silvery black copper is mixed with great amounts of lead (with an average ratio of 10 to 3) and cast in cakes. During cooling, silver passes from the copper to the lead. These liquation cakes are then heated up in a reducing atmosphere, above the fusion point of lead but below that of copper, so that the silvery lead would flow out. This first stage is called liquation. However, the separation is incomplete as the "exhausted liquation cakes" still retain some lead. Thus, they are retreated in a so-called drying furnace under an oxidizing airflow which purifies them from the remaining lead. This is the drying stage. Eventually, the metallurgist has separated copper from silvery lead which can be cupellated. Liquation and drying produce numerous by-products as well, mainly copper and lead oxides including litharge which have to be retreated. Agricola was the first one to describe extensively this new process in Book 11 of his *De re Metallica*. A few metallurgical treaties from the modern times evoke it as well, yet owing to the lack of archaeological data, very little is known about this process and its products.

Hence, several experiments reproducing the whole liquation and drying sequence were conducted on the experimental platform of Melle (France). Products and by-products were analysed with several methods (XRF, LA-ICP-MS, LIBS) so as to create a first reference corpus. This paper aims to present these experimental results and to compare them with analyses of copper-lead alloys coming from French archaeological sites and lead joints sampled in medieval monuments, such as Auxerre and Metz cathedrals and Vincennes castle. This comparison provides new perspective on the diffusion of this process in the northern part of the French kingdom in end of the Middle Ages.

Silver Refining : Contribution of Experimentations to the understanding of technological choices

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Cupellation was for a long time the only known method to retrieve silver from argentiferous lead. The operation takes place in a cupellation furnace, a structure made of a circular wall supporting a round sole and topped with a dome. The crucible, where the alloy is placed, is made from lute and ash. Bone ash is best; however because of the large scale, wood ash was often used as well. During the operation, lead oxidises and litharge is partially absorbed in the ash, but most of it has to be accumulated and extracted from the furnace. Therefore the alloy enriches in silver.

Since Renaissance, silver refining has been well documented in detailed and illustrated metallurgical treaties, such as Vanoccio Biringuccio's *De la pirotechnia* (1540), book III chapter 7, and particularly Georgius Agricola's *De re metallica* (1556), book X. Yet, there is very little archaeological evidence of this operation, mostly because all by-products were recycled, including litharge cakes, i.e. the ash crucibles impregnated by lead oxide. Since historical sources are incomplete and biased, conducting experimentations appeared necessary to understand all the technological choices of ancient metallurgists: structure of the furnace, ventilation, composition of the crucible, removal of molten litharge. They were carried out at the *Plate-forme d'Archéologie Expérimentale des Arts du Feu* in Melle (Deux-Sèvres, France), and are entirely based on Agricola's text, from the construction of the furnace to the conduct of the process.

Seven operations were conducted in successive steps over two years. The first point to solve was how to reach the needed oxidative atmosphere and temperature of 960°C. Two different set-ups involving changes in the ventilation process were compared. Then the making of clay and ash crucibles was considered, while the possibility of achieving cupellation in different places in the furnace was tested by distributing small assay cupels on the crucible. Where these assays were successful, the right conditions had been reached. The next step focused on observing how litharge propagates in the ash. Finally, the last experimentation was dedicated to extracting litharge from the furnace. Two ways are described in metallurgical treaties and both had to be tested. Molten litharge can either flow out of the furnace guided by a channel in the ash or be lifted up and rolled round with a stick.

The whole process is taken into account in this study: temperature and atmosphere conditions, refining efficiency, structure of the litharge cakes. The latter will be compared with the only litharge cake known in France for medieval and modern times, from the royal mint of La Rochelle (17th century). Next experimentations will enquire about different ash compositions for the crucible, how to handle larger quantities of alloy, or how to optimize the use of the bellows.

Keywords: cupellation, experimentations, litharge, ash

Slag? What slag? In search of evidence for medieval lead/silver smelting

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Most metalworking / smelting sites present the field archaeologist with sufficient slag to identify them; some have it in abundance and that is the case with post-medieval lead/silver smelting at Combe Martin, in North Devon. Late medieval lead/silver smelting in the Tamar Valley, on the Devon-Cornwall border, does, however, present researchers with difficulties in the lack of field evidence with which to identify sites. This paper reviews the documentary evidence for smelting and refining of silver bearing ores in the 13th to 15th centuries, and relates it to the lack of field evidence. The results of geophysical survey on one well documented site are discussed along with the economics of smelting which give rise to the disparity in field evidence between medieval and later smelting activity.

Understanding litharge cakes

Justine Bayley
English Heritage

Nearly 20 years ago Gerry McDonnell and I presented a poster at the 1990 Archaeometry Symposium in Heidelberg entitled 'Litharge cakes as evidence for silver refining'. Both before and since then Gerry has spent much of his time on ferrous metallurgy but I have continued with my original interest in litharge cakes. This paper presents my current work and thoughts on the topic.

Litharge cakes are a by-product of large-scale refining of silver by cupellation. They are normally found in urban contexts, often in association with debris from other non-ferrous metal-working or -refining processes. Some 40 litharge cakes of Roman to later medieval date have been sampled and investigated using a scanning electron microscope with an energy-dispersive X-ray analyser. The images and analytical data allow variations in the cupellation process to be documented.

The science behind the cupellation process will be explained, and reasons suggested for the varied structures and compositions seen.

Interim results of the Stanley Grange Medieval Iron Project

Dr. Patrice de Rijk

The University of Nottingham

In 1997 Trent and Peak Archaeological Trust excavated an extensive iron production site at Stanley Grange, Derbyshire. The excavations revealed the remains of at least seven furnaces with associated areas for clay extraction and ore dressing. The site was dated to the 13th century AD. In 2008 a detail post-excavation study was initiated funded by the Marie Curie Foundation. The aim of the project was to study the technical and socio-economical aspects of the iron industry at Stanley Grange set within a European framework.

The site is situated at the southern edge of a Carboniferous horst, which partly consists of Pennine Lower Coal Measures. This coal belt supplied a good source of coal, clay and ironstone nodules that were readily available at the surface. Nowadays hardly any ironstone is found here as the sources near the surface were the first to be exploited. In the 13th century the area around Stanley Grange was a semi-open landscape made up of woods, arable land and settlements. Besides the mining and production of iron, industrial activities including the mining and quarrying of coal and lime took place in this area as the oft-quoted objection of Queen Eleanor of Provence to the offensive smoke of coal in Nottingham in 1257 shows.

Shallow, bell shaped pits found during the excavation point to clay extraction for the construction of furnaces and/or the extraction of ironstone. In addition, local sandstone was used as reinforcement around the base of the furnace. The furnace remains are horse-shoe shaped with their mouth directed west to southwest. The slag ran into a shallow pit in front of the furnace via a narrow channel with steep sides. It was tapped repeatedly from the furnace forming layered slag with horizontal flowing structures. The first slag that solidified was usually dense whereas slag that solidified on top of this mostly was vesicular. Furthermore, frothy slag, often with glassy breaks was found. Hardly any gromps have been retrieved but many charcoal-rich pieces and iron stone concreted by iron oxide from the base of the furnace may point to the leaching of the now oxidised iron. The optical analysis of the slag suggests that an evolved stage of low bloomery technology was used at Stanley Grange.

The 13th century in Britain was a period of entrepreneurial activity associated with an increase in population. Both factors promoted the iron industry: more iron was needed for more people and for large building projects. The furnaces found at Stanley Grange fit well into this picture. They are silent witnesses of the desire to increase the iron output per furnace and the amount of iron in general.

Experimental Ironmaking in the 1720s

Dr Peter King

Independent Researcher

Making iron without charcoal was a long-sought objective. Abraham Darby made coke pig iron (though only for foundry use) from 1709, but not bar iron. The first successful bar iron process was devised by Roger Woodhouse and Thomas Tomkyns in 1722, but Tomkyns' imprisonment as a crown debtor hindered progress. The process (patented in 1723) was demonstrated at Nine Elms in Surrey in summer 1726. After this works were set up at Oakamoor in Cheadle, Staffordshire and 40 tons of iron was made there. Then the stock was apparently exhausted.

When William Wood (who had a rival – but ineffective – patented process) sought a charter of incorporation, Tomkyns and his friends opposed this, seeking a charter for themselves. The process was then in use at the copper and brass works at Taplow, near Maidenhead. The process apparently merely consisted of melting pig iron in a clean air furnace. According to the manager, the works could make five tons of iron per week from nine tons of pig iron. This is a poor yield compared to the charcoal finery process, where 1.3-1.4 tons of pig iron were needed for a ton of bar (not 1.8 tons). However the total cost of only £12.85 per ton product meant that the process was profitable, as English iron sold for £16 per ton.

Tomkyns was allowed to compound for his debts in 1732. Four 'Parliament men' financed works being set up in Gloucestershire. The presence of Tomkyns' associate William Goostrey among the partners who leased two of the Lydney forges in 1733 points to the precise location. The project however miscarried by 1736. According to one account, this was because they laid out all their money building 12 furnaces and great quantities of pig iron to make a show and raise a bubble. According to another, the process became unprofitable due to the low price of iron, because bar iron was so cheap. This was, in turn, the result of the great amounts imported.

Many years later, on hearing of the Cranage brothers' patent, William Wood's son Charles wrote of the process, which he regarded as the same as theirs, that good iron was made, but in small quantities and with great waste. The hammermen at Oakamoor had also like the iron mightily, and would rather draw it than any finery iron they ever worked in their lives.

Steel Blades: Made in Sheffield, 1624-1924

Dr Joan Unwin

The Company of Cutlers in Hallamshire

In 1624, a parliamentary Act of Incorporation established the Company of Cutlers in Hallamshire. Its purpose was to give structure to the cutlery industry centred on Sheffield and to give the Company the authority to enforce its rules. Although the Company focused on the cutlery trades, it gradually became involved in the steel trades, which eventually overshadowed the original core trades. Because one important criterion in the 1624 Act stated that all blades must have an edge of steel, the Cutlers' Company strove to maintain the quality standard of steel-edged blades; to provide reasonably priced steel through its storehouse in the 1680s and from its own cementation furnace in the 1750s.

As Sheffield steelmen developed manufacturing methods and increased their output, a growing number of people were outside the control of the Cutlers' Company, as not qualifying for Freedoms based on servitude. The steelmen and edgetool manufacturers were able to apply for their Freedom when the 1860 Act changed the requirements. In the following decades, internationally important steel manufacturers, such as John Brown, Charles Cammell and Edward Vickers became members of the Company and eclipsed the traditional cutlers. As Sheffield's steel and steel products carried the name of Sheffield around the world, the Company continued its traditional role of registering and attempting to protect the trademarks of manufacturers. False marking of goods to suggest quality or place of manufacture became a worldwide issue and the Company eventually achieved the certification mark of 'Sheffield'.

This poster will review the potential of three centuries of data within the Cutlers' Company's archives relating to the use and manufacture of steel in Sheffield, from its mercantile efforts to sell steel at cost, to the publicity afforded by visits of government ministers to the huge steel factories and ending with the introduction of stainless steel, described in the letters of its developer, Harry Brearley.

Packaging the iron industry: Is the technological package a useful concept?

David Cranstone
Cranstone Consultants

The paper will view the development of British ironmaking, from the Iron Age to the mid 19th century, as a sequence of four or five 'technological packages'

- Direct production of wrought iron by bloomery smelting coupled with manual hammer forging
- (Direct production of wrought iron in the water-powered bloomery coupled with water-powered hammer forging) – the status as a 'package' is perhaps borderline
- Indirect production of wrought iron using the charcoal blast furnace coupled with decarburisation in the finery and water-powered hammer forging
- Indirect production of wrought iron using the coke blast furnace coupled with decarburisation in the puddling furnace and steam-powered rolling
- Production of mild steel using the coke blast furnace feeding directly into the Bessemer converter or open hearth

Clearly this model is simplistic, but it appears empirically to have at least descriptive value; even at this level, it highlights an alternation between periods of relative stability (the 'classic' bloomery, charcoal-furnace and coke-furnace periods on which research has normally concentrated.), and periods of instability and rapid change between 'packages', which perhaps offer the most interesting research questions for the future.

More fundamentally, and very tentatively, it has some similarities to the models of 'punctuated evolution' developed by Stephen Jay Gould and others; does the concept of 'technological packages' have the potential to rise beyond the descriptive and open up a 'Gouldian' evolutionary archaeology at the species level, with more to offer than the Dawkinsian 'meme hypothesis'?

Craft specialisation and the manufacture and use of iron knives in Viking Dublin, Ireland

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The metallographic study of the knives from Viking Dublin is one of the most extensive and important studies of knives from a single period of settlement to be carried out to date. Other large studies of iron knives like those at Anglo-Scandinavian York and Novgorod, have sampled knives from well stratified contexts providing an excellent indication of how knife manufacture changed over time, but these studies concentrated on specific areas of excavation and therefore may not represent the entire settlement. Many of the Dublin knives are dated to the 10th-11th century but come from sites across the city, these different sites have revealed evidence that different craft activities were taking place. Therefore this study represents the first attempt to determine whether knife shape, manufacture and quality are linked to function, providing valuable information about craft specialisation and standardisation in Viking Dublin, which can then be compared and applied to other large urban centres in the Early Medieval period.

Very few studies have been carried out on Irish artefacts dated to the 10th-11th century AD, therefore this study is particularly important and will compliment previous work carried out on the iron from the earlier periods in Ireland. Not only is the study valuable to Irish archaeological knowledge but it also assists in the interpretation of other Viking and North Atlantic urban sites, such as York, UK and also provides a comparison for Novgorod, Russia and other European sites. Analysis of knives from Novgorod and York revealed a change in preference from butt-welded knives to 'sandwich' knives, occurring some time in the 9th-11th century. Therefore this extensive study of knives from Dublin may be able to throw new light on these apparent differences and periods of change.

Carbon Control prior to Bessemer

Arne Espelund

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For good reason, modern iron and steelmaking takes place in two consecutive processes: reduction to liquid pig iron in the blast furnace, in the presence of incandescent carbon, followed by refining in a refractory converter by means of inblown oxygen. The method reflects basic properties of the metal, above all the solubility of carbon in the metal, shown in the Fe-C-diagram.

Bloomery iron was produced as a solid at a temperature of some 1100°C, at which the saturation of carbon lies at some 2% C. This metal is brittle and cannot be forged. The desired low-carbon iron required some kind of control. This is particularly demanding as carbon as charcoal is present in order to secure a high temperature. In the presentation some 4 methods will be outlined. Carbon by means of slag control, according to the chemical equilibrium $\text{FeO} + \underline{\text{C}} = \text{Fe} + \text{CO}$ is indispensable.

In the presentation the author will refer mainly to furnace types found in Norway.

In the so-called Evenstad process (III), in operation from about AD 1400 to 1800, some roasted ore was added at a late stage, leading to slag formation and removal of carbon from the primary, carbon-rich metal. The method is step-wise, taking place in one and the same furnace.

For the “medieval” process II both theory and finds indicate that a two-step process was used. By a certain pre-reduction fresh or roasted bog iron ore was transformed from Fe_2O_3 and SiO_2 to a mixture of free FeO and silicate Fe_2SiO_4 . From this semi-product good iron was obtained in a second process by reduction of FeO in the presence of the silicate fayalite.

The carbon control in the Roman age furnace I was achieved by an intermittent activation of a FeO-rich zone next to the hot zone with slag and metal, as outlined in the other lecture. The method reminds of the Catalan process, used until about 1850 in the Pyrenees – Basque country. It is here named volume-zone control.

In the history of metallurgy also the puddling process developed by Cort is remarkable. A low-carbon iron was obtained by separating the grate with burning charcoal or coke from the pig iron, which was exposed to an atmosphere of flue gases, consisting of N_2 , CO_2 and also a little CO.

One of the remaining challenges is to propose a process for the pre-reduction of bog ore to the semiproduct of process II. It seems to have been achieved in the same type of furnace.

Some analytical observations and the origin of spheroidal hammerscale

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The broad context of the generation of both flake and spheroidal hammerscale is reasonably well understood. The more detailed origin of the melt forming spheroidal hammerscale is more controversial. Recent studies (Dungworth & Wilkes 2009) have provided evidence for a significant contribution to the chemical composition of spheroidal hammerscale from the slag inclusions present in the iron. This paper explores some of the other potential inputs to this material. The database of described hammerscale assemblages is small, but highlights the variability of smithing microresidues.

An example from a charcoal-fuelled hearth from early medieval Ireland shows relatively silicate-rich micro-residues at all but the finest grain sizes. Silicate melts generated from the tuyère tip are likely to be the dominant source of this material, although use of a silica-rich smithing flux cannot be ruled out. It is possible that the smith has actively encouraged the melt onto the workpiece in this instance. In contrast, hammerscale from a Romano-British smithy from South Wales and from a post-medieval forge in Bristol, both coal-fuelled, shows strong influence from the coal-ash. The high ash content of coal compared with charcoal means that direct contamination of the workpiece surface from the fuel is commonplace.

An example of 19th century spheroidal hammerscale from the shingling of puddled iron from Maesteg, South Wales, shows a chemical composition, microstructure and mineralogy that is quite distinct from the smithing residues. In this instance, expulsion of the large volume of entrained puddling slag gives rise to large quantities of these characteristic spheroids.

The spheroidal hammerscale from smithing commonly shows a close relationship with flake hammerscale. In some samples the majority of spheroidal particles include fragments of flake hammerscale into their marginal oxide crust.

Some of the spheroidal particles associated with the hammerscale are simply droplets of melt that have cooled in the hearth. These fuel ash droplets are particularly common in coal-fuelled contexts, but may occur in other, including non-metallurgical, settings. Iron-rich spheroidal particles have been recovered in significant concentrations from a peat-fuelled corn-drying kiln (Bornais, S. Uist). The identification of iron-rich magnetic spheroids does not automatically imply spheroidal hammerscale.

Hammerscale: high speed digital video and scanning electron microscope

David Dungworth

English Heritage

Ironworking generates a number of different types of residues (slag) which are diagnostic of particular processes. The forging (smithing) of iron at high temperatures is known to generate 'micro-slags' called hammerscale. Microscopic examination of hammerscale has shown that there are two principal forms: flake and sphere (Unglik 1991). The flake hammerscale is well understood: it is simply the oxidised surface of the iron. The spheres, however, are less well understood but it is usually assumed that they formed during fire-welding of iron. In order to test this theory we have carried out a detailed research programme. This has included the examination of cross-sections through flake and sphere hammerscale and the determination of chemical composition (using an X-ray spectrometer attached to a scanning electron microscope) for archaeological specimens and samples created experimentally. The experimental smithing took place under controlled conditions which allowed us to determine the proportions of flake and sphere generated by different smithing processes (essentially smithing and fire-welding). In addition, the moment of fire-welding was recorded using a high-speed digital video camera which showed the formation and movement of different types of hammerscale.

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Iron Cupola Furnaces in China and Europe

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Cupola furnaces for melting iron were used in China from about the 5th century BC, and in Europe from perhaps the 13th century AD, and continued to be the primary means of casting iron until the middle of the 20th century. The poster will present illustrations and descriptions of Chinese and European iron cupola furnaces, showing some of the considerations involved in their development.

Investigating the Effects of Phosphorus on the Iron Microstructure and its Implications on the Identification of the Alloy in Archaeological Artefacts

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This research project examined the iron alloys in use within Early Medieval England and their implications for the development of specialized smelting and smithing technologies. One such alloy, found in far higher quantities than expected, was phosphoric iron. Phosphoric iron is term coined by archaeometallurgists to generally describe a very “low” carbon iron (<0.1%C) with a relatively “high” phosphorus content (0.1-1%P). In previous studies (Tylecote & Gilmour 1986; McDonnell 1989; Chen *et al.* 2003 *pers. comm.* 24-26 September 2003; Godfrey *et al.* 2003) this alloy has been routinely identified through its microstructural characteristics, most notably the presence of “ghosting” after etching in Nital (2 or 4% Nitric Acid in alcohol), and/or increased grain size (often ASTM 1), as well as an increased hardness (in excess of 150 Hv_{0.1} compared to c 120Hv_{0.1} for ferrite). The role and significance of phosphorus in iron is poorly understood. One significant property of the alloy is its impedance of carbon diffusion (Suzuki *et al.* 1983 *pers. comm.* July 14, 1983; Vallbona 1997; Stewart *et al.* 2000 *pers. comm.* March 2002), hence its role in preserving carbon content in steel components of pattern-welded artefacts (Vallbona 1997).

The current understanding of phosphoric iron shall be challenged by this project. Over one hundred artefacts have been analysed utilizing metallographic analysis in the un-etched and etched condition, grain size measurements, and micro-hardness tests. These investigations were supported by the SEM-EDS analyses of all microstructures and EPMA analysis of selected samples. The results of this regime have demonstrated that the previous identifying features of phosphoric iron, such as ghosting, large grain size, and increased hardness are insufficient to characterise and distinguish phosphoric iron from ferritic iron. Ultimately, the resultant data indicates that a reassessment of the traditional archaeological definition of phosphoric iron is necessary, and the means by which it should be identified re-examined.

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**Reconstructing the blacksmithing landscape:
Results from a comprehensive and integrated analytical program**

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Abstract

The iron smith was one of the most important trades in antiquity and was essential to the Early Medieval settlements, be they rural or urban. Excavation of the smithy workshop and the analysis of the resulting assemblage provides archaeologists and archaeometallurgists with the best chance to understand more about this important trade, thus increasing our knowledge about ancient iron consumption and therefore the iron economy in that period. Often the assemblage is split up and sent to the relevant specialists, i.e. slag to the archaeometallurgists, artefacts to the artefact typologists and pots to the pot experts. We instead argue that only through comprehensive analysis of the entire assemblage will the whole picture to be revealed.

This poster re-interprets all the evidence from the smithy at Wharram Percy, East Yorkshire UK, in a more holistic way, setting the smithy in its landscape and considers how it functioned. In addition three generic ironworking landscape models are proposed, all of which can be applied to any site, in any period.

- 1) Self sufficient model; where a site smelts and produces all the iron it needs to produce its own tools
- 2) Complex smithy model; where stock iron is imported into the site to produce any tools required
- 3) Basic smithy model; where the tools themselves are imported and the smithy only repairs or recycles these using whatever materials are available

Combined metallographic analysis of iron artefacts and archaeometallurgical analysis of the slag, as well as a detailed examination of the entire smithing assemblage revealed that the Wharram smithy fitted mostly with model 2. This evidence also allows us to suggest the skill of the Wharram Percy smithy. This poster most importantly demonstrates the potential of integrated archaeometallurgical and artefact research.

A geochemical investigation towards discriminating between lava and ironworking slags from Iceland.

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A sample of Icelandic lava from Budir on the south coast of the Snaefellsness Penninsula (SW Iceland) was compared with examples of three different morphologies of ironworking slags recovered from archaeological excavations at Hofstaðir in Mývatn, NE Iceland. Morphologically the lava has a strong similarity to iron working slag classified as 'flowed slag' and has a similar density. This raises an important question of distinguishing between these two materials, one natural and the other man-made, on archaeological sites in Iceland as it will have significant implications.

To begin to address this, two different approaches were utilised to characterise the lava and slag samples: geochemical analysis via Scanning Electron Microscopy (SEM) and a suite of magnetic measurements. The aim of the SEM analysis was to provide compositional data for comparison with ironworking slags. The results show that when compared to iron working slags, the lava is enhanced in: MgO, Al₂O₃, SiO₂, CaO and TiO₂, and is depleted in FeO.

The most efficient magnetic parameters for characterisation studies are the intensity of natural remanent magnetisation (NRM) and the bulk magnetic susceptibility. The results of the magnetic analyses indicate that the slag and lava samples hold a strong and stable remanence, probably due to the presence of high proportion of fine grained magnetite within their matrices. All three types of slag and the lava sample investigated here presented similar magnetic properties so discriminating between slag and lava will require more detailed analysis. However, the magnetic mineralogy of slags may record details that can be used to reconstruct furnace and hearth operating procedures.

Craft Specialisation in Iron Age Orkney

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This poster presents the results of an intensive geochemical and magnetic susceptibility survey undertaken in an Iron Age structure at the site of Mine Howe, Orkney, UK. The aim of this research was to make a contribution to the understanding of function within a structure classified as a workshop from the archaeological evidence. The analysis used three different methodologies: magnetic susceptibility, soil phosphate and inorganic element analysis via X-Ray Florescence (XRF). The results were integrated and the resultant distribution plots provided compelling evidence of distinct activity areas within the structure. In particular the elemental evidence suggests that both copper and iron alloys were worked at this location.

Cementation Steelmaking 'Slags'

Rod Mackenzie

It has often been assumed that, apart from fuel ash slags, there are no diagnostic slag-like residues associated with cementation steelmaking. However, excavations of several furnaces in Sheffield have produced characteristic residues from the inner surfaces of cementation chests.

My research aims to characterise these residues and if possible to compare to chest linings from other countries/regions to see if they are the result of local practice or diagnostic of the cementation process.

Kilns: Chopwood or Potash

Janis Heward

Chopwood kilns also known as kilnwood or whitecoal kilns were generally stone-lined pits built into banking and surrounded by low stone walling with a gap, but so were potash kilns! Now all that remains are mounds of stone covered with turf.

What were the differences and how can we differentiate between them?

Chopwood Kilns

Janis Heward

Chopwood kilns were built to produce whitecoal - the fuel for lead smelt mills using the ore hearth process from the mid16th to late 17th century. Chopwood – coppiced wood which was stacked on a grid of wooden baulks, balanced on the top of a low stone wall surrounding a stone lined pit with a fire in the base. There is a great deal of interest in mining and smelting but the production of the fuel is rarely considered.

200 chopwood kilns are reputed to be located in and around the Yorkshire Dales - what did they look like and how did they operate?

The Gresham shipwreck: An archaeometallurgical investigation into the Iron bars

Thomas Birch

Institute of Archaeology, UCL

In 2003 'The Gresham Ship' was salvaged from the Thames estuary, together with some forty iron bars, as well as lead and tin ingots and other artefacts. The wreck has been identified as an armed merchant ship built from English oak that was felled around 1574 (Wessex Archaeology 2004, Auer & Frith 2007). At least four guns were also recovered including one bearing a grasshopper motif and the initials 'TG', the mark of Sir Thomas Gresham, a well established Tudor merchant with royal connections. It is thought that the ship was sailing fully-laden outbound from London or the River Medway. However, this is yet to be confirmed. With some doubt and concern of over the future conservation and storage of the iron bars, the importance of their study cannot be underestimated. This poster summarises the results from such an analytical study.

Iron Technology in peninsular Thailand: evidence from 2nd century BC sites at Khaeo Sam Keao and Phu Khao Thong.

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Various craft productions documented at Khaeo Sam Keao (2nd Century BC), beads, glass, and copper show evidence of foreign influence from China and India. This study examines the material relating to iron technology, including artefacts from a similar site at Phu Khao Thong, being the first such study of iron technology in peninsular SEA. Slag from smithing and iron artefacts were analysed using optical microscopy, scanning electron microscopy with energy dispersive spectrometry (SEM-EDS), energy dispersive x-ray fluorescence (ED-XRF), standard metallographic techniques and slag inclusions analysis. While confirming the previous lack of evidence for metal smelting at the site, the study attests smithing activities using simple forging techniques, utilising metal from multiple sources. More sophisticated techniques extant in China and India at the time are not evidenced in the securely dated artefacts, but can be seen amongst others, some of which are almost certainly modern. Inconclusive attempts to distinguish between iron production methods by slag inclusion analysis highlight the need for further work on cast iron slag compositions. This study will allow integration of iron technology into the KSK project considerations of trans-Asiatic trade networks and provides a valuable source of comparative data for when iron smelting sites are found in the region.

Lead in Iron Age in Iberian Peninsula: Use and Practical Applications

Núria Morell Cortés

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Among the Iron Age societies of eastern Iberian Peninsula (the Iberians) there are quite a few examples of spaces, structures, instruments and slags associated with the lead metallurgy and fabrication. Moreover, the studied area (north-eastern Iberian Peninsula) is far from the main mining districts where the extraction of silver by cupellation took place (an activity that implies the manipulation of great amounts of lead). This is the reason why I have attempted to approach this metallurgy mainly through the elaborated objects or pieces of metal, following two principal lines of work:

- the evaluation and comparison (chronological, geographical) of the lead percentages in copper based alloys (analyses of elementary composition, ED-FRX). Bronze is possibly the most widespread application of lead during the pre-Roman period.
- the study and quantification of the metallic lead remains (drops, scraps, ingots, bars or any semi-elaborated or finished object), coming from an archaeological context.

In the quantitative comparison of the use of lead, I have noticed important geographical and chronological differences, which are evaluated in relation to the different roles and hierarchies of settlements, the proximity/distance of trading ports and commercial and producing centres.

In general, it can be said that among the northern Iberian societies, lead was very rarely used as an independent metal. Until the end of the 3rd century BCE, the fragments interpreted as ingots and metal in reserve, as well as droplets and scraps, predominate; however, a real diversification concerning the use of lead only becomes noticeable when the Iberian territories are incorporated to the Roman rule, even though many of these uses were already known by the Iberian societies as a result of their previous contacts with different colonial elements (Greek and Punic).

Beyond deposition: Workshop strategies and non-ferrous metal-working on Gotland in the early middle ages.

Ny Björn Gustafsson

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Gotland is the largest island of modern-day Sweden, situated in the Baltic Sea 90 Km (56 miles) east of the mainland. The island is made up by sedimentary rock (mainly lime- & sandstone) and no worthwhile ore deposits – with the exception of bog iron– are to be found. Despite this Gotland formed a centre for a rich and dynamic non-ferrous metal production all through the Scandinavian Iron Age and early medieval period. The emphasis lay on a wide array of indigenous jewellery but it is evident that the Gotlanders also produced items typical for their neighbouring areas.

Viking period Gotland has been a focal point for archaeological research since the 19th Century. Several scholars have examined and presented various cultural features, and since Gotland's material culture differs from that of mainland Scandinavia a lot of effort has been invested in examining cultural markers, such as dress accessories. Accordingly Animal-head brooches (swe: *djurhuvudformiga spännen*) and Box brooches (swe: *dosformiga spännen*) can serve as examples of find-groups which have been painstakingly examined, interpreted and published. In both cases a lot of effort has been put into identifying depositional patterns which is then used to identify possible production areas on the island. The abundant silver hoards that are regularly rediscovered are another focus for research. The imminent threat of metal detector-aided plundering of the hoard-sites has led to systematic re-surveying of them. These campaigns have not only resulted in the recovery of coins and other items of precious metals, but also in the collecting of a wealth of more normal everyday artefacts. At some localities the rate of craft-specific finds is very high, indicating that more or less organized metal working has taken place. Such crafts-indicating finds are for example slag, sprues, smelts, shards of metal-induced crucibles and technical ceramics.

The here presented surveys aim to go *beyond* deposition since it is evident that an object by no means need to have been *produced* where it was later *deposited*, and later still recovered. This will eventually be done by applying an overlay analysis drawing from the results from several studies. One focuses on workshops, i.e. where they are to be found in the geographical and social landscape. A second on the crafts performed in the hitherto identified workshops and if these differ between the localities. A third study uses tool marks as a means to find the produce of individual workshops, i.e. an artisan is likely to have used the same tools for a series of objects, tools which leave more or less identical marks on the objects. A fourth study tries to identify the artisans themselves via Trace elements analysis based on the hypothesis that low-technical metalwork exposes the persons involved for increased levels of certain elements. Hence a number of individuals from inhumations, some with and others without smithing related tools, have been sampled to determine the amount of for example lead present in the bones.

When combined these results will hopefully broaden the picture of Gotlandic metal crafts and, at least to some extent, answer who partook in it, how it was organized and how new influences and goods spread in the Baltic Sea-area

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