

# THE ARCHAEOMETALLURGY OF IRON

Recent Developments in Archaeological and Scientific Research



Edited by Jiří Hošek, Henry Cleere & Ľubomír Mihok  
Institute of Archaeology of the ASCR, Prague, v.v.i. | Prague 2011

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Recent Developments in Archaeological and Scientific  
Research

Dedicated to Professor  
Radomír Pleiner

Edited by  
Jiří Hošek, Henry Cleere and Lubomír Mihok

The book was printed with the support of the Academy of Science of the Czech Republic

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Published by the Institute of Archaeology of the ASCR, Prague, v. v. i.  
Letenská 4, 118 01 Praha 1, Czech Republic

Editors: Jiří Hošek, Henry Cleere and Ľubomír Mihok

Copy editor: Petr Meduna

Setting: Johana Brokešová

Cover: Jiří Hošek

Printed by Helvetica & Tempora, s. r. o.,

Pod kaštany 246/8, 160 00 Praha 6

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and the Authors, 2011

**ISBN 978-80-87365-41-0**

Available at: Archeologický ústav AV ČR, Praha, v. v. i.

Letenská 4, 118 01 Praha 1, Česká republika

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**Radomír Pleiner: the magister ferrariarum at 80**

*Henry Cleere*

Radomír Pleiner was a *rara avis* in the early 1960s when we first met. In those days I was working as an editor at the Iron and Steel Institute in London, but I had already become deeply interested in archaeology and had begun studying the subject in my spare time at the London University Institute of Archaeology (now part of University College London). At the suggestion of the then Director of the Institute, Professor W F (Peter) Grimes, I decided to look in depth at the iron industry of protohistoric and Roman Britain. However, I found the literature on early ironmaking was very sparse and so I consulted the late Ronnie Tylecote at Newcastle University. He told me that I should read the work of an archaeologist named Pleiner at the Archaeological Institute in Prague, one of the very few archaeologists working on this neglected field.

When I represented the Iron and Steel Institute at a conference organized by the UN Industrial Development Organization in Prague in 1963 I took the opportunity to seek out Radomír, who invited me to his remarkable office/laboratory in the Letenská basement. Our first expedition together was to look at slag that had been discovered during roadworks in a small Bohemian town, and from there we went to visit his wife's important excavations at Březno. This marked the beginning of a fruitful collaboration and a friendship that has lasted to the present day.

We next met in Prague at the 7th Congress of the International Union of Prehistoric and Protohistoric Sciences (IUPPS/UISPP) in 1966, which saw the birth of the *Comité pour la sidérurgie ancienne* (Ancient Iron-making Committee). Radomír's energetic and enthusiastic secretaryship of this remarkable international group ever since its creation has made an immense contribution to our understanding of this neglected field of research and fieldwork, once relegated to a secondary role and largely the province of metallurgists and local archaeological amateurs. Its birth was celebrated in great style by a party at Radomír and Ivana's apartment, which brought together veterans such as Kazimierz Bielenin, Elżbieta Nosek, and Ronnie and Liz Tylecote. At this delightful occasion the new Committee launched what has become a tradition – that of singing songs from many countries (often to the accompaniment of Rado's guitar).

Radomír was born on 26 April 1929: his father Vladimír was a Czech painter and member of the famous Czech Legion, his mother originated

## A new perspective on the ancient slag-pit bloomery smelting furnace

*K. Bielenin*

*The ancient slag-pit smelting furnace is a fundamental component of the metallurgical technology used in the ancient Europe outside the boundaries of the Roman Empire. The main element of this furnace, which survived for many centuries and is the basic source of research, is the slag block – a waste product which settled in the lower part of the furnace, known as the slag pit.*

*Using this furnace the smelter made an important advance which had a great impact on the following centuries. This consisted in transferring slag from the reduction zone of the furnace into the specially prepared pit (Fig. 3: a, b, c). As a result the ancient master could separate slag from the iron bloom as it collected and obtain a piece of iron ready to be forged.*

*The highlighted elements on the surface of the slag block include the elements subject to unimpeded solidification (Fig. 4). These elements provide evidence of the metallic iron zone, free of slag, in this furnace. Furthermore, the resulting product was not a conglomerate of slag and iron, as was the case of the experimental research, but a deslagged iron bloom typical of a furnace from which the slag is tapped. The iron bloom from the bloomery furnace did not require the so called post-reduction stage as it has been assumed so far.*

*The results presented here, which stem from the analysis of the surface of the unimpeded solidification on the slag block, and a new perspective on the bloomery furnace, are currently subject to verification and metallurgical research at the AGH University of Science and Technology in Kraków.*

Smelting furnace - Slag-pit bloomery furnace - Bloomery process

## Introduction

The ancient slag-pit bloomery shaft furnace and the metallurgical process involved were first studied at the beginning of the 1950s by Zespół Historii Polskiej Techniki Hutniczej [the Study Team for the History of Polish Metallurgical Technology] under the leadership of Professor Mieczysław



## The canal-pit and its role in the bloomery process: the example of the Przeworsk culture furnaces in the Polish territories

*S. Orzechowski*

*Some bloomery slag-pit furnaces in the Przeworsk culture area exhibit various types of side canal connecting the ground surface with the pit. These are the remains of devices to support the blowing system of the bloomery furnace, located in its shaft part. Several types of these devices were identified, ranging from a simple widening of the side of the pit to regular bow-shaped canals. The devices were not widely used, though in some regions (particularly Mazovia) 10–15% of the furnaces were equipped with them at various times. It has been assumed that such canals facilitated drying the pit and enhanced the draft only at the initial stage of the smelting process. However, numerous bloomery furnaces from Mazovia and the Świętokrzyskie Mountains region indicate that their role did not end at that stage and that they could have facilitated operation of the furnace during the whole smelting process.*

Archaeology - Ancient metallurgy - Przeworsk culture - Slag-pit furnace - Canal-pit -  
Bloomery process

### Introduction

Slag-pit furnaces used by the peoples inhabiting the central and northern Europe at the end of antiquity played a role that is impossible to overestimate in the history of those regions (Bielenin 1973, 1992; Pleiner 2000, 45–47, 149–63; 2006). This unique technological and cultural phenomenon constituted the basis for iron production for over half a millennium, in many regions showing astonishing stability of form and the solutions applied. Huge metal-producing centres which, during that period, existed in the Polish territories within one of the greatest and longest-lasting cultural creations of barbarian Europe, known in archaeology as the Przeworsk culture, were based almost solely on that type of furnace (Orzechowski, 2007a).

The slag-pit furnace still remains a mystery for science and poses serious problems in the correct reconstruction of the smelting process involved.

## The oldest iron smelting furnaces in Denmark

*A. Jouttijärvi and O. Voss*

*The oldest Danish iron smelting furnace (Fig. 14) was excavated in 1966 at Skovmark, North Jutland, and radiocarbon-dated to 90–110 AD. It opened at the bottom into a working pit. In 1986 another furnace of the same type was excavated at Espevej, West Zealand, together with separate clay tuyères that were not found in situ. A reconstruction of this furnace was published (Fig. 18). The tuyère plate was placed close to the bottom of the furnace with an opening below it for removal of the slag. In this paper a new reconstruction is presented (Fig. 17) based on the excavation of a Skovmark furnace at Sønder Holsted, South Jutland, in 2000. It is our theory that the origin of the Skovmark furnace can be traced back to the South German furnaces from the La Tène period.*

Iron smelting furnace - Reconstruction - Denmark - Pre-Roman Iron Age - Tuyère plates -  
Radiocarbon date

### Introduction

The slag-pit furnaces in Denmark were, according to radiocarbon dates, in use from 140 to 610 AD, but prior to that time there were a group of older furnaces. The first of those (Fig. 14 /Plate VI/) was excavated in 1966 in North Jutland at a site called Skovmarken, not far from Aalborg, and it has been radiocarbon-dated to 90–110. These Skovmark furnaces from the Late Pre-Roman and Early Roman Iron Age are all found connected to settlements. In most cases, only 10–15cm of the bottom part of the furnaces are left. They usually contain only a small amount of slag, which often makes it difficult to recognize it as a part of an iron-smelting furnace.

Since 1966, about twenty sites with Skovmark furnaces have been found in Denmark. In 2000 at Sønder Holsted in the southern part of Jutland, we had the opportunity to excavate three more of these furnaces. One was partly destroyed because the pit had been dug into it and had taken away one side of the furnace (Fig. 15 /Plate VI/, photo and plan). In this secondary pit, an important fragment of the furnace was found; it

## Archaeometallurgy in Hungary: some results and questions

*J. Gömöri*

*Newly discovered Avar iron production centres were excavated in the large areas of motorway construction in Transdanubia. There are two important periods of iron production in this part of Pannonia: the earlier one is connected with the middle and late periods of the Avar Empire, from the 7th to 8th centuries AD up to the Carolingian period in the 9th century. The later period began with the founding of the Hungarian state in the 10th century. Up to the present two sites where furnaces were found from both periods are known. The first result of the most recent archaeometallurgical research is that Avar ironmaking was more significant in Pannonia than previously thought. These extensive centres of iron production and smithing (possibly of weapons) may have been directly in the zone in which the Avars came together, to organize campaign against Byzantium on the line of the main Roman roads. A further question relates to the origins of Pannonian Avar iron metallurgy. Our present knowledge suggests that iron production has no local antecedents from the Roman period. One of the results of the new excavations is correction of dating of the supposed Roman age furnace at Sopron to the 11th–12th century.*

Pannonia - Roman period - Avar - Iron production - Bloomeries - Tuyères

### New results from south of Lake Balaton

Some new discovered Avar iron production centres were excavated in Somogy County by the Somogy County Museum, with Zsolt Gallina as the director of the excavation. Only short preliminary reports have been published of this research, carried out on the plains of the Zamárdi-Kútvolgy (Gallina, Hornok & Somogyi 2007) and Kaposvár-Fészerlak-puszta sites (Gallina 2002).

In 1986–87 the first professional archaeometallurgical excavation in Somogy County was carried out at the village of Zamárdi (Gömöri 2000), close to the southern shore of Lake Balaton, which resulted in the discovery of an important iron-producing centre from the late Avar period. Remains of two furnaces and eleven roasting pits or the bases of charcoal-burning

## Some aspects of the development of Great Moravian iron metallurgy

*V. Souchopová, J. Merta and O. Merta*

*This paper introduces some of the findings of the latest stage of intentional research on the metallurgy of iron in the central part of the Moravian Karst, which began in the sixties of the last century. It includes a brief history of the project, identification and dating of the types of furnaces and ironworks, details of their distribution in space and time, and the method of their control. There has been progress on the question of the status of the mining-smelting district which, despite its geographical location, has in terms of total extent and work productivity and specialized production features, being assigned to Great Moravian power centres. Production and distribution of iron in this important pre-industrial area were presumably controlled by one of the Moravian centres, and the community of smelters most likely ranked among servants (familia) belonging to one of the noblemen of the time.*

Moravian Karst - Metallurgy of iron - Bloomery - Space-time dislocation - Ducal family (familia) - Early medieval

### Introduction

At the present time a summary and complete appraisal of the results of archaeological excavations of bloomeries in mining districts in the central part of Moravský kras (the Moravian Karst) from the 8th–11th centuries is being carried out. This paper outlines some of the knowledge that has been gained.

Right from the beginning, from the 1960s, research work was carried out as a part of a planned long-term project of archaeological excavation of bloomeries on the outskirts of Blansko. At that time it was announced that bloomery slags had been found in two different locations in the ore-bearing central part of the Moravian Karst (Souchopová 1970, 15–23). That alerted us to the possibility of gaining a certain amount of knowledge to complement earlier knowledge, with the help of archaeological excavations in more bloomery locations. The remains of old ironworks

## Norway as a bloomery iron producer

### *A. Espelund*

*Archaeometallurgical studies of bloomery sites in Norway since about 1982, greatly aided by the  $^{14}\text{C}$ -method, have led to a new picture of this activity. A large shaft furnace with a slag pit was in use from about 300 BCE to 600 AD, the smaller shaft furnace with side tapping from about 700–1300, and the most recent – a dug-in furnace with no tapping of slag – from 1400 to 1800. The use of induced draft during the first period created by direct insertion of wood and a transformation to charcoal in the furnace represents a striking alternative to the conventional picture of an operation requiring charcoal and bellows. The changes of technology some time between 600 and 800 as well as around 1300–1400 raise challenging questions. The author is heavily involved in a study of the carbon control in all three types of processes, not to be dealt with in the present paper. They can tentatively be classified by volume-zone control, a two-step process and time control.*

Mid-Norway - Metallurgy - Bloomery ironmaking - Three periods - Slag control

## Introduction

Three major impulses have given impetus to the study of early iron-making in Norway:

- a) the introduction of the radiocarbon ( $^{14}\text{C}$ ) method for dating of both charcoal from slag heaps and also objects of iron and steel containing a minimum of carbon.
- b) the lasting inspiration to the study of the archaeometallurgy of iron by Radomír Pleiner and his group in the Comité pour la sidérurgie ancienne.
- c) the involvement of extractive metallurgy with roots in physical chemistry as a supplement to archaeology, for both laboratory studies and process analysis.

In Norway bloomery iron was made from bog iron ore during three periods with booms around the years 200, 1100, and 1600. Each period is characterized by a specific type of process, documented by furnace remains,

## The chemical and metallographic analyses of the prehistoric ring from the 'Bull's Rock' cave

*K. Stránský*

*The paper presents the results of the metallographic and X-ray VD electron microprobe chemical analyses of the prehistoric hollow ring from the Bull's Rock (Býčí skála) cave. This Hallstatt hollow ring is dated to 600–500 BCE. The analyses resulted in the following conclusion: in the structure of a ring fragment, mostly of iron oxides, small quantity of copper oxides and traces of metallic copper and tin were found. The Hallstatt ring from the Bull's Rock cave was most probably forged of steel with a low carbon content. It was not either grey or white cast iron.*

Bull's Rock cave - Hallstatt prehistoric ring - Electron microprobe analyses - Metallographic analyses - Iron and copper oxides

### Introduction

The ground plan of the Bull's Rock cave is shown schematically in Fig. 38. The hollow ring from the cave is shown in Fig. 39 /Plate XIV/; its external diameter is 43mm, internal diameter *c* 20mm, and wall thickness less than 2mm. The weight of the ring is 22g and its density is 6.98g/cm<sup>3</sup> (Absolon 1970, 215).

The prehistoric ring has an attractive modern history. It was discovered by a Moravian archaeologist, medical doctor H. Wankel, in a Hallstatt forging shop in the Bull's Rock cave (Fig. 38) situated near the little town of Adamov in 1872. Dr Wankel assumed this ring to be made of grey or white cast iron and considered it to be the oldest iron casting in the world. This interpretation of the origin of the ring was not shared by most European metallurgists, who were Germans. An archaeologist, Professor K. Absolon, the grandson of Dr. Wankel, interpreted the production of the prehistoric ring as a foundry technology.

After World War I a prominent metallurgist, Professor V. Jareš, used metallographic analysis in 1919 to ascertain the structure of the ring (Jareš & Absolon 1919). It is remarkable, that he considered the microstructure of the ring to correspond with that of forged iron. After the World War II

## The craft of the Dacian blacksmiths

*L. Mihok and V. G. Kotigoroshko*

*The paper presents the results of chemical and microscopic analysis of slag and metallographic analysis of four iron swords found in excavations of the Dacian hillfort Malaya Kopanya, dated to 60 BCE to 100 AD. The finds resulted from the long-term excavation campaign of the Uzhgorod National University (which is still in progress). The analysis of many pieces of slag showed they originated in two sources: in the process of iron smelting in low shaft reduction furnace and in the process of the smithing of iron objects. Metallographic analysis of four iron swords showed four different production techniques, from a standard one to an excellent one. The reason for the swords found in a single complex around the Malaya Kopanya hillfort being produced by different methods needs analyses of more swords and other iron objects from the site.*

Dacian settlement - Iron smelting - Smithy working - Slag - Iron swords - Metallography

### Introduction

The swift changes in the political situation in the Carpathians–Danube region in the first half of the 1st century BCE is connected with the arrival of a young branch of the Goths and Dacians on the historical map of Europe, led by ‘the first and the greatest king of the Thracians’ – Burevista (*Inscriptiones . . .*, 1916, I, 246).

The expansion of the Dacians resulted in the destruction of the La Tène culture of the area. In the Central Danube area the settlements and *oppida* of the Bojs and Tarrisks, in the Lower Danube area the settlements of the Skordisks, and in the West Pontis, from Olvium to Appolonium, the Greek cities were destroyed (Strabo, V, 1, 6; Crişan 1992, 27–35; Kotigoroshko 1999, 106). New data show that the Dacians came to the Upper Tisza North Thracian environment around 60 BCE. Here the *oppidum* of Halish–Lovachka was destroyed and a series of hillforts were built – Zemplín, Malaya Kopanya, Solotvyno, Bila Cerkva, and Ontcheshty (Kotigoroshko 2004, 398–99, Fig. 1).

Among these key centres of Dacian culture the Malaya Kopanya hillfort is considered to be one of the most important in terms of its size, its

## Early medieval knife manufacture in Britain; a comparison between rural and urban settlements (AD 400–1000)

*E. Blakelock and G. McDonnell*

*Iron knives are frequently found on early medieval sites and provide archaeometallurgists with good opportunities to investigate methods of manufacture, the alloys available, the skills of the blacksmith, and therefore the iron economy as a whole. Previous studies of knives have revealed some clear differences in knife manufacture in early medieval (400–1000) England, when comparing urban settlements with rural cemeteries. This paper compares knives found at rural and urban settlements. Two knife assemblages from rural sites, Wharram Percy and Burdale, have been analysed and compared with contemporary urban settlements at Hamwic and York. This study has shown that, while there is no difference in knife manufacture between these sites, there are other differences, the most dramatic of which is the smaller number of heat-treated knives found in the rural settlements.*

Iron - Knives - Metallographic Analysis - Early medieval England - Urban - Rural

### Introduction

Over the last 50 years numerous archaeometallurgical studies of iron artefacts have been carried out, by many different researchers, in countries across Europe. The knife is one of the most common iron artefacts recovered during excavations, and they are particularly common on many early medieval sites. Knives are often composite artefacts utilizing the different properties of each iron alloy available, and also different blacksmithing skills, e.g. heat-treatment, welding, etc. Therefore metallurgical analysis of knives can provide an insight into ironworking technology. The blacksmith was vital both to urban settlements, by creating tools for craft workers, but also to rural settlements by creating and repairing agricultural tools.

During a review of the metallographic analysis of English early medieval knives it became clear that there were patterns emerging, including a distinct difference between those from early medieval settlements and



## Metallography of knives from the medieval village of Hrdlovka and the burial ground of Zlončice, Bohemia

*J. Hošek and P. Meduna*

*The chapter presents results of metallographic examination of 10th–13th century knives from the Bohemian sites of Hrdlovka and Zlončice. Within the framework of the systematization of the description of medieval (or early medieval) sites, Hrdlovka and Zlončice represent two antitheses: the first is a settlement, the second is a burial ground. Their common feature is the topography; both are part of the rural settlement system, without direct spatial links to fortified settlements. Another common feature is their ‘commonness,’ i.e. the sites do not differ in a number of details from comparable settlements or cemeteries of the period in Bohemia. Since both common and luxury knives have been identified at both these sites, the study clearly indicates that the standard division stronghold = ostentatious and rural site = second-rate is deficient and may be misleading.*

Knife - Metallography - Bohemia - Rural settlement - Rural burial ground

### Introduction

Radomír Pleiner considered medieval knives a vital source of information about medieval technology from the very beginning, and as early as 1956 he published, together with F. Plzák and O. Quadrat, a study dealing with the manner of the fabrication of early medieval blades, including both knives and swords of Bohemia (Pleiner *et al.* 1956).

The investigation of knives is undoubtedly important for archaeometallurgical and archaeological research because it reflects the technological, organizational, economic, and even aesthetic demands and possibilities of the craftsmen involved (blacksmiths, blade-smiths, cutlers, etc.) and the customers. A knife, as a common everyday tool and nowadays a frequent archaeological find, enables direct comparison of the quality and applied techniques achieved on one type of tool in the context of different social environments. Systematic research into cutlery can therefore gradually enhance our knowledge of the distribution of society and social levels when considering a certain time and territory.

## Technological traditions in the craft of the blacksmith in old Russian Shestovitsa

*G.A. Voznesenskaya*

*The technical culture of the Slavic and Old Russian peoples in south-eastern Europe in the field of blacksmithing was inherited from Scythian metalworking, with certain influences from Celtic technology, most notably in the Late Roman period. Many blacksmith artefacts found in the village of Shestovitsa, near Chernigov, were subjected to metallographic investigation. The nature of the trade and crafts of the settlement is demonstrated by numerous finds of tools, finished products, and waste materials from iron smelting, forging, and pottery making from all parts of the site. About 55% of the 195 knives from the settlement and burial mounds of Old Russian Shestovitsa were made according to the Slavic productive tradition and the remaining 45% in the Scandinavian tradition. It can be said that improved metalworking technologies invented by the craftsmen of the ancient world spread and developed in the Old Russian state thanks largely to the influence of the Scandinavian craft traditions.*

Blacksmith craft - History of archaeometallography - Metallographic research - Scientific literature

By the end of the 20th century scientists in Moscow and Kiev studying the origins and development of European ironworking were working together on the technological traditions in the craft of the blacksmith in the northern and southern regions of Russia (Voznesenskaya & Kovalenko 1985, 95–109; Rozanova 1988, 57–59; Voznesenskaya *et al.* 1996, 80–124; Rozanova 1997, 265–295; Voznesenskaya 1999, 117–126).

It is evident that simple techniques of iron processing prevailed in the craft of the blacksmiths working in the towns of southern Russia: the products were made from solid iron or steel and the earlier technological tradition of finished product and blank carburization continued. The culture of the Slavic and Old Russian blacksmiths in south-east Europe was based on that of the Scythian metalworkers, with some influences from Celtic technology, particularly in the Late Roman period (Voznesenskaya 1995, 47–52; Voznesenskaya *et al.* 1996, 17–23, 42–60).

## Further metallographic studies on early armour from Churburg

*A. Williams*

*Thirteen elements from five suits of plate armour made in Milan during the late 14th and early 15th centuries and kept in Churburg Castle have been examined. Out of the late 14th/early 15th century examples, one has been successfully hardened by quenching and three more have had some increase in hardness brought about by attempts at heat-treatment. All of the mid-15th century examples have been hardened by quenching, four out of five to around 300-400 VPH.*

Plate armour - Metallography - Churburg - South Tirol - Italy

### Introduction

The suit of plate armour was a unique European invention, which does not resemble body armour made in any other culture. It was first developed in North Italy during the course of the 14th century, and reached a level of excellence by the middle of the 15th century. Lombardy, and especially Milan and Brescia, had developed a considerable industry in the manufacture of arms and armour before 1300, but the production of the large plates needed for an articulated suit of plate placed new demands upon the metallurgy of the time.

Large quantities of armour from the 16th century and later survive, but complete suits of armour from the 15th century are scarcer. One of the most important collections of complete early armours is the collection of the Counts Trapp in their castle of Churburg, now in North Italy. The author was allowed to study a large number of these important armours by microscopic examination (Williams 1986). Subsequently, further armours at Churburg have been examined, and the results are published here.

### Methods of investigation

Surface hardness measurements were taken with a Branson-Krautkramer electronic hardness tester. Metallography was carried out in the Wallace

## From Soissons to Beauvais: the use of iron in some French cathedral

*P. Dillmann*

*Samples were taken on ferrous reinforcements of three French cathedrals (Beauvais, Amiens, and Soissons) located in Picardy. They were analysed using classical metallographic methods and slag inclusions analytical methodology already set up to distinguish ironmaking processes and homogeneous groups. The results made it possible to place the ferrous reinforcements in their historical and technological contexts, which differ for each monument.*

Bloomery process - Indirect process - Iron - Cathedrals

### Introduction

Over the last ten years in France multidisciplinary studies that have brought together archaeologists, historians, and chemists have made it possible to demonstrate that significant weights of iron reinforcements were used in building medieval monuments. This is, for example, the case for the Palais des Papes in Avignon (Dillmann *et al.* 2003; Bernardi & Dillmann 2005; Dillmann *et al.* 2004), Rouen cathedral (Dillmann & L'Héritier 2007; Barret *et al.* 2006; L'Héritier *et al.* 2005; Dillmann *et al.* 2004), or Vincennes Castle (Amoudruz *et al.* 1997; Clément-Charpentier 2001). These studies have revised opinions on the use of ferrous materials in the architecture of this period.

The present paper will focus on three monuments of French Gothic architecture, all located in Picardy: the cathedrals of Beauvais, Soissons, and Amiens. The aim will be here to show different applications of slag-inclusion analyses using the NRC ratio approach (Dillmann & L'Héritier 2007). This makes it possible on the one hand to determine the ironmaking process used to obtain the iron, and on the other to verify the homogeneity of some of the samples. Depending on the case, this information will help to date the ferrous reinforcement or to better understand the way they were put in the building.

## Archaeological metallography in Russia: historiographic notes

*V.I. Zavyalov*

*Metallography has been actively used to study ancient metal artefacts for more than sixty years. It was B.A. Kolchin who formulated the main principles of the metallographic method for archaeological material. Among the scientists originated the new method of archaeological material research was Professor Radomír Pleiner.*

*The main stages in the development of archaeological metallography and some achievements in studying the craft of the ancient blacksmith by Russian scientists are examined in this paper. The list of publications on East European ferrous metallurgy includes over 500 titles. Most of the articles and monographs were dedicated to the craft of Slavic and Old Russian blacksmiths. A considerable part of the work is also devoted to another important problem – the origin of ferrous metallurgy and metalworking in Eastern Europe.*

Blacksmith craft - History of archaeometallurgy - Metallographic research - Scientific literature

Metallography has been actively used to study ancient metal artefacts for more than sixty years<sup>3</sup>. It was B.A. Rybakov who justified the need to apply special natural scientific methods to the study of the ancient crafts (Rybakov 1948, 237). The main principles of using of the metallographic method for archaeological material were formulated by B.A. Kolchin in the late 1940s and early 1950s. He outlined the capabilities of the method and the circle of questions that could be resolved by it, and was the founder of a new school in the historical studies of the blacksmith's craft – archaeological metallography (archaeometallurgy).

Among the scientists who were the originators of the new method of archaeological material research was Professor Radomír Pleiner, whose studies have contributed greatly to the world literature on the history of metallurgy and the blacksmith's craft, and today no serious work on archaeometallurgy is complete without references to them. Radomír Pleiner

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<sup>3</sup>The present article only covers subjects related to the problems of ferrous metallurgy and metalworking.

## Archaeometallography in solving historical and cultural problems

*V.I. Zavyalov, L.S. Rozanova and N.N. Terekhova*

*Archaeometallography holds a prominent place among various methods of studying archaeological artefacts. B.A. Kolchin was the first to use metallographic methods for the study of large series of archaeological artefacts in the late 1940s to early 1950s.*

*The metallographic group formed by the authors of the present article now works actively in the Institute of Archaeology as a part of the Laboratory of Natural Scientific Methods. We have compiled an extensive archaeometallographic database for different epochs and areas including more than 11,000 analysed samples.*

*By the end of 1980s the problem of classification, generalization, and conceptualization of considerable heterogeneous data on Eastern Europe ironworking methods and technology starting from the earliest centuries up to the Middle Ages had become important. The work on this problem resulted in the book *Essays on the history of ancient iron working in Eastern Europe*. Later the main research trend of the metallographic group became the problem of 'Traditions and innovations in the production of ancient peoples (using the example of the blacksmith's craft)'.*

*Special attention was paid to the problem of the development of blacksmith traditions among the Finno-Ugrian peoples of the Volga and the West Ural regions. The history of the development of the Finno-Ugrian blacksmith's craft revealed the phenomenon of early (8th–6th centuries BCE) and the sudden appearance of iron objects with developed shapes in the area of the Middle Volga. In the 9th century the blacksmith's craft of the Volga and the West Ural Finno-Ugrian peoples saw a dramatic leap forward connected with these peoples entering into the trans-European trade system by the Great Volga–Baltic Route.*

*Another important part of the project is the problem of development of production traditions in the Old Russian blacksmith's craft. The results obtained makes it possible to state that traditions of pre-Mongol times survived in the crafts of the Old Russian smiths in the Golden Horde period.*

*The materials presented here are the major problems in the history of the craft of the East European blacksmith that could be resolved on the basis of archaeometallographic data not only from the historico-technological point of view, but also in terms of wide-scale historical generalizations.*

**The multidisciplinary approach (archaeology and archaeometry) to bloomsmithing activities in France: examples of results from the last twenty years**

*P. Fluzin, S. Bauvais, M. Berranger, G. Pagès and P. Dillmann*

*Over the last twenty years, archaeological and archaeometrical research implemented in France has made it possible to define the various stages of the chaîne opératoire in iron and steelmaking (Mangin & Fluzin 2008) as well as the indicators that are linked to them (archaeological structures, wastes). These studies reveal that the chaîne opératoire may (or may not) split in space and time, but may also contain varying degrees of intensity (mini-maxi production). This implies that the production sites can be from different natures: they may include partial or complete chaîne opératoire, and are part of a social context (e.g., rural, urban, specialized, or domestic craft). The relationships within the chaîne opératoire create links between the sites and form a technological, economic, and social network through trade in semi-finished and manufactured products. The evolution of these networks must be studied by taking into account the cultural and political contexts of each period to draw up a coherent understanding of this organization. The determination of site activities (smelting, refining, elaboration, consumption, recycling), as well as intensity, allow a dynamic cartography of these activities, both synchronic and diachronic, to be realized. The physicochemical linkages between the ore, the smelting slag, the post-smelting slag, and the metal produced make possible an eventual understanding of the connection between sites that are part of the same exchange network. This in turn reflects the regional development of metallurgical organization and the trade in iron semi-products and manufactured goods.*

*The typological attribution (morphology, level of impurities, iron/carbon composition, phosphorus contents, etc) of semi-products worked on the forging sites also makes it possible to refine the vision of what circulate and of what the sites acquire (Bauvais et al. in press). Thus, an archaeological and historical study of these data can structure the relative image we have of these relations in the various periods (Mangin et al., 2000a; Mangin et al. 2000b).*

## Cast iron from a bloomery furnace

*P. Crew, M. Charlton, P. Dillmann, P. Fluzin, C. Salter and  
E. Truffaut*

*A series of experiments have been carried out at Plas Tan y Bwlch smelting high-manganese bog ores as part of a research programme linked to the excavations of the 14th century bloomery at Llwyn Du, North Wales. In experiment 92 the blowing was done with two large hand-bellows, giving a much higher air rate and charcoal burning rate than is usual for a small bloomery furnace. The product was a block of cast iron, which had formed in the normal position of a bloom, held in place by the sticky low-iron slags. This unintended result shows that cast iron in some quantity can be produced relatively easily in a bloomery furnace. There are interesting implications for the increasing number of bloomery sites, from all over Europe, where cast iron and high-carbon steels have been found.*

Experiment - Bloomery furnace - Bog ore - Manganese - Cast iron

## Introduction

Iron-working experiments have been carried out since 1986 at Plas Tan y Bwlch, the Snowdonia National Park Study Centre in North Wales. Mainly bog iron ores have been smelted in a programme of research linked to the excavations at the prehistoric sites of Bryn y Castell and Crawcwellt (Crew 1991; Crew & Salter 1991, 1993; Crew 1995; Salter & Crew 1997; Serneels & Crew 1997). In 1997 and from 2001 to 2006 excavations were carried out at the 14th century bloomery at Llwyn Du. The iron working there was on a much larger scale than at the prehistoric settlements. Historical records indicate that some 50kg of raw bloom were made each week, refined to some 30kg of bar iron. The smelting was carried out in a large thick-walled furnace with an internal diameter of 40cm, using manganese-rich bog ores and producing tap slags (Smith 1995; Crew & Crew 2001).

As a consequence of these excavations a new series of experiments has been carried out, to explore the problems of smelting with Mn-rich bog ores. In the first experiment (XP90), 20kg of ore was smelted at a blowing



## ***The Celtic Sword: a source of practical inspiration***

***J. Lang***

*Pleiner's work was part of the inspiration behind a series of experiments that the present author undertook between 2003 and 2005 to explore the mechanical properties of differently constructed pre-medieval swords. The variations may have been partly aesthetic, but there were probably practical reasons as well. This paper outlines the results of a series of mechanical tests on modern iron/steel bars forged by the author with different configurations. The conclusions and the limitations of the work are discussed briefly.*

Sword - Wrought iron - Steel - Forge welding - Pattern welding - Mechanical testing

### **Introduction**

In his essential work, *The Celtic Sword* (1993), Radomír Pleiner considered his subject 'in the round'. His own extensive metallographic studies were included, of course, together with a comprehensive review of other published material, but he also placed the Celtic sword in its pre-historic, archaeological, and cultural setting. In an innovative initiative, he arranged for a blacksmith to make two swords with dimensions typical of Celtic long swords, in order to investigate the practical procedures and usage of materials employed in sword-making. As he pointed out, the microstructures cannot provide this information, which has important implications for the study of metal working sites and the economics of resources.

Pleiner's work was part of the inspiration behind a series of experiments that the present author undertook between 2003 and 2005 to explore the mechanical properties of differently constructed pre-medieval swords. Pleiner's study made it very clear that several different arrangements of metal strips or bars were used during the Iron Age, a practice which eventually developed into pattern welding. The reason for this may have been partly aesthetic, but there were probably practical reasons as well. In tribute to the inspirational work of Radomír Pleiner, this paper outlines the results of a series of mechanical tests carried out on forged