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Editorial

This issue of *Archeologické rozhledy* is devoted to the study of early ironworking and brings you some of many papers presented at the highly successful international conference *Iron in Archaeology: Bloomery Smelters and Blacksmiths in Europe and Beyond* which was held in Prague in 2017 and was organized in honour of Professor Radomír Pleiner.

The date of the conference was not chosen at random, but because 2017 was the 50th anniversary year of the *Comité Pour la Sidérurgie Ancienne* (CPSA). Founded by Radomír Pleiner in 1966 and active since 1967, the CPSA represents the oldest and one of the most important platforms for bringing together specialists in research on early ironworking. The greatest credit for this goes to Pleiner who was the secretary of the CPSA for nearly 40 years. During this time he was also the editor of the CPSA Communications, published twice yearly in *Archeologické rozhledy* until 2002. The Communications, totalling 67 issues, contain reports on conferences, excavations, scientific work and other research, and, above all, abstracts of publications. Thus, in the pre-internet era, the Communications were a crucial source of information in the field of the archaeometallugy of iron. The CPSA was also involved in twenty-one conferences which were organised under its auspices. The first such conference was held at Schaffhausen in 1970 and the last one at Uppsala in 2001. In 2002, a flood badly affected the Institute of Archaeology in Prague and completely destroyed the CPSA archive kept in Pleiner's basement office. This resulted in the activity of the CPSA being interrupted for some time. Pleiner continued to hold the post of secretary until 2004, when Janet Lang became the new secretary. Despite her enormous effort the CPSA activity declined, mainly because of the changes in the method of retrieving information due to the development of the internet. In 2015, the CPSA was revived in a new format through the pages of Academia.edu (https://independent.academia.edu/CPSA) which serve both as an archive of CPSA activity and publications and as a single location where scholars of early ironworking and their papers can be found. The CPSA also aims to revive the tradition of scientific conferences focussed on the issue of early ironworking, starting with the 2017 Prague conference, which was held 30 years after Pleiner himself organized the CPSA conference at Liblice near Prague. The next conference will be in Fribourg in 2021, organised by Vincent Serneels, who is now the President of the CPSA.

Although the papers published in this issue represent only a small sample of the contributions to the Prague conference, they provide new information for improving our knowledge both of the history of early ironworking and of the developments in its study and they bring a new impetus for further scientific discussion. We sincerely hope that you will find these articles interesting and useful, and we should like to thank all the authors who prepared their papers for this issue, as well as all the anonymous peer-reviewers whose work contributed to its realisation.

Jiří Hošek and Peter Crew

Editorial

Tento svazek Archeologických rozhledů je věnován studiu dávné výroby a zpracování železa. Přináší výběr z mnoha příspěvků prezentovaných na mezinárodní konferenci IRON IN ARCHAEOLOGY: BLOOMERY SMELTERS AND BLACKSMITHS IN EUROPE AND BEYOND, která proběhla v Praze roku 2017 k poctě profesora Radomíra Pleinera.

Datum uspořádání konference nebylo zvoleno náhodně: na rok 2017 připadlo padesátileté výročí *Comité Pour la Sidérurgie Ancienne* (CPSA). Tento komitét, založený Radomírem Pleinerem roku 1966 a aktivní od roku 1967, představuje nejstarší a zároveň jednu z nejvýznamnějších platforem sdružujících specialisty na výzkum dávného železářství. Největší zásluhu na tom má samotný Pleiner, který byl sekretářem CPSA téměř čtyřicet let. Během té doby byl rovněž editorem CPSA *Communications*, publikovaných dvakrát ročně v Archeologických rozhledech až do roku 2002. *Communications*, celkově čítající 67 vydání, obsahují zprávy o konferencích, archeologických výzkumech, vědecké práci i dalším bádání, a především abstrakty publikací. Ve své době tak *Communications* představovaly na poli archeometalurgie železa zcela zásadní zdroj informací. CPSA je rovněž spjato s 21 konferencemi, které byly organizovány pod jeho záštitou. První proběhla roku 1970 v Schaffhausenu, poslední pak v roce 2001 v Uppsale. V roce 2002 byl Archeologický ústav v Praze těžce zasažen povodní, která zcela zničila archiv CPSA nacházející se v Pleinerově pracovně. To zapříčinilo dočasné přerušení aktivit CPSA. Pleiner setrval na postu sekretáře do roku 2004, kdy ho vystřídala Janet Lang. Navzdory jejímu enormnímu úsilí aktivity CPSA postupně ustaly, a to zejména v souvislosti se změnami v metodách získávání informací, jež souvisely s rozvojem internetu. Činnost CPSA byla obnovena v roce 2015 přes webové stránky Academia.edu (https://independent.academia.edu/CPSA), které slouží jako archiv jejích aktivit a publikací, i jako místo, kde lze dohledat badatele pracující na poli dávného železářství a jejich práce. CPSA rovněž usiluje o obnovení tradice vědeckých konferencí zaměřených na problematiku dávného železářství, a to počínaje pražskou konferencí, jež proběhla třicet let poté, co sám Pleiner zorganizoval obdobnou konferenci v Liblici u Prahy. Další konference bude uspořádána ve Fribourgu roku 2021 Vincentem Sernleelsem, současným prezidentem CPSA.

Články z tohoto svazku AR představují zdroj nových informací prohlubujících znalosti dějin dávného železářství i vývoje jeho studia a přinášejí nové podněty v odborné diskusi. Závěrem bychom rádi poděkovali jak autorům, tak recenzentům, jejichž práce přispěla k realizaci tohoto svazku.

Jiří Hošek a Peter Crew

Doubting radiocarbon dating from in-slag charcoal: five thousand years of iron production at Wetzlar-Dalheim?

Pochybné radiokarbonové datování z dřevěného uhlí uvízlého ve strusce: pět tisíc let železářské výroby ve Wetzlar-Dalheim?

Guntram Gassmann – Andreas Schäfer

A Roman-Period bloomery smelting site had been excavated in the Lahn valley at Wetzlar-Dalheim in central Germany during 2006–2012. The production unit consisted of a big rectangular workshop pit with 13 slag pit-furnaces, two waste dumps and a small sunken hut. The stratigraphical sequence, along with abundant pottery and small finds, allows the dating of short-lived smelting activity to a time slot around the third quarter of the first century AD. As a first series of radiocarbon measurements from in-slag charcoal samples resulted in a bewildering date range from the Iron Age right back into the Neolithic, a second dating series has been undertaken. This time exclusively charcoal samples taken from the bottom of the furnace pits have been analysed. The resulting dates fit to the archaeologically derived dating. It is clear that the ^{14}C content of the in-slag charcoal samples must have been altered already during the process in antiquity. With none of the analysed dates younger than the archaeologically fixed date of the bloomery production unit, it is obvious that a contamination with fossil carbon must have taken place. The wide and inconsistent date range suggests that fossil carbon has entered the metallurgical system within the furnace in an uncontrollable manner. The observed phenomenon has wide implications for other metallurgical sites with high temperature processes under strongly reducing conditions. Charcoal samples from such sites, especially from inside slags, might be contaminated to an unpredictable degree and produce seemingly older dates. A first review of previously published data series calls for a reconsideration of the reliability of radiocarbon dates from metallurgical slags.

radiocarbon dating – methodology – charcoal samples – slag – fossil carbon

V průběhu let 2006 až 2012 byla v údolí řeky Lahn ve Wetzlar-Dalheimu ve středním Německu odkryta lokalita s doklady výroby železa z doby římské. Výrobní jednotka sestávala z velké dílenské jámy obdélníkového půdorysu se třinácti pecemi se zahloubenou nístějí, dvěma odpadními haldami a malou polozemnicí. Stratigrafická posloupnost spolu s hojně přítomnou keramikou a drobnými nálezy umožňují datovat krátkodobou výrobní činnosti do zhruba 3. čtvrtiny 1. stol. n. l. Jelikož první série radiokarbonových měření provedená na kouscích dřevěného uhlí, které uvízlo ve strusce, vymezila ohromující časový úsek od doby železné až po neolit, byla provedena druhá datovací série. Tentokrát byly analyzovány výlučně vzorky dřevěného uhlí, které byly odebrány z nístějí pecí. Výsledné datování vykazovalo shodu s datováním archeologickým. Vzhledem k tomu, že kontaminaci po exkavaci můžeme vyloučit, je zřejmé, že obsah ^{14}C ve vzorcích dřevěného uhlí musel být změněn už při výrobním procesu v průběhu starověku. Široký a nekonzistentní časový interval naznačuje, že fosilní uhlík vstupuje do metalurgického systému v peci nekontrolovaně. Pozorovaný fenomén má velký dopad na další lokality s doklady metalurgických aktivit, při kterých vysokoteplotní procesy probíhaly za silně redukčních podmínek. Vzorky dřevěného uhlí z takových lokalit, zejména pak uhlíků ze strusek, mohou být kontaminovány nepředvídatelným způsobem a zapříčinit zdánlivě starší datování. První přezkoumání dříve publikovaných datových řad vyzývá k přehodnocení spolehlivosti údajů z radiokarbonového datování metalurgických strusek.

radiokarbonové datování – metodika – vzorky uhlíků – struska – fosilní uhlík

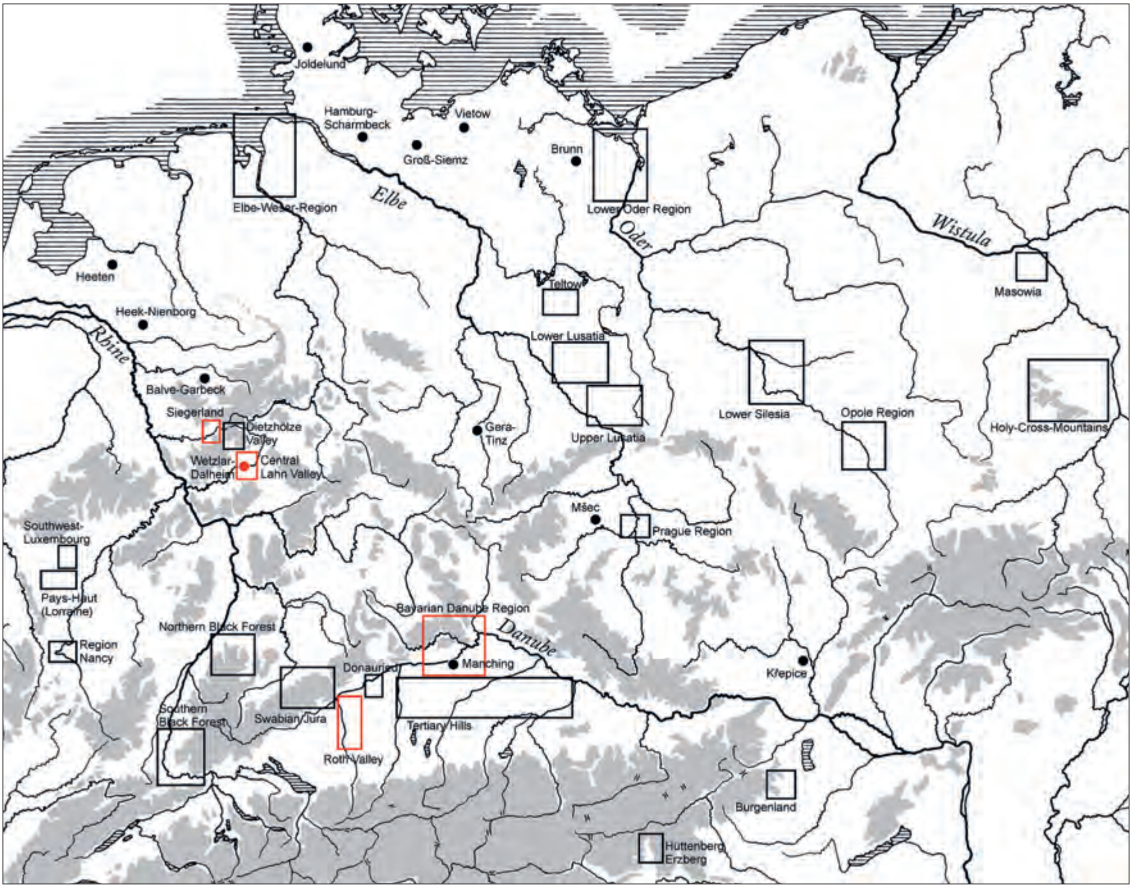

Fig. 1. Important sites and regions of early iron production in Central and Eastern Europe with those mentioned in the text highlighted in red (adapted from *Schäfer 2009*, 218 fig. 128).
Obr. 1. Lokality a oblasti významné pro poznání časného železařství ve střední a východní Evropě; místa zmiňovaná v textu vyznačena červeně (podle *Schäfer 2009*, Abb. 128).

1. The setting

During the years 2006–2012 a bloomery smelting site of the early Roman Period had been excavated in the Lahn valley in Hesse, central Germany (*fig. 1*; *Schäfer 2014*; cf. *Gassmann – Schäfer 2014*, maps B and C with further references). The production unit at Wetzlar-Dalheim, Lahn-Dill-District, site C86 ‘Unterbodenfeld’ had survived well preserved in the infill of a natural gully and could be uncovered completely using single find recording. It consisted of 13 slag-pit furnaces with free-standing shafts typical of the Roman Period (*Pleiner 2000*, 152), two waste dumps and a small sunken hut (*fig. 2*). The iron smelting furnaces were situated alongside the walls in a large rectangular workshop pit, with two ground plans overlapping each other. The furnaces would have been used up to a dozen times each, as dislocated slag blocks and evidence of structural repairs at the furnace bases

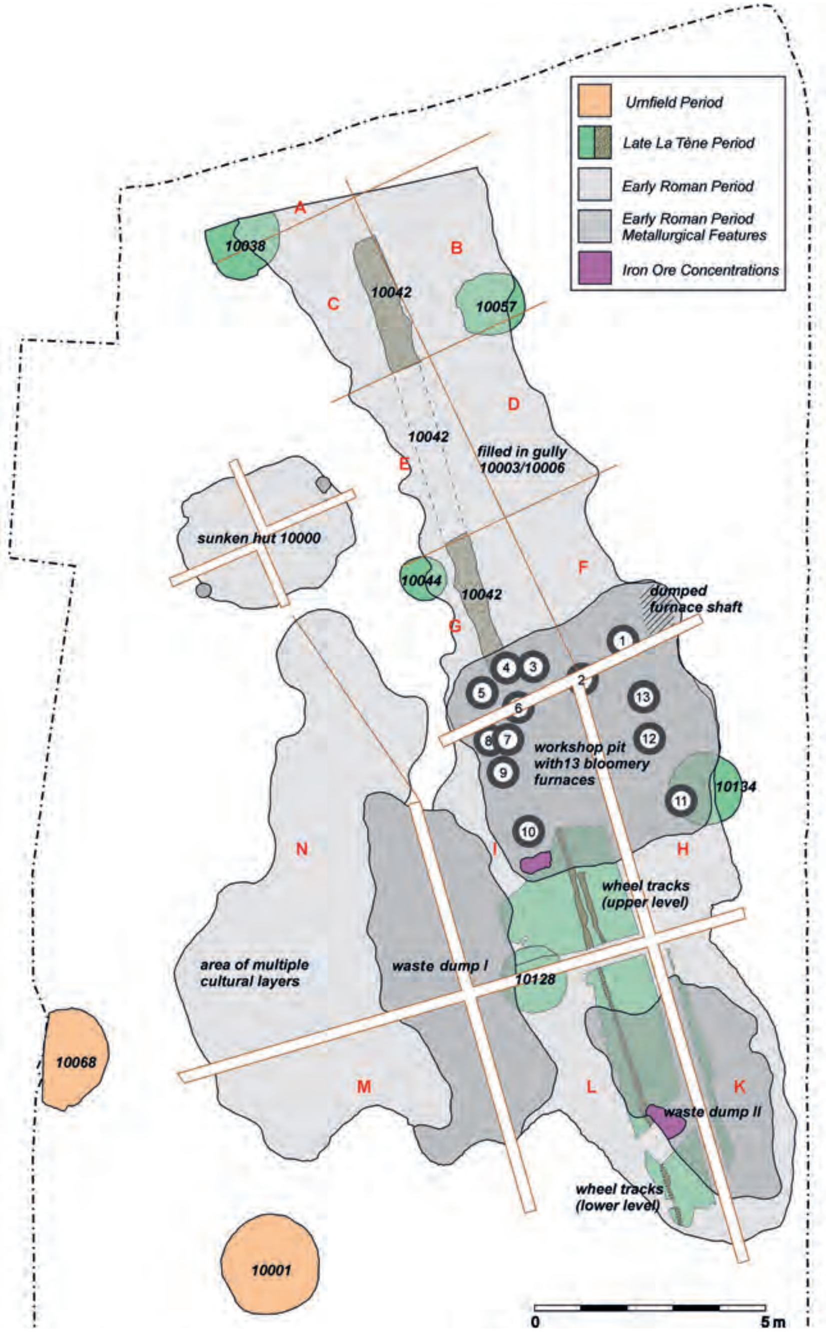

Fig. 2. Wetzlar-Dalheim, Lahn-Dill-District, Germany, Site C86 'Unterbodenfeld'. Schematic site plan with chronological phases (graphics A. Schäfer and B. Schroth).

Obr. 2. Wetzlar-Dalheim, zemský okres Lahn-Dill, Německo, lokalita C86 „Unterbodenfeld". Schematický plán lokality s chronologickými fázemi.

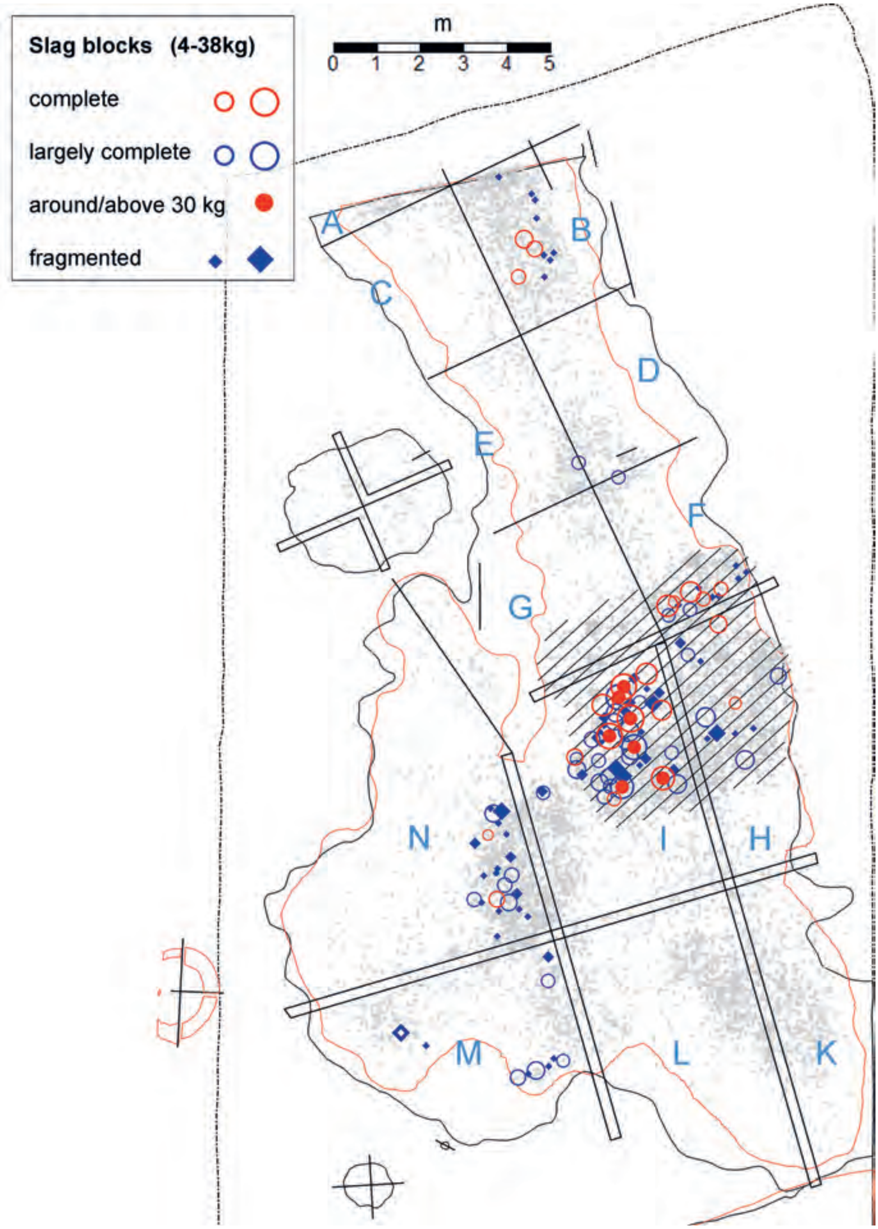

Fig. 3. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Spatial distribution of slag blocks and their fragments (> 1 kg). The mass of small slag fragments (n = 8900) is plotted underneath. Most of the slag blocks had been left inside the workshop pit (hatched). Only smaller pieces and fragments were deposited on the dump or in the gully (no details available yet for sections K and L). Graphics in figs. 3, 6–8 and 11 A. Schäfer.
Obr. 3. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Prostorová distribuce struskových bloků a jejich fragmentů (> 1 kg). Množství malých fragmentů strusky (n = 8900) je vyneseno ve spodnější vrstvě. Většina struskových bloků zůstala uvnitř dílenské jámy (vyšrafováno). Pouze menší kusy a fragmenty byly odkládány na haldu nebo do strouhy (detaily pro úseky K a L zatím nejsou k dispozici).

Lab. No.	Find No.	Material	Conventional ^{14}C age (yr BP) (± 1σ)	Delta C13 (‰)	Calibrated calendar age (cal AD/BC) (2σ)
ETH-35454	490	organics, charcoal?	*no carbon for dating*		
ETH-35455	2205	organics, charcoal?	*no carbon for dating*		
ETH-35456	2211	organics, charcoal?	2825 ± 50	-34.1 ± 1.3	1130BC (95.4%) 840BC
ETH-35457	89	organics, charcoal?	2010 ± 45	-21.0 ± 1.3	170BC (4.0%) 130BC 120BC (91.4%) 80AD
ETH-35458	3831	organics, charcoal?	2015 ± 45	-21.8 ± 1.3	170BC (95.4%) 80AD
ETH-35459	4241	organics, charcoal?	2045 ± 45	-21.7 ± 1.3	180BC (95.4%) 60AD
ETH-35460	4421	organics, charcoal?	1990 ± 45	-26.3 ± 1.1	110BC (95.4%) 130AD
ETH-35461	3681	organics, charcoal?	3055 ± 45	-20.8 ± 1.2	1430BC (95.4%) 1190BC
ETH-35462	4215	organics, charcoal?	3065 ± 45	-21.5 ± 1.2	1440BC (95.4%) 1210BC
ETH-35463	6588	organics, charcoal?	2175 ± 45	-17.8 ± 1.2	380BC (95.4%) 100BC
ETH-35464	6616	organics, charcoal?	2040 ± 45	-24.9 ± 1.1	180BC (95.4%) 60AD
ETH-35465	A0982	organics, charcoal?	4695 ± 70	-34.3 ± 1.5	3640BC (95.4%) 3350BC
ETH-35466	7865	organics, charcoal?	*no carbon for dating*		
ETH-35467	6469	organics, charcoal?	3110 ± 50	-28.7 ± 1.1	1500BC (95.4%) 1260BC
ETH-35468	6472	organics, charcoal?	2410 ± 45	-22.1 ± 1.2	760BC (16.7%) 680BC 670BC (6.5%) 610BC 600BC (72.2%) 390BC
ETH-35469	6949	organics, charcoal?	2275 ± 45	-29.3 ± 1.1	410BC (40.3%) 340BC 330BC (55.1%) 200BC
ETH-35470	7093	organics, charcoal?	*no carbon for dating*		
ETH-35471	7118	organics, charcoal?	*no carbon for dating*		
ETH-35472	7119	organics, charcoal?	2120 ± 45	-24.8 ± 1.1	360BC (13.2%) 280BC 240BC (82.1%) 20BC
ETH-35473	7163	organics, charcoal?	*no carbon for dating*		
ETH-35474	A0582	organics, charcoal?	2320 ± 45	-26.8 ± 1.1	520BC (73.3%) 340BC 310BC (22.1%) 200BC
ETH-35475	A0592	organics, charcoal?	2715 ± 55	-31.5 ± 1.5	1000BC (95.4%) 790BC

Tab. 1. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. First set of radiocarbon measurements, taken in 2008, mostly from in-slag charcoal samples (cf. *fig. 6*). Calibration with Oxcal Version 3.10 (data provided by ETH Zurich [I. Hajdas, G. Bonani]).

Tab. 1. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. První série radiokarbonových měření, která byla provedena v roce 2008 povětšinou na vzorcích dřevěného uhlí uvízlého ve strusce (srov. *obr. 6*). Kalibrováno programem OxCal Verze 3.10 (Data poskytl ETH Zurich [I. Hajdas, G. Bonani]).

indicate. The metallurgical debris from the site amounts to about 2.8 tons of bloomery slag together with vitrified furnace wall, tuyère fragments and iron ores. Most of the about 120–150 slag blocks of 8–38 kg in weight had been left in the workshop right next to the furnaces. Only a comparatively small number had made their way to the adjacent dumps or the infill of the gully (*fig. 3*).

Judging from the small number of furnaces and the comparatively modest amount of metallurgical waste, the smelting activities could hardly have been going on for more than a few seasons, if not just one or two. Abundant pottery and small finds, including a fair number of Roman imports, date the production unit at Wetzlar-Dalheim quite precisely to a short time slot in the second half of the first century AD (*Schäfer 2010*, 77–81). Thus,

Fig. 4. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Furnace 6 (features 10052/53) cutting through pebble reinforcement (feature 10042) of Iron Age trackway. Photograph B. Schroth.
Obr. 4. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Pec 6 (objekty 10052/53) protínající oblázky zpevněnou stezku (objekt 10042) z doby železné.

from the archaeological point of view the metallurgical complex at site C86 at Wetzlar-Dalheim with its workshop pit and the two waste dumps clearly marks one contemporaneous assemblage. Taphonomic analysis is indicative of a systematic abandonment of the site. After shutting down the last furnaces in the northwest corner of the workshop, the remaining structure was refilled with cultural debris of the nearby settlement.

The workshop was found in superposition to a preceding late Iron Age trackway that had made use of the natural gully. The small road or path, linking the nearby Lahn River to a settlement further up the hill, was flanked by large storage pits on either side. Tracks of cart wheels and some reinforcement with gravel and pebbles could be identified over a distance of more than 20 metres in the loess subsoil. In a clear stratigraphical sequence, the Roman Period slag pits cut into the Iron Age trackway underneath (*fig. 4*).

2. The radiocarbon dates

A first series of radiocarbon dates was analysed in 2008 with the excavation still in an early stage (*tabs. 1* and *2*). The charcoal samples were directly extracted from the inside of broken up or cut up slag blocks to make sure to date the production process itself. Apart from these in-slag samples some ‘normal’ charcoal samples were also analysed from the adjacent sunken hut and a Bronze Age storage pit.

Figures 5–6 show some of the analysed slag blocks and display the very astonishing results of this first series of AMS-radiocarbon measurements.[1] Taking only the six dates from slag blocks that derive directly from inside the early Roman workshop pit, the date range of the analyses reaches from the later Neolithic (A0982), through the Bronze Age

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[1] Thanks are due to I. Hajdas and G. Bonani (ETH Zurich) for the radiocarbon measurements (cf. *Hajdas et al. 2004*) and for some helpful comments on an earlier draft. Some of the in-slag charcoal samples from this data set seem to have been quite low in carbon content (I. Hajdas, ETH Zurich, pers. comm.), other samples handed in did not contain any carbon for dating (cf. *tab. 1*). Due to sample size the tree species could not be established.

AMS ^{14}C Lab Code	HEKAL Sample Nr.	Sample name (sample material dated)	furnace / charcoal layer pl. = planum	Carbon yield (%)	Conventional ^{14}C age (yr BP) (± 1σ)	Calibrated calendar age (cal AD/BC) (2σ)
DeA-10950	I/1446/8L	C86-A1726 (Charcoal-Fagus)		22.35	1910 ± 22	*control measurement*
DeA-10966	I/1446/8H	C86-A1726 (Charcoal-Fagus)	furnace 01, pl. 06	27.48	1968 ± 23	cal BC 37 – cal AD 77
DeA-10951	I/1446/9L	C86-B2571 (Charcoal-Quercus)		24.88	2008 ± 23	*control measurement*
DeA-10952	I/1446/9H	C86-B2571 (Charcoal-Quercus)	furnace 03, pl. 10-11	31.24	2026 ± 23	cal BC 94 – cal AD 49
DeA-10953	I/1446/10L	C86-B2572 (Charcoal-Quercus)		25.80	1983 ± 23	*control measurement*
DeA-10954	I/1446/10H	C86-B2572 (Charcoal-Quercus)	furnace 03, pl. 10-11	29.66	1974 ± 24	cal BC 39 – cal AD 73
DeA-10955	I/1446/11L	C86-B2570 (Charcoal-Fagus)		25.81	1946 ± 23	*control measurement*
DeA-10956	I/1446/11H	C86-B2570 (Charcoal-Fagus)	furnace 04, pl. 10-11	30.55	1967 ± 23	cal BC 37 – cal AD 78
DeA-10957	I/1446/12L	C86-B2621 (Charcoal-Fagus)		23.09	1921 ± 23	*control measurement*
DeA-10958	I/1446/12H	C86-B2621 (Charcoal-Fagus)	furnace 04, pl. 11-12	30.97	1910 ± 23	cal AD 28 – cal AD 133
DeA-10959	I/1446/13L	C86-B2939 (Charcoal-Quercus)			1966 ± 23	*control measurement*
DeA-10960	I/1446/13H	C86-B2939 (Charcoal-Quercus)	furnace 05, pl. 11-12	27.50	2031 ± 23	cal BC 105 – cal AD 47
DeA-10961	I/1446/14L	C86-B2968 (Charcoal-Quercus)		25.39	2013 ± 23	*control measurement*
DeA-10962	I/1446/14H	C86-B2968 (Charcoal-Quercus)	furnace 05, pl. 11-12	31.72	1981 ± 23	cal BC 39 – cal AD 66
DeA-10963	I/1446/15L	C86-B3845 (Charcoal-Quercus)		24.96	2049 ± 23	*control measurement*
DeA-10964	I/1446/15H	C86-B3845 (Charcoal-Quercus)	furnace 07, pl. 09-10	30.00	1989 ± 23	cal BC 42 – cal AD 60
DeA-10978	I/1446/16L	C86-B3716 (Charcoal-Quercus)		27.43	1971 ± 25	*control measurement*
DeA-10979	I/1446/16H	C86-B3716 (Charcoal-Quercus)	furnace 09, pl. 08-09	27.05	1974 ± 25	cal BC 39 – cal AD 73
DeA-10980	I/1446/17L	C86-B3749 (Charcoal-Tilia)		22.66	1926 ± 26	*control measurement*
DeA-10981	I/1446/17H	C86-B3749 (Charcoal-Tilia)	furnace 09, pl. 09-10	29.87	1954 ± 24	cal BC 32 – cal AD 122
DeA-10968	I/1446/18L	C86-B3731 (Charcoal-Quercus)		20.83	2024 ± 24	*control measurement*
DeA-10969	I/1446/18H	C86-B3731 (Charcoal-Quercus)	furnace 10, pl. 07-08	30.26	2019 ± 24	cal BC 90 – cal AD 52
DeA-10970	I/1446/19L	C86-B6516 (Charcoal-Quercus)		28.99	1991 ± 24	*control measurement*
DeA-10971	I/1446/19H	C86-B6516 (Charcoal-Quercus)	furnace 12, pl. 08-09	28.97	1990 ± 24	cal BC 43 – cal AD 61
DeA-10972	I/1446/20L	C86-B6565 (Charcoal-Carpinus)		27.76	2004 ± 25	*control measurement*
DeA-10973	I/1446/20H	C86-B6565 (Charcoal-Carpinus)	furnace 12, pl. 08-09	30.06	2029 ± 24	cal BC 104 – cal AD 49
DeA-10974	I/1446/21L	C86-B4033 (Charcoal-Quercus)		23.51	1962 ± 24	*control measurement*
DeA-10975	I/1446/21H	C86-B4033 (Charcoal-Quercus)	layer 10096, pl. 07-08	30.25	1992 ± 24	cal BC 43 – cal AD 60
DeA-10983	I/1446/22L	C86-A4797 (Charcoal-Quercus)		23.21	1986 ± 28	*control measurement*
DeA-10984	I/1446/22H	C86-A4797 (Charcoal-Quercus)	layer 10021, pl. 04-05	28.69	1982 ± 27	cal BC 42 – cal AD 70
DeA-10985	I/1446/23L	C86-B3970 (Charcoal-Quercus)		25.76	2044 ± 26	*control measurement*
DeA-10986	I/1446/23H	C86-B3970 (Charcoal-Quercus)	layer 10021, pl. 07-08	23.38	2019 ± 26	cal BC 92 – cal AD 54

Tab. 2. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Second series of radiocarbon measurements directly related to the production process, taken in 2017. Calibration data set: intcal13.14c (data provided by Isotoptech Zrt., Debrecen [I. Futó, M. Molnár, V. Mihály]).

Tab. 2. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Druhá série radiokarbonových měření přímo souvisejících s výrobním procesem, pořízená v roce 2017. Kalibrační datová sada: intcal13.14c (Data poskytl Isotoptech Zrt., Debrecín [I. Futó, M. Molnár, V. Mihály]).

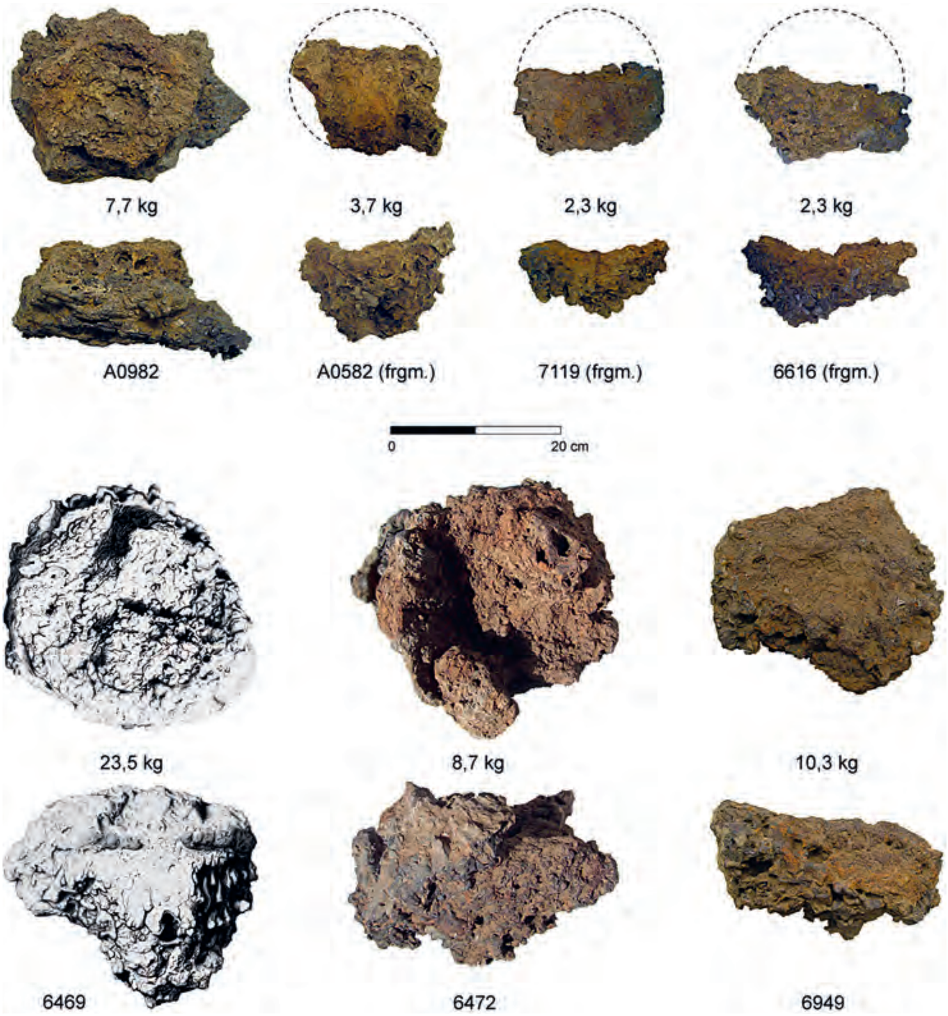


Fig. 5. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Range of slag blocks from the Roman-Period smelting site dated by radiocarbon analysis. The charcoals extracted from inside the slags yielded dates from the later Neolithic (A0982), the Bronze Age (6469), the Hallstatt to early La Tène Periods (6472, A0582, 6949), the later La Tène Period (7119) and the late Iron Age/Early Roman Period (6616). Drawing P. Thomas; photographs A. Schäfer.

Obr. 5. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Škála struskových bloků z lokalit s doklady železářské výroby datovaných radiokarbonovou metodou do římského období. Kousky dřevěného uhlí vyjmutého ze strusek byly datovány do mladšího neolitu (A0982), do doby bronzové (6469), halštatské až rané doby laténské (6472, A0582, 6949), mladší doby laténské (7119) a pozdní doby železné/doby římské (6616).

(6469; A0597) to the Early Iron Age (6472; A0582) and the Later Iron Age (7119). Four of these slag blocks were dumped in a layer of debris stratigraphically superseding the slag pit of furnace 1 after its abandonment and destruction. Three more samples in slag blocks from the infill of the gully (6588; 6949) and from the western dump (2211) produced dates

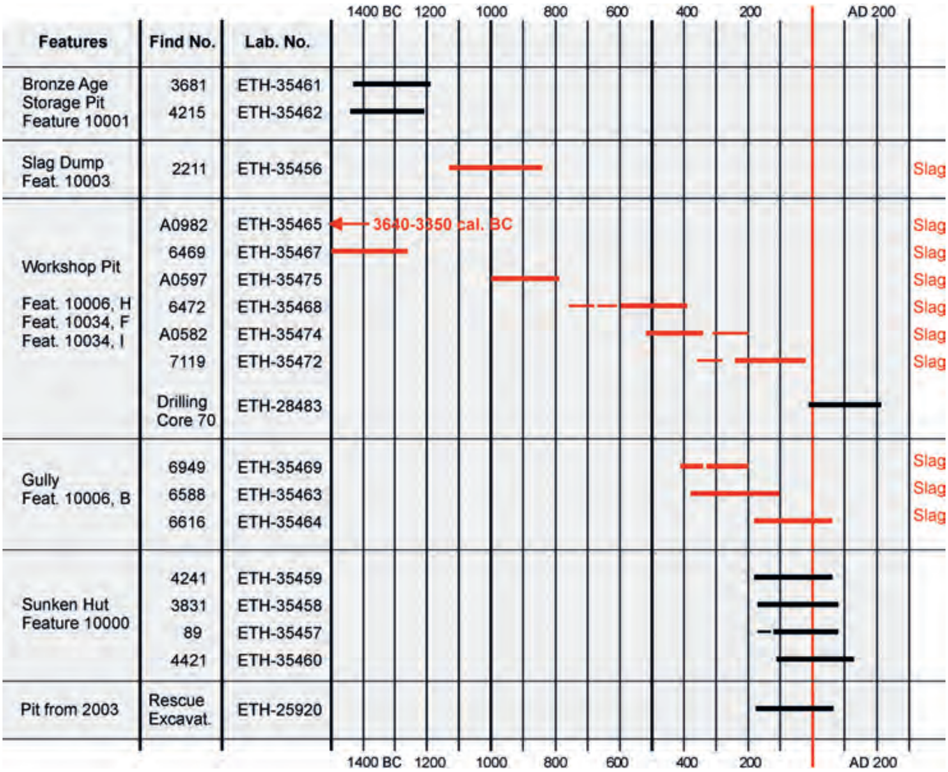
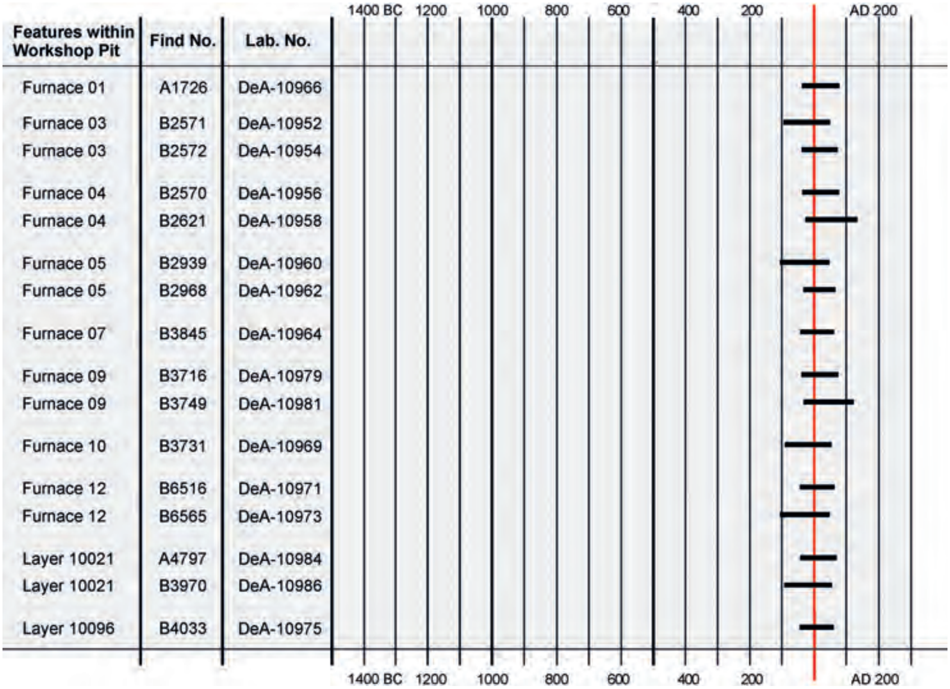


Fig. 6. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Results of the first series of radiocarbon measurements, taken in 2008, mostly from in-slag charcoal samples (in red). 2σ standard deviation (data provided by ETH Zurich [I. Hajdas, G. Bonani]).

Obr. 6. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Výsledky první série radiokarbonových měření, pořízených v roce 2008, povětšinou provedených na vzorcích dřevěného uhlí uvízlého ve strusce (červeně). Směrodatná odchylka 2σ (data poskytl ETH Zurich [I. Hajdas, G. Bonani]).

of the Bronze Age and the Later Iron Age respectively. Only one of the ten samples (6616), located furthest north in the gully, produced a late Iron Age/early Roman Period date in accordance with the archaeological evidence. While the in-slag samples yielded these astonishing results, the ‘normal’ charcoal samples taken from the sunken hut and the Bronze Age storage pit matched the archaeologically derived dating. Two more samples, processed a few years previously, also produced Roman Period dates and did not derive from slags. One was taken from a drilling core from inside the working pit close to one of the furnaces (core 70). The other derives from the infill of an archaeological feature immediately north of our excavation trench. There, tuyère fragments, slags and charcoal may belong to another production unit further up the hill and were collected there in 2003 during rescue work in a freshly cut cable trench along the road.

The broad date range of this first dating series with some clearly unacceptable results brought us to hand in another series of samples for radiocarbon dating also directly related to the smelting activities. This time we restricted our samples to charcoal fragments from



Features within Workshop Pit	Find No.	Lab. No.
Furnace 01	A1726	DeA-10966
Furnace 03	B2571	DeA-10952
Furnace 03	B2572	DeA-10954
Furnace 04	B2570	DeA-10956
Furnace 04	B2621	DeA-10958
Furnace 05	B2939	DeA-10960
Furnace 05	B2968	DeA-10962
Furnace 07	B3845	DeA-10964
Furnace 09	B3716	DeA-10979
Furnace 09	B3749	DeA-10981
Furnace 10	B3731	DeA-10969
Furnace 12	B6516	DeA-10971
Furnace 12	B6565	DeA-10973
Layer 10021	A4797	DeA-10984
Layer 10021	B3970	DeA-10986
Layer 10096	B4033	DeA-10975

Fig. 7. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Results of the second series of radiocarbon measurements in 2017. The charcoal samples were exclusively taken from the bottom layers within the slag pits of the bloomery furnaces and from two additional charcoal-bearing layers inside the workshop pit. 2σ standard deviation (data provided by Isotoptech Zrt., Debrecen [I. Futó, M. Molnár, V. Mihály]).
Obr. 7. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Výsledky druhé série radiokarbonových měření z roku 2017. Vzorky dřevěného uhlí byly výlučně odebírány ze spodních vrstev zahloubených nístějí železářských pecí a ze dvou dalších vrstev obsahujících dřevěné uhlí uvnitř dílenské jámy. Směrodatná odchylka 2σ (data poskytl Isotoptech Zrt., Debrecín [I. Futó, M. Molnár, V. Mihály]).

the bottom of the slag pits of as many furnaces as possible.[2] The resulting radiocarbon dates consistently back up the archaeological dating of the production unit, all staying within the two centuries around the turn of the Christian era (*fig. 7*).[3] The location of all samples on site addressed in this paper can be seen in *fig. 8*.

3. Discussion

The two dating series feed the suspicion that we had uncovered a severe methodological problem in radiocarbon dating of in-slag charcoal samples. The clear discrepancy of the two data sets rules out any effect of the old-wood theory, 'the perpetual bug bear of archaeolo-

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[2] Four tree species were represented in the 16 samples: *Quercus* (11), *Fagus* (3), *Tilia* (1), *Carpinus* (1).

[3] Thanks are due to I. Futó, M. Molnár, V. Mihály (Isotoptech Zrt., Debrecen) for the radiocarbon measurements. (cf. *Molnár et al. 2013a*; *2013b*).

Fig. 8. Wetzlar-Dalheim C86, Lahn-Dill-District, Germany. Location of charcoal samples referred to in the text.

Obr. 8. Wetzlar-Dalheim C86, zemský okres Lahn-Dill, Německo. Nálezová poloha vzorků dřevěného uhlí, na které je v textu odkazováno.

gists' (*Hendrickson – Hua – Pryce 2013*, 45), as the most common remedy for radiocarbon results that are too old to match the archaeological record. While we do not want to rule out the odd old oak tree ending up in a charcoal burning fire, it is to be rendered wholly impossible that it was only their charcoals being trapped in the slags inside the furnace while contemporary charcoals gathered at the bottom of the slag pits. What is more, the use of branches and smaller trees in charcoal production for metallurgical purposes is regularly to be found in archaeological contexts[4], while the valuable timbers of large trees were carefully selected for building and construction.

The enormous range of dates in our first radiocarbon sequence for the very short-lived smelting activities at Wetzlar-Dalheim C86 points to a contamination of the samples within the slag blocks. To a varying degree the dates obtained tend to be (much) older than the dates expected from the archaeological record. There is not one measurement younger than the expected date of deposition in the earlier Roman Period. As all other samples from our site that were not extracted from a slag block do not show any significant deviations from the expected time range, we can rule out a contamination of the specimens after deposition as well as during or after sampling.

So we are clearly left with a problem inherent in the carbon of the charcoal samples from inside the slags themselves. The temperatures within a bloomery furnace reach up to 1250 °C. Fayalitic bloomery slag has a liquifying point between 1150–1200 °C. The charcoals trapped in such slags would have been subjected to very high temperatures for several hours in a closed system under highly reducing conditions.

It is at this point in the process that the contamination must have occurred. The only explanation for a radiocarbon date getting older than the true date of the original sample is the addition of fossil carbon. So we have to conclude that our in-slag charcoal samples from Wetzlar-Dalheim have been contaminated with fossil carbon to a varying and unpredictable degree.

4. Implications

If this is true for our site, there could be similar problems at other sites where high temperature metallurgical processes have been dated by radiocarbon analysis from charcoals within slags. As this short note cannot present a systematic survey of radiocarbon datings from metallurgical contexts, we will only pick out a few sites and regions to show the range of possible implications (see *fig. 1*). It is not our intention to offend any of our colleagues but to raise awareness of a methodological problem in radiocarbon dating that has been there right from the beginning, but has not been addressed to date and has always been explained away with the help of 'the old wood story'.[5] One could even argue that the 'old

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[4] *Thiébault 2002*; *Tegtmeier 2009* (Iron Age, Middle Ages); *Stöllner et al. 2014*, 55–57 (Iron Age); *Overbeck 2011*, 287–293 (13th–14th cent. AD); *Nelle 2003* (post medieval; more likely related to glass making).

[5] It may be noted, that one of the largest laboratories for radiocarbon analysis in the world already for an number of years explicitly does not recommend in-slag charcoal samples for radiocarbon dating: […] 'many times the charred material found in slag originates from very large "old" trees that were used in the fires for smelting operations. As such, the wood can be several hundreds of years old when it is burned and this old wood (charcoal) ends up in the slag yielding a much older age than the actual time of manufacture. We have

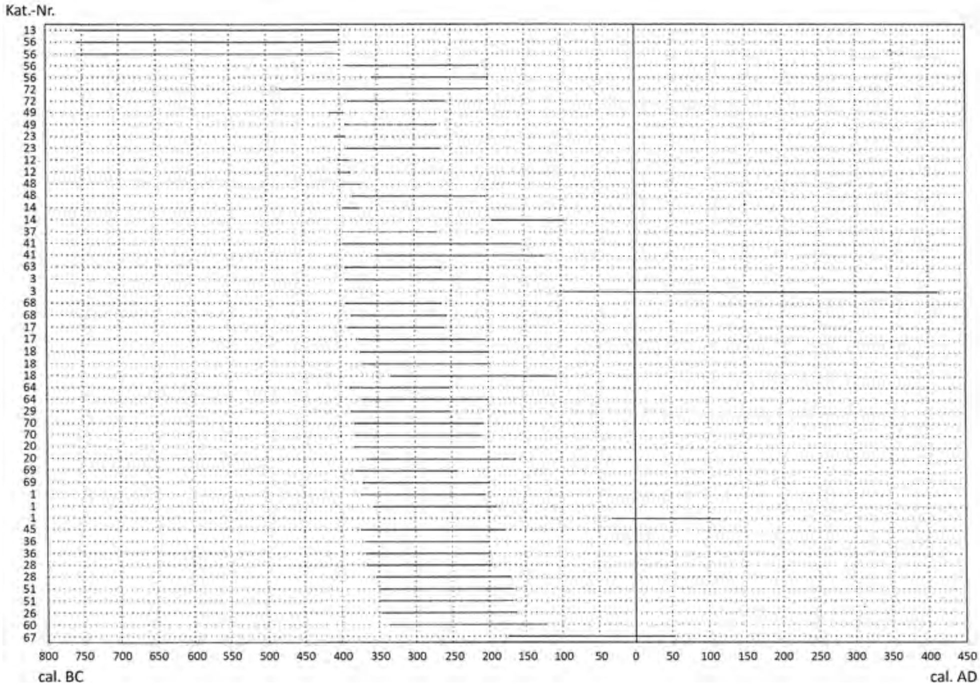

Fig. 9. Roth Valley, Bavarian Suebia, Germany. 52 AMS-radiocarbon measurements (1σ standard deviation) from 28 bloomery production sites of the region (after *Ambs – Gassmann – Wischenbart 2001*, 25, fig. 13).
Obr. 9. Povodí řeky Roth, Bavorské Švábsko, Německo. 52 AMS-radiokarbonová měření (směrodatná odchylka 1σ) z 28 lokalit s doklady železářské výroby v daném regionu (podle *Ambs – Gassmann – Wischenbart 2001*, 25, fig. 13).

wood effect' has up to now severely inhibited any serious scientific discussion on interpreting (too) old dates, especially from charcoals taken from inside metallurgical slags.

The first example we would like to draw attention to is from an Iron Age smelting region in southern Germany, south of the Danube in the Roth-valley in Bavarian Suebia. Here a large series of 53 AMS-radiocarbon dates were published in 2001 (*Ambs – Gassmann – Wischenbart 2001*, 23ff., tab. 3, 25, fig. 13). The samples all derive from charcoals extracted from bloomery slags from 28 smelting sites of the region. Apart from three dates reaching back to the Hallstatt-Period calibration plateau, the samples very consistently show a date range between the 4th to 2nd centuries BC (*fig. 9*). So in this case there does not seem to be a problem. Another example where no alterations were discernible may be quoted from the region around the La Tène-Period oppidum of Manching in Bavaria (*Gassmann – Schäfer 2013*, 355, Tab. 2).

A very important early iron production district in Germany is the Siegerland region only about 50 km north of the Lahn valley. From early in the twentieth century onwards

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seen this several times when working with this type of sample, and it is why we typically don't recommend this type of material for radiocarbon dating.' (http://www.radiocarbon.eu/carbon-dating-blog/1067/charred-material-dating/ [last call 28.10.2017, 18:40]).

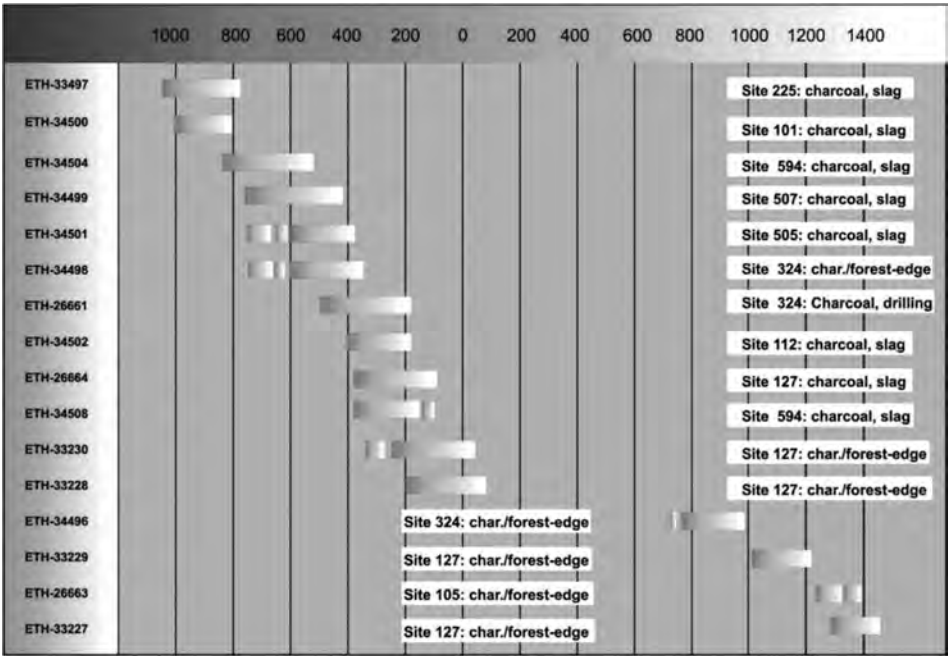

Fig. 10. ^{14}C-dates (2σ standard deviation) from sites investigated between 2002 and 2007 in the north-western part of the Siegerland, Central Germany (after *Stöllner et al. 2014*, 54, fig. 11).
Obr. 10. ^{14}C data (směrodatná odchylka 2σ) z lokalit zkoumaných v letech 2002 až 2007 v severozápadní části Siegerlandu ve středním Německu (podle *Stöllner et al. 2014*, 54, Abb. 11).

it had been famous for its late Iron Age bloomery production and also features a second production phase in the Middle Ages. New research has been undertaken there in recent years (*Stöllner et al. 2009*; *Zeiler 2013*) and a series of radiocarbon dates from several smelting sites has been published (*fig. 10*; *Stöllner et al. 2014*, 54, fig. 11). A closer look reveals a similarly wide range of dates as in Wetzlar-Dalheim. For the Siegerland, however, the published sequence ‘only’ goes back to the late Bronze Age, also without a distinct concentration of dates in the archaeologically known main production periods. The first five dates from the beginning of the sequence were all derived from charcoals in slags. Yet some of the dates indeed fall into the production periods expected by archaeology. Thus the differences between the radiocarbon dates and the archaeological evidence are not as marked and obvious as at Wetzlar-Dalheim. This may probably be true for a great many other sites, where similar date ranges occurred without being as clearly unacceptable as at Wetzlar-Dalheim.

The argument may be pushed further yet. We can suspect that there would be quite a number of unreported cases, where the dates obtained by radiocarbon analysis were too old to be plausibly connected to iron production. Who would want to publish a ‘sensational’ Neolithic or early Bronze Age iron smelting activity in Central Europe? At the beginning of our research in the Lahn valley in 1999 we ourselves put aside a first and seemingly isolated far too early date from charcoal within a slag from a later Iron Age smithy site

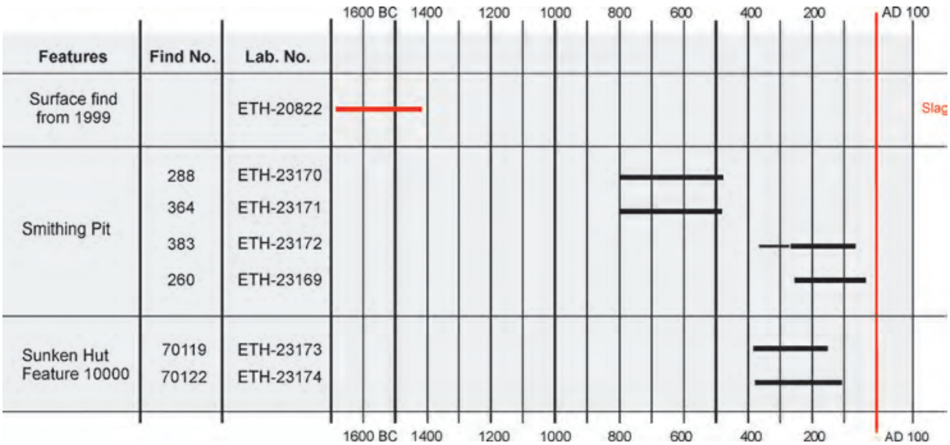

Fig. 11. Lahnau-Atzbach, Lahn-Dill-District, Germany (excavation 2000). Radiocarbon dates from a later Iron Age smithy with 2σ standard deviation (data from ETH Zurich [I. Hajdas, G. Bonani]).
Obr. 11. Lahnau-Atzbach, zemský okres Lahn-Dill, Německo (arch. výzkum 2000). Radiokarbonové datování (směrodatná odchylka 2σ) materiálu kovárny z mladší doby železné (data poskytl ETH Zurich [I. Hajdas, G. Bonani]).

at Lahnau-Atzbach, Lahn-Dill-District (*fig. 11*; cf. *Schäfer – Stöllner 2002*, 104, fig. 15). While we used the old-wood theory to explain two dates on the Hallstatt-Period calibration plateau (*Schäfer – Stöllner 2002*, 99 with note 42), we left aside the middle Bronze Age date from a small surface slag as somehow severely altered or contaminated. This example additionally raises the issue that the dating problem might also affect materials from iron working (smithing) contexts.

More than twenty years ago, a series of very old iron production sites in Sweden were published that astonished scholars at the time (*Hjärthner-Holdar 1993*). While we do not want to question the results in Sweden in general, it could be worth having a new and fresh approach to them, in the light of the new evidence presented here.

The last case study that we want to put forward adds a global perspective and sums up the inherent problems very well. It is concerned with medieval iron production of the Angkorian Khmer Period (9th–15th centuries AD) in Cambodia (*Hendrickson – Hua – Pryce 2013*). Here, analysis of in-slag charcoal was deliberately adopted to reconstruct the ‘spatial history’ of over a dozen iron smelting sites with substantial slag deposits within the 22 km^2 large temple complex Preah Khan in Preah Vihear province, Cambodia. The decision for the sampling strategy was identical to our own intentions at Wetzlar-Dalheim, trying to make sure to date the production process itself. At Preah Khan slag blocks or cakes were collected from the surface or upper edge of the slag heaps to date the end of the production sequence. Fifteen AMS ^{14}C results were obtained from twelve slag cakes, representing seven separate slag concentrations from four different sites (*fig. 12*). While the archaeological evidence presents itself rather uniformly (site topography and layout, typology of tuyères, slag cakes), the radiocarbon measurements cover a period of more than 600 years. Typically again, no concentration of any main production period may be seen, but rather a continuous flow, spanning the times from the early 11th to the mid-17th centuries AD (*Hendrickson –*

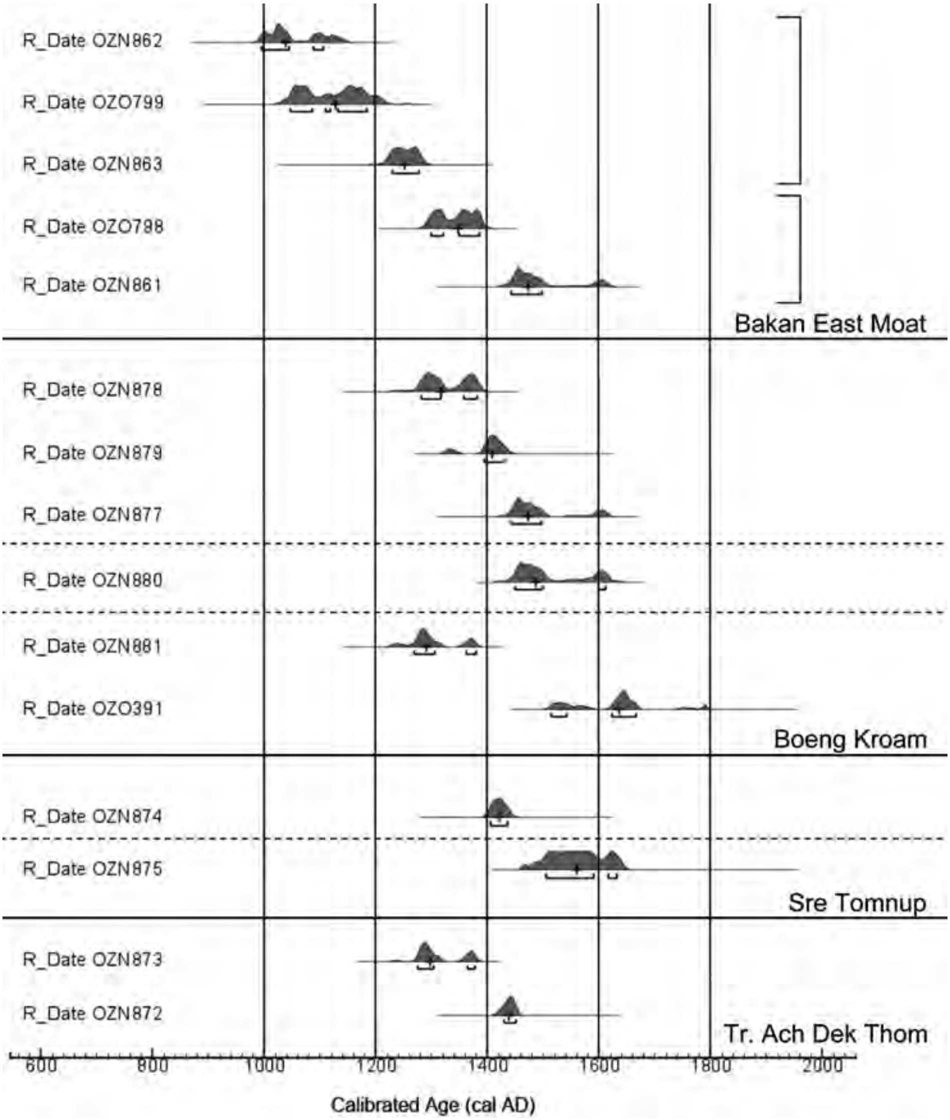

Fig. 12. Calibrated radiocarbon ages (2σ standard deviation) of in-slag charcoal samples from slag cakes of four bloomery production sites of the Angkorian Khmer Period at Preah Khan in Preah Vihear province, Cambodia (rearranged and altered after *Hendrickson – Hua – Pryce 2013*, 42, fig. 7).
Obr. 12. Kalibrované radiokarbonové stáří (směr. odchylka 2σ) vzorků dřevěného uhlí zataveného v koláčích strusky ze čtyř lokalit s doklady železářské výroby v období „Angkorian Khmer" v provincii Preah Vihear v Kambodži (upravené a pozměněné podle *Hendrickson – Hua – Pryce 2013*, 42, fig. 7).

Hua – Pryce 2013, 42, fig. 7). In two cases more than one sample was taken from an individual slag cake and the resulting dates all differed markedly from each other. The three most ancient dates of the published sequence even derive from within one single slag.

This last example can stand for a great many more that do show signs of 'something not being quite right' but are not as disastrous not to be explainable any more. What is more, the ageing effect for samples from the Middle Ages or the Post Medieval Period, when more ^{14}C is still available in the sample, might not be as marked as at older sites, so that a small amount of fossil carbon will not alter the sample too dramatically and render the result wholly impossible.

What are the possible sources of fossil carbon to cause the contamination? The examples listed above have shown that in some cases the radiocarbon datings match with the archaeologically derived dates and in some cases there are more or less severe differences. In our first example in the Roth valley (Bavarian Suebia), where we had matching results, it is evident that the local geology does not contain any calcium carbonate in the soils. The Central Lahn valley at Wetzlar-Dalheim, however, features a geology rich in limestone and loess. Both contain fossil carbon in high amounts. Under strongly reducing conditions and at temperatures above 900 °C calcium carbonate ($CaCO_3$) disintegrates completely into CaO and 2CO. The CaO will react with the slag and is not important for our dating problem.[6] With the carbon monoxide, however, we have a possible source of gaseous fossil carbon entering the slag smelting system. We do not know exactly what happens during the several hours within the semi-liquid slag block, but it seems to be enough time and the right conditions to cause a contamination with fossil carbon. The most likely source of calcium carbonate entering the furnace would be via the furnace wall/lining or coming in with the charge in regions with natural calcium carbonate resources. Incidentally in some regions the iron ore itself contains fossil carbon in the form of limestone, dolomite ($CaCO_3 \cdot MgCO_3$) or siderite ($FeCO_3$).

5. Conclusions

In recent years an ever growing number of seemingly old radiocarbon dates from bloomery sites have become known. The dating series from Wetzlar-Dalheim and the others discussed above have shown the inherent problems when dating charcoal samples from inside metallurgical slags. The problem is aggravated as datable archaeological material like pottery or small finds is often conspicuously absent at metallurgical sites especially from survey programmes and charcoal from slags may often be the only possibility to obtain a date.[7]

Our results suggest that radiocarbon analysis of in-slag charcoal samples should not be the first – let alone the only – choice, when dating bloomery sites.[8] It became apparent, that especially in regions with high fossil carbonates like in loess or limestone areas, severe problems with contamination during the ancient reduction process could have occurred.

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[6] Yet, a considerable CaO content in the slag may reflect a contribution of calcium carbonate to the smelting process: cf. *Oinonen et al. 2009*, 878 f.

[7] Cf. the survey find of a 13.6 kg slag block from Clemency 'Hansenbernsheck', Luxembourg, that morphologically belongs to a Roman Period slag pit furnace but yielded an Iron Age date (*Gassmann – Schäfer 2017*, 40 ff.; 46 fig. 37). In-slag charcoal samples of two slag tongues from the surface of a medieval slag heap in the vicinity at Clemency 'Lamerbierg' yielded disparate dates from cal 570–780 and cal AD 800–1020 respectively (*ibid.*, 46, fig. 37).

[8] Contrary to *Park – Rehren 2011* and *Hendrickson – Hua – Pryce 2013*, 37.

Thus, such datings should be judged with great caution, all the more so when only isolated analyses of that kind are available for a site. As our second dating series from Wetzlar-Dalheim indicates charcoal samples from the bottom layer of a furnace base may be a better choice. The same probably applies for charcoal layers within slag heaps. For future investigations we suggest that more emphasis should be given to typological and technological studies to get further hints on the chronological differentiation. The value of a slag typology is still not widely recognised, but will in many cases be able to provide a technological and chronological framework for metallurgical complexes in a given region.

The methodological problem in radiocarbon dating from in-slag charcoal samples was discussed above with reference to the iron technology. But of course the same problems will occur with other metallurgical technologies, where slags were produced at high temperatures under strongly reducing conditions, like in copper, lead and silver smelting.

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GUNTRAM GASSMANN, ARGUS Company, Kastellweg 10, DE-72072 Tübingen; argus.gassmann@t-online.de
ANDREAS SCHÄFER, Institute of Archaeological Sciences, Heritage Sciences and Art History, University of Bamberg, DE-96045 Bamberg; andreas.schaefer@uni-bamberg.de

Two iron technology diffusion routes in Eastern Europe

Dvě trasy šíření znalosti zpracování železa ve východní Evropě

Vladimir I. Zavyalov – Nataliya N. Terekhova

Archaeometallographic data suggest that there were two technological models in Eastern Europe as early as the Bronze Age–Early Iron Age transition period (9th–7th centuries BC). We link their development to two routes via which knowledge of use of ferrous metals diffused from Anatolia. The first route reached the North Caucasus, the second route passed through Greece and the Balkans to Central and Eastern Europe.

archaeometallography – Eastern Europe – ferrous metals – transition period

Archeometalografická data naznačují, že již v přechodu mezi dobou bronzovou a ranou dobou železnou (9.–7. stol. př. n. l.) existovaly ve východní Evropě dva technologické modely zpracování železa. Jejich rozvoj spojujeme se dvěma trasami, kterými se znalosti užívání železných kovů z Anatolie rozšířily. První trasa překročila Zakavkazsko, druhá trasa vedla přes Řecko a Balkán do střední a východní Evropy.

archeometallografie – východní Evropa – železné kovy – přechodné období

The issue of emergence and spread of ferrous metallurgy is still relevant despite the fact that it has been on the research agenda for quite a long time. *L. Morgan* (*1935*, 28) argued that ‘The production of iron was the event of events in human experience, without a parallel, and without an equal, besides which all other inventions and discoveries were inconsiderable, or at least subordinate’.

Most researchers tend to believe that telluric iron production originated in Anatolia. The region had all basic preconditions, such as focused and systematic search of ore minerals; understanding properties of minerals which could be turned to metal; pyrotechnological structures; use of artificial blowing to achieve high temperatures (when smelting); charring of wood (*Waldbaum 1978*, 23). The earliest artefacts made from iron (second half of the third millennium BC) have been found in Anatolia. The finds include an iron mace head (Troy, 2600–2400 BC), a blade of a gold handled dagger, two pins with gold heads, a pendant, a cross-shaped plaque, fragments of a knife (Alaça Höyük, 2400–2100 BC), a twisted bracelet from Tilmen Höyük (*Esin 1976*, 225; *Yalçin 1999*, 179), a piece of corroded iron (Tarsus, 2100 BC). However, this list has been recently modified. It has been established that the mace head from Troy is a piece of slag or ore rather than metallic iron (*Pernicka 1990*; *Yalçin 1999*). Initially, because of high content of nickel (up to 3.91 %), a number of researchers even believed that this artefact was made from meteoric iron (*Waldbaum 1978*, 20; *1980*, 92).

In the first half of the second millennium BC iron artefacts were widely spread across the Eastern Mediterranean. Items made from ferrous metal and dated to this period have been found not only in Anatolia, but also in Mesopotamia, Egypt, Crete and Cyprus. Iron artefacts dated to the second half of the second millennium BC have been retrieved from sites in Greece, the Aegean islands, the Balkans, the Levant, Transcaucasia, and Eastern Europe. It was the time when the knowledge of iron metallurgy began to spread; this is attested by the presence of metallurgical centres dated to the 14th–13th centuries BC discovered in the Levant, Eastern Georgia and Serbia (*Abramishvili 1961*; *Abramishvili – Mikeladze 1970*; *Fritz et al. 1991*; *Liebowitz – Folk 1984*; *Stojić 2006*).

R. Pleiner paid a lot of attention to the issue of the diffusion of iron from Anatolia. At the same time he thought Europe to be a secondary area of iron industry development. On the maps that he made (*Pleiner 1980*, 382; *Pleiner 2000*, fig. 8), he traces the following routes of ironworking knowledge diffusion: one route passed through Greece and the Balkans to Western and Eastern Europe; another route runs through the Caucasus to the North Black Sea maritime steppes and the Volga Region (*Pleiner 1980*, 376; *2000*, 30–31). In this case R. Pleiner relied purely on archaeological data, i.e. finds of iron artefacts. Given high relevance of this issue, we would like to revisit it and offer conclusions based on the technological data. Indeed, archaeological artefacts found in Eastern Europe and results of their archaeometallographic studies conducted so far have provided an opportunity to clarify some of Pleiner's conclusions.

The earliest items made of ferrous metal and coming from Eastern European sites are dated to the end of the second millennium BC (*fig. 1*; see *Bidzilya et al. 1983*; *Grakov 1958*; *Chizhevsky 2012*; *Shramko et al. 1977*; *Shramko – Buynov 2012*). These items have been found singly, which means that knowledge of the new metal reached the local populations for the first time. Archaeometallographic studies of such finds are not numerous. Only four artefacts coming from Ukraine, namely three knives and an awl, have been examined so far. One knife was forged entirely from bloomery iron (Lyubovka /Любовка/ settlement, late 2000s – early 1000s BC: *Radzievska – Shramko 1980*, 103); another knife was made of iron and showed traces of unintentional (?) carburization (Oskol /Оскол/ settlement, 11th–9th centuries BC: *Bidzilya et al. 1983*, 18); the third knife was made from inhomogeneous bloomery steel (Chervonny Shlakh-1 /Червоный Шлах-1/ settlement, 11th–9th centuries BC: *Buynov 2003*, 6). The awl (Tashlyk 1 /Ташлык 1/ settlement, 13th century BC) was made from iron, which was slightly carburized in places. When forging the awl the blank was folded and welded several times as evidenced by chains of slag inclusions interpreted by the author as welding seams (*Bidzilya et al. 1983*, 15). Therefore, what we have is an early stage of ironworking, which does not fit entirely within the Late Bronze Age. No specific techniques typical for ironworking in Eastern Europe of that time have been recorded. The Late Bronze Age – Early Iron Age transition period in Eastern Europe falls within the 9th–mid-7th centuries BC as evidenced by artefacts recovered at the sites in the Northern Caucasus and the North Black Sea maritime steppes. This stage is characterized by a substantial increase in the number of both iron artefacts and their types.

The so-far gathered analytical (archaeometallographic) data, characterizing technology used to produce the earliest iron artefacts, support the conclusion that various technological models, underpinned by various technological traditions, began to emerge in Eastern Europe at that time. The technological model is understood to comprise three interrelated components, namely: a technical and technological stereotype, production traditions, and influence of alien cultures. The technical and technological stereotype includes a certain set of attributes and the correlation between them which characterize material, categories,

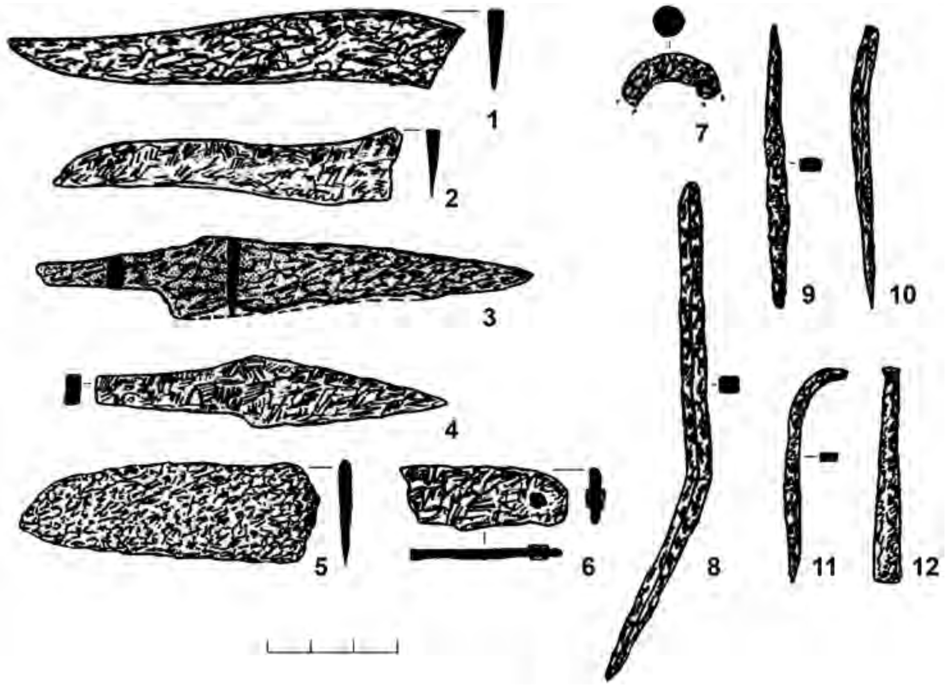

Fig. 1. The earliest iron objects from Eastern Europe 12th–9th century BC (Ukraine, by I. B. Shramko): 1 – Lyubovka /Любовка/ settlement; 2 – Kicevka /Кицевка/ settlement; 3 and 7 – barrow near Vishnevy Dol /Вишневый Дол/ village; 4 – Oskol /Оскол/ settlement; 5 – Chervony Shlyakh /Червоный Шлах/ settlement; 6, 11 and 12 – Velikaya Topolyakha /Великая Тополяха/ settlement; 9 – Bondarikha /Бондариха/ settlement; 8–10 – Tymchenki /Тимченки/ settlement.
Obr. 1. Nejstarší železné předměty z východní Evropy 12.–9. století př. n. l. (Ukrajina, od I. V. Šramka): 1 – sídliště Ljubovka; 2 – sídliště Kicevka; 3 a 7 – mohyla poblíž vsi Višnevyj Dol; 4 – sídliště Oskol; 5 – sídliště Červonyj Šlach; 6, 11, 12 – sídliště Velikaja Topoljacha; 9 – sídliště Bondaricha; 8–10 – sídliště Timčenki.

techniques and methods of making items in a specific archaeological culture. The technical and technological stereotype in blacksmith craft is a stable element of culture. Transfer of a technical and technological stereotype from generation to generation throughout a long period of time is the essence of production traditions.

Two different technological traditions have been traced by examining artefacts from sites in the Northern Caucasus dated to the Late Bronze Age – Early Iron Age transition period; the so called Eastern European tradition and the Trancaucasian/Southwest Asian tradition.

The Eastern European tradition developed in the North Black Sea steppe and forest-steppe zones in the Belozer culture period (the 11th–10/9th centuries BC: *Terekhova – Erlikh 2002*, 135). This tradition was based on the technical and technological stereotype associated with the use of simple techniques such as forging of artefacts entirely of iron or heterogeneous bloomery steel (i.e. directly from unhomogenized ingots formed from blooms). Only a few artefacts showed evidence of carburizing and heat treatment, i.e. techniques improving mechanical properties of iron objects (or parts thereof).

The use of techniques typical for ironworking such as carburizing and heat treatment is a distinctive feature of the so-called Transcaucasian technological tradition (it should be noted that heat treatment included only quenching and tempering/annealing, which have been determined by presence of sorbite or even spheroidised pearlite in the samples examined). Employment of these techniques, representing a cutting-edge technology of the time, led to a significant improvement in mechanical properties of iron objects.

As has been noted earlier, these traditions underpinned two different technological models, the so-called Eastern European model and the Caucasian model. There is numerous evidence for the Eastern European model retrieved from the sites of the steppe and forest-steppe zone in Eastern Europe dated to the 9th–8th centuries BC (Klin Yar /Клин-Яр/, Pshish /Пшиш/, Kubansky and Psekupsky /Кубанский and Псекупский/ burial grounds, Sofievka /Софиевка/, Verkhny Bishkin /Верхний Бишкин/, Subbotovo /Субботово/ (*Terekhova 1997*; *Terekhova et al. 1997*, 48–55; *Shramko et al. 1977*). Most likely, the development of the Eastern European model was influenced by the Hallstatt blacksmith traditions. Recently published archaeological materials demonstrate that the Hallstatt populations made a rather strong impact on the development of the populations who lived not only in the Carpathian Region and the West Volynia Region but also across the entire forest-steppe area of the North Black Sea maritime areas (*Kashuba 2012*, 237; *Krushelnitskaya 1991*, 24; *Levitsky – Kashuba 2011*, 153). As metallographic study of iron objects from the Hallstatt sites suggests, simple technological techniques (such as forging items out of iron and bloomery steel) were predominantly employed. Items with carburized points or cutting edges are rather rare and their heat treatment was rarely applied (*Pleiner 1980*, 388–389; *Hošek 2010*).

The second (the so-called Caucasian) model has been traced through the artefacts yielded by the sites in the North and Central Caucasus (Fars, Serzhen-Yurt, Tliysky /Фарс, Сержень-Юрт, Тлийский/ burial ground: *Voznesenskaya 1975*; *Terekhova 1999*; *2002*). It emerged on the basis of ironworking experience of the Transcaucasian centres. The technique of man-made carburizing was mastered by Transcaucasian craftsmen as early as the end of the second millennium BC (*Abramishvili 1961*; *Abramishvili – Mikeladze 1970*). The Transcaucasian centres developed under the influence of the Near East centre where carburizing and heat treatment techniques had been employed as early as the 12th century BC. For example, a sorbitic quenching as a specific method of heat treatment has been documented by examining a series of iron artefacts from Urartu (*Piaskowski – Wartke 1989*, 93). It may be argued that Transcaucasian craftsmen who maintained close cultural and historical links with Anatolia absorbed both metallurgical innovations and high-tech ironworking techniques.

These two models appear to reflect different routes by which the knowledge of the use of iron penetrated into Europe from one centre (*Terekhova – Erlikh 2002*) located in Southwest Asia. The first route associated with the 'Caucasian' model traversed the Transcaucasian Region and reached the Northern Caucasus. The second route passed through Greece and the Balkans to Central and Eastern Europe (*fig. 2*).

The data discussed above show that different technological models developed in the Early Iron Age societies although knowledge of ironworking diffused from one source (Anatolia). It seems that technically advanced methods of ironworking such as carburizing and heat treatment were developed in Asia Minor at the end of the second millennium BC

Fig. 2. Map showing directions of the diffusion of iron and the knowledge of iron metallurgy at the decline of the Bronze Age as suggested by *R. Pleiner* (*2000*, 30–31, fig. 8), corrected by authors; gray area: area of the beginning Iron Age in the Near East (15th–11th centuries BC); hatched areas: areas with a developed civilization of iron at the decline of the Bronze Age; yellow arrows: hypothesized Thraco-Hallstatt-Venetian route; blue arrows: Caucasian route; red arrows: Greek and Phoenician routes.
Archaeological sites mentioned in this article: 1 – Lyubovka /Любовка/; 2 – Oskol /Оскол/; 3 – Chervonny Shlakh-1 /Червоны Шлях-1/; 4 – Tashlyk 1 /Ташлык 1/; 5 – Klin Yar /Клин-Яр/; 6 – Pshish /Пшиш/; 7 – Kubansky cemetery Кубанский могильник; 8 – Psekupsky cemetery/ Псекупский могильник/; 9 – Sofievka /Софиевка/; 10 – Verkhny Bishkin /Верхний Бишкин/; 11 – Subbotovo /Субботово/; 12 – Fars /Фарс /; 13 – Serzhen-Yurt /Сержень-Юрт/; 14 – Tliysky cemetery /Тлийский могильник/; 15 – barrow near Vishnevy Dol /Вишневый Дол/ village; 16 – Kicevka /Кицевка/ settlement; 17 – Velikaya Topolyakha /Великая Тополяха/ settlement; 18 – Bondarikha /Бондариха/ settlement; 19 – Tymchenki /Тимченки/ settlement.
Obr. 2. Mapa znázorňující směry difúze znalosti železné metalurgie na konci doby bronzové, navržená *R. Pleinerem* (*2000*, 30–31, fig. 8) a poopravená autory článku. Šedá oblast: oblast počátku doby železné na Blízkém východě (15.–11. století př. n. l.); šrafované oblasti: oblasti s rozvinutou výrobou železa v závěru doby bronzové; žluté šipky: předpokládaná trasa thrácko-halštatsko-benátská; modré šipky: kavkazská trasa; červené šipky: řecká a fénická trasa. Archeologické lokality zmíněné v tomto článku: 1 – Ljubovka; 2 – Oskol; 3 – Červony Šljach-1; 4 – Tašlyk 1; 5 – Klin-Jar; 6 – Pšiš; 7 – Kubanskoje, mohylové pohřebiště; 8 – Psekupskoe, mohylové pohřebiště; 9 – Sofievka; 10 – Verchnij Biškin; 11 – Subbotovo; 12 – Fars; 13 – Seržen-Jurt; 14 – Tlijskoe, mohylové pohřebiště; 15 – mohyla poblíž vsi Višnevyj Dol; 16 – sídliště Kicevka; 17 – sídliště Velikaja Topoljacha; 18 – sídliště Bondaricha; 19 – sídliště Timčenki.

(*Fritz et al. 1991*; *Wheeler – Maddin 1980*). However, in the 13th–12th centuries BC links between the states of Asia Minor and the populations of the Eastern Mediterranean were disrupted by invasions of the Sea Peoples which hampered the transfer of innovative technological knowledge along the route going to the west and further to Eastern Europe. On the contrary, in the case of the north-eastern route that runs across Transcaucasia to the Northern Caucasus, there was no impediment in the diffusion of the technological knowledge. Technological innovations in Transcaucasia and the Northern Caucasus, which spread in a culturally similar environment were kept by local craftsmen as professional secrets and did not have a substantial influence on other regions of Eastern Europe. Hence, the development of the two technological models that emerged as early as the Late Bronze

Age – Early Iron Age transition period can be linked to two routes via which knowledge of ferrous metal spread from Anatolia.

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VLADIMIR I. ZAVYALOV, Institute of Archaeology RAS, ul. Dm. Ulyanova 19, 117036 Moskva, Russia
v_zavyalov@list.ru
NATALIYA N. TEREKHOVA, Institute of Archaeology RAS, ul. Dm. Ulyanova 19, 117036 Moskva, Russia
nnterekhova33@mail.ru

The early iron metallurgy in the Siberian Arctic

Raná metalurgie železa v sibiřské Arktidě

Evgeny Vodyasov

Archaeological excavations conducted at the settlement-sanctuary of Ust-Polui, located just north of the Arctic Circle in Western Siberia yielded the oldest remains of early iron production in the Circumpolar region of Asia. Ust-Polui archaeological finds associated with metallurgy of iron are dated back to the 3rd century BC – 2nd century AD. Hence the finds date the origins of metallurgical technologies used in the north of Western Siberia virtually several centuries back in time and geographically extend the spread of iron metallurgy between the eras significantly. It seems that Ust-Polui is the most northern point on the Earth where iron metallurgy was developed by ancient people. The discovery of new iron production site poses an important question – what are the reasons and ways of appearance of the iron smelting technologies in the Polar North of Siberia? It is possible that all knowledge was obtained from outside via contacts with metal producing societies, who lived in the eastern regions of the Ural Mountains (*to the southwest of Ust-Polui*)*, and knew how to produce iron about two thousand years ago.*

Circumpolar Region – Siberia – iron smelting – Early Iron Age

Archeologické výzkumy osady-svatyně Ust-Polui, nacházející se severně od arktického kruhu v západní Sibiři, odkryly nejstarší pozůstatky rané výroby železa v polárních oblastech Asie. Archeologické nálezy spojené s metalurgií železa jsou datovány od 3. stol. př. n. l. do 2. stol. n. l. Datují tak počátky užívání metalurgických technologií v severozápadní Sibiři prakticky o několik století dříve a geograficky výrazně rozšiřují prostor, v němž se železná metalurgie mezi danými obdobími šířila. Zdá se, že Ust-Polui je nejsevernějším bodem planety, kde byla starověká metalurgie železa rozvinuta. S objevem nové lokality s doklady metalurgie železa vyvstává důležitá otázka – z jakých důvodů a jakým způsobem se metalurgie železa za polárním kruhem na severu Sibiře objevila? Je možné, že veškeré poznání bylo získáno zvenčí prostřednictvím kontaktů se společnostmi vyrábějícími kovy, které žily ve východních oblastech Uralských hor (*na jihozápad od Ust-Polui*) *a které si osvojily znalost výroby železa již před dvěma tisíci lety.*

polární oblast – Sibiř – výroba železa – starší doba železná

1. Introduction

The Iron Age in Arctic Siberia is one of the most interesting and at the same time challenging periods in the study of ancient societies. The challenges are associated, first of all, with the extreme lack of archaeological data on iron metallurgy in the vast territory of Northwestern Siberia.

Another problem has to do with sources being underexplored, in addition to their scarcity. Unfortunately, it should be admitted that most publications make scant mention of the evidence of ancient iron production and hardly ever provide essential information about contexts, slag weight or amount, its type or morphological properties, furnace schemes or cross sections, geochemical data, etc. Most often, Russian researchers simply ignore the huge information potential of slag (*Vodyasov – Zaitceva 2010*; *2017a*). Moreover, even

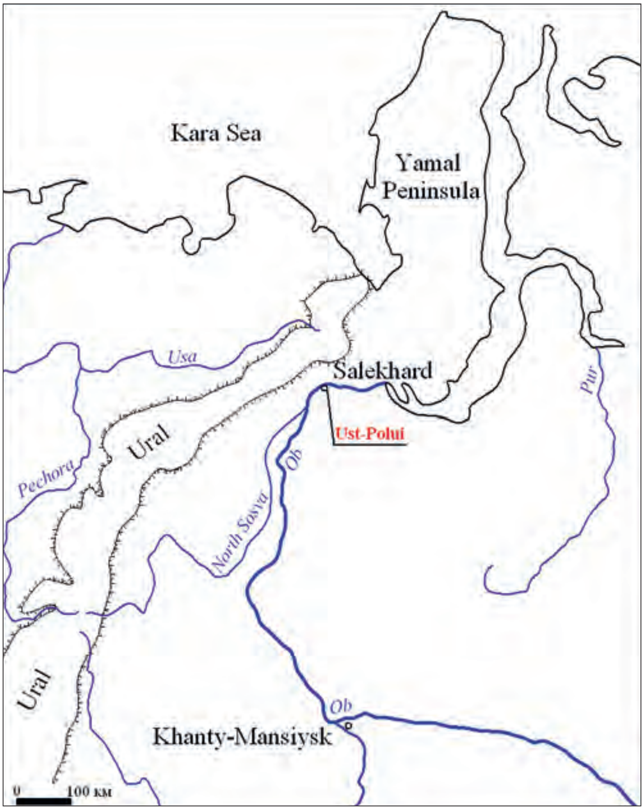

Fig. 1. Location of the Ust-Polui archaeological site.
Obr. 1. Poloha archeologické lokality Ust-Polui.

the existing scarce data remains unavailable for the international scientific community as majority of articles is published in Russian-language journals.

Traditionally it is believed that people of the Arctic Siberia had been unable to produce iron artefacts. Allowing this option was hard for the lack iron production 1000 BC – 1000 AD sites discovered in the region 'Due to the Lower Ob River basin being under-explored, we have no sufficient information to trace back the earliest iron production sites', Valery Chernetsov wrote (*Chernetsov 1953*, 231). Today, as over half a century has passed since Chernetsov's cited work was published, the situation has changed very little. As Sergey Parkhimovich indicates, 'Despite the ample archaeological fieldwork in the taiga zone of Northwestern Siberia conducted over the last decades, the question how local iron metallurgy was born and developed remains under investigated. Hundreds of early Iron Age and medieval artifacts have been excavated to varying extents all over the broad territory that includes the Lower and Middle Ob /Обь/ River areas as well as the Lower Irtysh /Иртыш/ River region, yet evident remains of metallurgical furnaces have only been discovered by the Konda /Конда/ River and in the lower reaches of the Irtysh River' (*Parhimovich 2013*, 100).

The smithies of the first millennium AD in the basin of the Bolshoy Yugan /Большой Юган/ River of Surgut Ob /Сургутское Приобье/ River Region used to be considered the

Fig. 2. Slag and furnace wall (lining) from Ust-Polui, Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera). Vasily Adrianov's expedition of 1936. 1–4 – blacksmith slag, 5 – furnace clay wall (lining). Photo by A. Gusev.
Obr. 2. Struska a stěna (výmaz) pece z Ust-Polui, Petrovo velké antropologické a etnografické muzeum (Kunstkamera). Arch. expedice Vasila Adrianova v roce 1936. 1–4 – kovářská struska, 5 – hliněná stěna (výmaz) pece.

most northern and ancient (reliably dated) sources on iron metallurgy in Western Siberia (*Chemjakin 2011*). However, the smithies only proved that the population of Western Siberia's taiga zone had smithing but not smelting technologies.

Evidence of iron metallurgy in the ancient sanctuary of Ust-Polui /Усть-Полуй/ became a prominent scientific discovery. The ancient sanctuary of Ust-Polui is one of the most extraordinary archaeological sites in Western Siberia. An extremely rich cultural layer with numerous finds such as bronze, bone and wooden art objects, along with excellently preserved organic matter, have made Ust-Polui a reference site for studying the Early Iron Age in Northern Eurasia. The site is located to the north of the Arctic Circle (*fig. 1*), in Salekhard /Салехард/ (the lower reaches of the Ob River, Northwestern Siberia), and dates back to the cusp of the eras.

Excavations at Ust-Polui began in 1935–1936 under direction of Vasily Adrianov. The site was also excavated by Valery Chernetsov and Vanda Moshinskaya in 1946, Natalya Fedorova's expedition in 1993–1995 (*Fedorova – Gusev 2008*), and Andrey Gusev in 2006–2015.

There has been ongoing debate whether Ust-Polui is a settlement or a sanctuary, as well as debate over the number of layers and stratigraphic dating. However, iron-smelting and smithing facility remains discovered by Andrey Gusev in 2010, 2012 and 2015, and their further study, making an invaluable contribution to research on the origin of iron metallurgy in the Arctic, is the point of this study. Both radiocarbon and archaeological dating have revealed that both the furnaces and slag come from the period between the 3rd century BC and the 2nd century AD. Up to date, the discovered traces of iron metallurgy are the most ancient and the only dating from the Early Iron Age in the Arctic. The results of the study of the Ust-Polui iron metallurgy are for the first time summarized in this article.

2. Archaeological evidence of iron metallurgy at Ust-Polui

The first fragments of slag and furnaces were found at Ust-Polui by Vasily Adrianov as early as 1936, but Adrianov did not identify his finds as remains of iron production and never revealed them to the public. All the known pieces of slag excavated in 1936 are smithing slag (*fig. 2*). Of special interest is the slag cake (*fig. 2: 1*), 8 cm in diameter and 3 cm thick. The formation of the slag cake marks the necessary stage of an iron bloom processing (*McDonnell 1991*; *Pleiner 2000*, 255). A bloom taken out of furnace and, when still hot, forged immediately to became more compact and free of slag, should later be reheated in a hearth to be forged and cleaned of any remaining slag. At high temperatures in a hearth (over 1200 °C), slag drains down the bloom and solidifies under a tuyere or at the bottom of the hearth in the form of plano-convex 'cake'. Unfortunately, there is no information on whether furnaces themselves were found, or whether all the slag was included in the collection or not. Neither the context nor the location of the finds are known. For this reason, we cannot make any conclusion more precise than that the population of Ust-Polui, regarding the finds from 1936, might have been able to forge 'raw' iron blooms.

3. Archaeological evidence of 2010–2012 and 2015

Remains of iron metallurgy at Ust-Polui were first documented and identified in 2010–2012. An important find made during the 2010 expedition was a large slag cake (*fig. 3: 1*) evidencing iron production at Ust-Polui as such. The cake (sample No. 2438) had a weight of about 2,500 g, a diameter of 20 cm, and a density of 2.6 g/cm^3.

This type of slag (furnace bottom) is formed at the bottom of a bloomery furnace that has no special canal for tapping liquid slag from the hearth. As a result, slag flows down on to the so-called 'carbon bed' (a layer of hot coal), taking the specific plano-convex form. Despite being similar in their form to smithing slag cakes, furnace bottoms are larger in size and can weigh up to a few kilos, while smithing slag cakes weigh on average 300–400 g and rarely exceed 15 cm in diameter (*Pleiner 2000*, 216–217).

The first iron production site at Ust-Polui was explored by Gusev's expedition in 2012 (*Vodyasov – Gusev 2016*). A 2×1.2 m stain of an up to 0.15 m thick carbonaceous layer filled with soot and fish bones was stripped; a fraction of slag was also found within the feature. The furnace might have been right on that spot, but its design is impossible to reproduce as very little has survived. Associations of bloomery walls, fragments of clay lining, and slag were found on the slope and at the bottom of a ditch about 1–3 m to the north.

All the furnace walls and lining fragments have a lot of slag in them, its total weight being about 0.5 kg. Slag is represented by small fractions of smithing cakes no larger than 7 cm in diameter and about 1–3 cm thick (*fig. 3: 3*). Nearly all of them cracked and chipped off. They are likely to have been formed during further smithing operations rather than ore smelting. Most probably, there was a smithing hearth over that part of the ancient ditch.

The iron production site was abandoned as soon as the work was finished, and slag and wall fragments later shifted and slipped down the slope as a result of archaeological processes. It is not improbable, however, that ancient smelters simply disposed of waste by dumping it down the ditch.

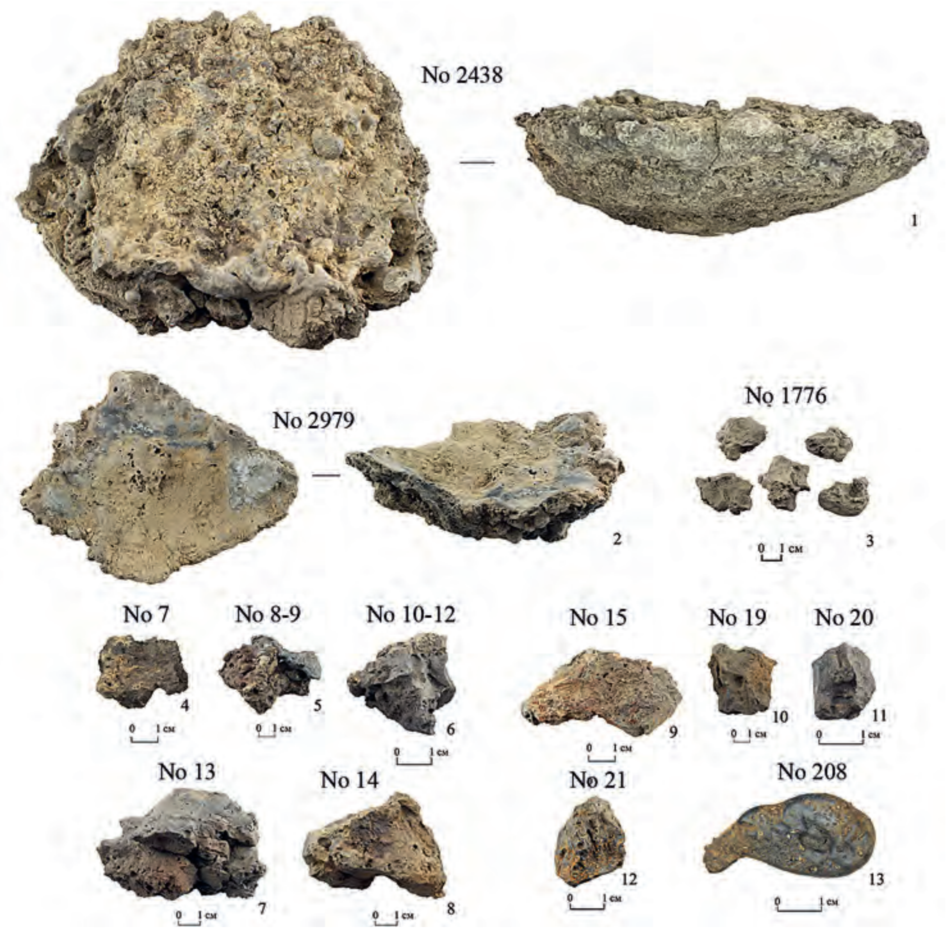

Fig. 3. Slag and bloom fragments. 1–2 – slag excavated in 2010, 3 – slag excavated in 2012, 4–12 – slag excavated in 2015, 13 – bloom excavated in 2015.
Obr. 3. Fragmenty strusky a železných hub. 1–2 – struska z výzkumu z r. 2010, 3 – struska z výzkumu z r. 2012, 4–12 – struska z výzkumu z r. 2015, 13 – železná houba z výzkumu z r. 2015. Foto E. Vodyasov.

For dating purposes, it is especially important that iron was produced at the same time that the ditch was functional, which follows from the context of the iron production remains discovered in 2010–2012 in various parts of Ust-Polui. Even if we assumed that the metallurgical installations could have appeared much later, when the ditch had already been filled with earth and organic matter, it would be hard to explain how the metallurgical waste distributed so evenly along the edges of the ditch and spread to its slopes and bottom, too. One piece of slag was found right next to the bridge over the ditch. Using a wood sample, the Laboratory of Dendrochronology of the Institute of Plant and Animal Ecology (Ural Branch of the Russian Academy of Sciences) determined the chronological date of the bridge to be 77–76 BC (*Gusev – Fedorova 2012*, 21). It should be made clear, however, that dendrochronological dating determines the age of the bridge, not that of the ditch, so

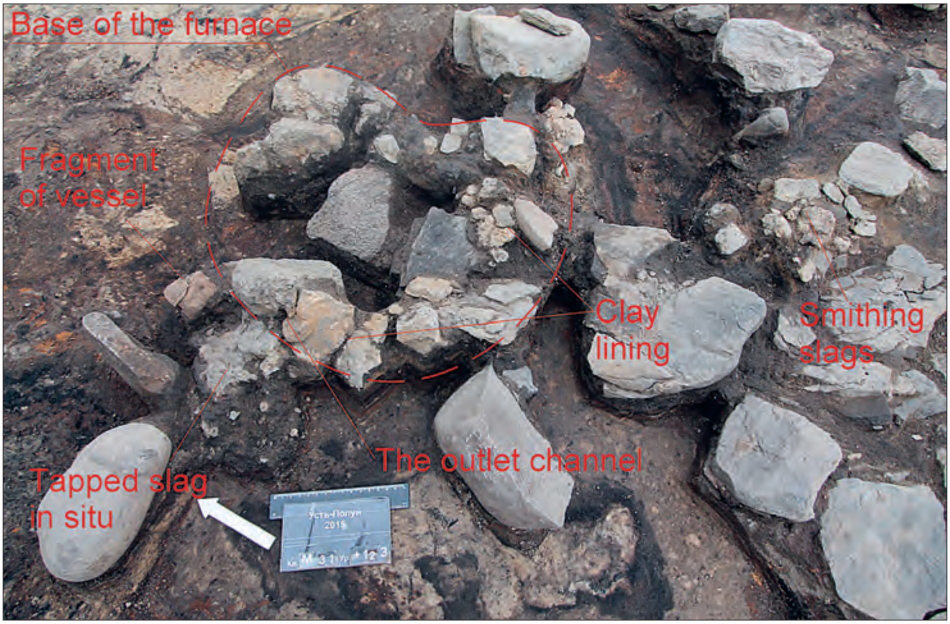

Fig. 4. The ancient sanctuary of Ust-Polui. Remains of a bloomery furnace (expedition of 2015). Photo by A. Gusev.
Obr. 4. Starobylá svatyně v Ust-Polui. Zbytky železářské pece (expedice v r. 2015).

it is entirely possible that the fortification could have existed within a broader time period, namely from the very end of the first millennium BC to the early first millennium AD.

In order to date the iron production site investigated in 2012, two samples of charcoal were taken from the ditch and dated by the Laboratory of Geology and Cenozoic Climate (Siberian Branch of the Russian Academy of Sciences). The resulting calibrated dates are as follows: COAH-9421 – 2030±105 BP (cal 178 BC – 75 AD) and COAH-9422 – 2150±100 BP (cal 236 BC – 88 BC). As we can see, these dates match the period between the 3rd century BC and the 1st century AD.

Since all the remains of iron production found in 2010–2012 were attributed to the ditch, the period of time specified above can be taken as the earliest date of such production. The same timeframe embraces the most of the period when the Ust-Polui cultural layer was accumulated.

The largest metallurgical site at Ust-Polui was explored at the inner side of the ditch in 2015. It was located about 40 m south of the slag accumulations found in 2012.

The finds included remains of an iron-smelting furnace and the smithing hearth (*Vodyasov – Gusev – Asochakova 2017*). The 30–35 cm diameter base made of rock debris and clay has been preserved, and surrounded by furnace walls (*fig. 4*). Some 1–2 cm fragments of clay lining with adhered slag were found on the same spot.

It is difficult to reconstruct the height of the furnace, but it was hardly more than 0.5 m, as judged by the amount of wall fragments. A 1.5 cm tap channel was a curious engineering feature of the furnace (*fig. 4*). The channel for taping liquid slag was located by the

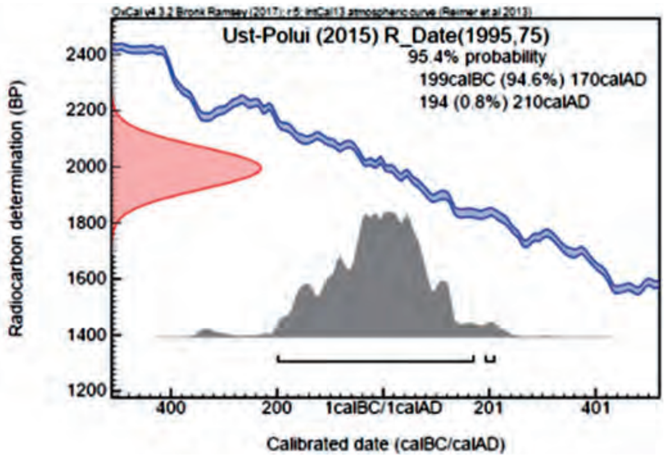

Fig. 5. Radiocarbon dating of the bloomery furnace excavated in 2015 (calibrated in OxCal).
Obr. 5. Radiokarbonové datování železářské pece odkryté v roce 2015 (kalibrované v OxCal).

very base from the western side. A slag monolith was discovered right by the tap hole. That was the first reliably documented record of slag tapping in Northwestern Siberia dating back to the Iron Age. Bloom forging was carried out in immediate proximity to the furnace: an accumulation of tiny slag pieces of 1–3 cm in diameter, small smithing cakes, and a fragment of bloom were found 0.5 m south-east of the furnace (*fig. 3*: *13*).

Apart from iron production waste, the stones and slag also reveal traces of bronze casting: tiny bronze drippings, a small fragment of a flat-bottom crucible, and a wall of a bronze boiler. The fact that remains of bronze casting were discovered together with iron slag might be indicative of the multi-purpose nature of this feature.

A ceramic vessel lip was lying close to the tap channel (*fig. 4*). Numerous similar ceramic fragments have been excavated within the main complex of Ust-Polui (*Moshinskaja 1965*, 23, fig. 11) and in the contemporaneous site of Katravozh /Катравож/. Beyond the lower reaches of the Ob River, such vessels have been found in large numbers in Surgut Ob River Region (*Chemjakin 2008*, 180, fig. 74) and Tomsk Region /Томская область/ (*Chindina 1984*, 249, fig. 43). The latter two studies attribute them to the Sarovo period of the Kulay culture /Кулайская культура/ and date them back to the last centuries BC – first centuries AD. The major Ust-Polui stratum containing such fragments has been dated to the period between the 2nd century BC and 1st century AD.

Dating was performed using a sample of charcoal embedded in smithing slag and other production waste. Upon calibration in OxCal, the investigated complex was dated to the 2nd century BC – 2nd century AD (*fig. 5*).

4. Results of archaeological surveys of iron metallurgy at Ust-Polui

The surviving archaeological evidence of early iron production in the Polar region allow reconstructing some iron-making techniques of the Early Iron Age in the Circumpolar region of Siberia. The metallurgical features and types of slag provide direct evidence of use of iron making and processing technologies by the ancient Ust-Polui society.

No	Slag No	SiO_2	TiO_2	Al_2O_3	*FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	Sum
1	**2979**	21.83	0.16	5.16	48.68	0.18	2.48	3.91	1.50	1.37	5.01	0.10	90.37
2	**2438**	29.77	0.25	6.34	44.36	0.17	2.54	7.42	0.72	1.91	2.56	>0.01	96.06
3	**1776**	36.47	0.35	6.68	39.05	0.04	3.16	6.43	0.91	1.57	1.59	0.016	96.28
4	**4/940**	40.37	0.41	11.68	29.66	0.121	5.86	5.87	0.34	0.88	0.60	0.004	95.78
5	**7/1527**	48.06	0.55	8.86	25.86	0.311	3.11	4.49	2.23	2.13	0.79	0.006	96.38
6	**9/912**	33.45	0.43	7.51	40.17	0.037	3.10	4.49	1.65	1.54	1.34	>0.001	93.71
7	**10/1429**	26.20	0.50	7.82	36.06	0.405	3.78	9.39	2.30	2.41	6.40	>0.001	95.26
8	**13/927**	29.39	0.34	7.11	41.23	0.153	2.80	6.73	0.16	1.65	3.66	>0.001	93.21
9	**15/931**	25.50	0.30	6.66	41.93	0.144	2.37	8.75	0.15	1.80	5.62	>0.001	93.23
10	**19/945**	31.67	0.31	6.90	42.45	0.068	3.63	4.21	2.40	0.95	1.02	>0.001	93.61
11	**20/1277**	37.71	0.53	10.69	30.17	0.155	4.51	6.05	2.52	2.06	1.94	0.006	96.34
12	**21/1349**	29.10	0.28	5.21	49.39	0.001	2.42	3.78	0.16	0.27	0.48	0.001	91.11

Notes: **$FeO=FeO+Fe_2O_3$. No. 1–2 – slags from excavation 2010, 3 – slag from excavation 2012, 4–12 – slags from excavation 2015.

Table 1. Slag XRF analysis (wt%). The analyses were performed on The Oxford ED2000 X-ray fluorescence (XRF) analyzer by E.M. Asochakova (Tomsk State University).
Tabulka 1. XRF analýza strusky (hm%).

Two types of furnaces were used to produce iron. The first type is represented by a small heating furnace with no liquid slag tapping. Furnaces of this type have not been found at Ust-Polui, but their existence in the ancient times is proved by large slag cakes excavated in 2010. Such furnaces were made of clay, as judged by associations of wall fragments discovered in 2010–2012. Their original design is impossible to reproduce.

Furnaces of the second type, made of stones and clay, had a small above-ground shaft and a special hole near the base for tapping slag during smelting. This slag-tapping technology increased the furnace productivity, and its use indicates a rather high level of iron production at the time. Only one furnace with a slag trough has been found at Ust-Polui (at an iron production feature excavated in 2015).

Charred bones found in two metallurgical features in 2012 and 2015 had most probably been used by smelters as fluxes to promote slag fluidity and reduce iron losses during slagging. Archaeological remains and radiocarbon dating results reveal that furnaces of different types coexisted between the 3rd century BC and the 2nd century AD Back then, iron production and processing at Ust-Polui was concentrated along the fortified edge of the ditch.

The Ust-Polui slag is characterized by an elevated calcium oxide concentration of 6 %, which is its distinctive feature (*table 1*). Concentration of calcium oxide is affected by ore composition, fuels and fluxes (*Crew 2007*). Such a high percentage of calcium in ancient slag is associated with charred animal bones that were added to charge as fluxes. For comparison, average CaO concentration in archaeological slag from other sites in Western

Fe	Mn	Ni	Cu	Zn	Pb	Sum
98.2	1.06	0.06	0.13	0.03	0.51	99.99

Table 2. Bloom fragment XRF analysis (wt%). The X-ray fluorescence analysis was performed by Yu.A. Podosenova (Perm Scientific Center, Ural).
Tabulka 2. XRF analýza fragmentu železné houby (hm%).

Siberia is only 1.2 % (*Zinyakov 1997*; *table 2*). Elevated concentrations of manganese (Mn) in the bloom were also documented by X-ray fluorescence analysis (*table 2*). Manganese passes from ore into slag, substituting some of the iron and combining with $Si0_2$; hence Mn acts as a slag-forming ingredient (see e.g. *Pleiner 2000*, 136).

Phosphorus (P) affects both physical and mechanical properties of iron. Based on the finds from 2010–2015, the average concentration of P_2O_5 in Ust-Polui slag is 2.5 %. Concentration of phosphorus in iron can be estimated using the Piaskowski's formula (*Piaskowski 1965*; *Pleiner 2000*, 265): P (iron) = (0.12–0.35)×P_2O_5 (slag). It follows that iron produced by ancient Ust-Polui smelters contained about 0.3–0.8 % of phosphorus, i.e. it was a high-phosphorus iron (*Piaskowski 1988*). High concentrations of phosphorus enhanced mainly hardness and brittleness of iron (*Pleiner 2000*, 265). Phosphorus in iron ores also prevented iron from carburization during smelting (*Zavyalov – Rozanova – Terehova 2009,* 62). Therefore, smelting high-phosphorus ores yielded iron with low carbon content.

J. Piaskowski believed that the concentration of phosphorus in iron product can be used to identify the type of ore smelted. High-phosphorus iron (0.18–1 % of P) was usually produced from limonites (bog iron ores; *Piaskowski 1988*). Radomír Pleiner states that limonites were an important source of ore in ancient iron making as they got easily deoxidized in furnace and could be found pretty much anywhere in Northern Eurasia (*Pleiner 2000*, 88). Limonites are often referred to as 'bog ores' in Russia, while Scandinavian researchers dub them as 'lake ores'. Bog iron ores normally have high concentrations of phosphorus (0.5–3 %) and manganese (*Pleiner 2000*, 88). As described above, these two elements passed from ores to bloomery iron and slag of Ust-Polui in calculable proportions. Ancient Ust-Polui smelters might have mined limonites in the basin of the River Ob. However, high concentrations of phosphorus in slag could have also been caused by adding fluxes, so any conclusions about the type of ores smelted would be premature today. Unfortunately, no iron ore have been found in any of the expeditions. Raw material must have been prepared outside the site, probably close to ore deposits. Most importantly, identical chemical composition of slag from different Ust-Polui excavations (*tab. 1*) indicates that all of it came from the same deposit.

The weight of slag excavated at Ust-Polui totals about 8 kg. Naturally, such small-scale iron-making operations at Ust-Polui only capture the very first steps in the evolution of iron making technology in the Arctic at the turn of the AD era. However, it cannot yet be excluded that major iron production sites could have been located outside the archaeological site of Ust-Polui. Besides, as mentioned above, the exact amount and weight of slag excavated in all Ust-Polui excavations of the 20th century remains unknown.

5. Phenomenon of the earliest iron production in the Siberian Arctic

Only five iron smelting sites of the Early Iron Age are known today in the whole Western Siberia. All of them are located at least 1,000 km further south than Ust-Polui.

The only Early Iron Age metallurgical site in the basin of the River Ob (before the Ust-Polui site was discovered) had been a furnace dating to the 1st century BC – 4th century AD, which was found at Sarovo /Сарово/ hillfort, modern Tomsk Oblast (*Chindina 1984*, 105–106, 141). Lyudmila Chindina, who led the excavation works, believes that the furnace had been used for iron smelting and concludes that iron had been smelted in pots (!), yet no substantiation is provided (*Chindina 1984*, 141).

In the basin of the Irtysh River, remains of iron production dating to the specified period have been excavated at Rafaylovo /Рафайлово/ and Andreevo-VII /Андреево-VII/ hillforts of the 7th–5th centuries BC and Duvan-II /Дуван-II/ settlement of the first millennium BC – early first millennium AD (*Zinyakov 1997*, 228–229; *Beltikova 2005*, fig. 2). Rafaylovo and Andreevo-VII hillforts are associated with the eastern area of the Itkul /Иткуль/ center of iron production (*Beltikova 2005*). Duvan-II settlement belongs to the Sargat culture /Саргатская культура/ (*Koryakova 1988*). Given the small number of Early Iron Age archaeometallurgical objects in the wide lands of Western Siberia, a question arises naturally, how iron-making technologies could penetrate the territory as far north as to the Siberian Arctic.

We have no other evidence of iron production or processing in the Arctic region at the cusp of the two eras. The Middle Ages are the earliest period to which iron metallurgy sites in the Scandinavian Arctic date, while all the other Early Iron Age furnaces are located much further south of the Polar Circle (*Stenvik 2003*, 125). There is no data on Early Iron Age bloomeries found anywhere in the polar region of North Asia. The earliest evidence of iron production in North America (Newfoundland Island) date to as late as the 10th–11th centuries AD and relates with Vikings' expeditions (*Ingstad 1969*). Ust-Polui may thus be the most northern point on Earth where humans produced iron in the ancient times.

We believe that such unexpected emergence of a small iron production center in the Far North should be associated with the spread of Ural iron-making traditions, which forced out bronze casting in the Ural completely and expanded beyond the region in the 3rd century BC (*Koryakova – Kuzminykh – Beltikova 2011*, 12–14). The conception and development of iron metallurgy in the Ural in the first millennium BC, amidst the Ananyino culture /Ананьинская культура/, was favored by numerous deposits of high quality iron ores. It is important that the Ust-Polui site virtually borders the Polar Urals in the west (the Ural Mountains are 60 km from Ust-Polui). The influence of the Ananyino culture traditions reached as far as the Polar Urals. A number of researchers believe that it was not until the middle of the first millennium BC that iron artifacts appeared on the northern periphery of the Ananyino culture (*Kuzminykh – Chizhevsky 2008*, 37). Unfortunately, no research paper summarizing the results of complex surveys of iron production in this culture has been found. The study of Ural metallurgy of the first millennium BC is much better represented in papers on smithcraft (*Zavyalov – Rozanova – Terekhova 2009*), which touch only slightly upon iron smelting.

The iron-making technology of the Ananyino culture was inherited at the end of the first millennium BC by members of the successive Glyadenovo culture /Гляденовская культура/, contemporaneous to Ust-Polui metallurgy. However, it appears impossible to compare Ust-Polui iron production technology to that of Glyadenovo due to the very low degree of exploration of the latter. Very little is known about Glyadenovo furnaces, iron working characteristics and the level of ancient production development (*Zavyalov – Rozanova – Terekhova 2009*, 87–88). Much more information is available on the Itkul metallurgy of the 8th–3rd centuries BC, the center of which was located on the eastern slopes of the Urals (*Beltikova 2005*; *Koryakova – Epimakhov 2007*, 196; *Koryakova – Kuzminykh – Beltikova 2011*, 13).

Despite varying degrees of exploration of Early Iron Age metallurgy across regions of the Urals, there is no doubt of the fact that iron began to be produced in the Urals much earlier than in Western Siberia. It could have been the Ural traditions that came to the north of Western Siberia along the left tributaries of the River Irtysh (*Vodyasov – Zaytseva 2017b*). A single center of production could have developed at Ust-Polui, in the lower reaches of the Ob River, as a result of culture contacts or even individual migrations of the Ural people, which had mastered new technologies by the cusp of the eras. Anyway, there surely must have been an external cultural impetus that prompted the spread of iron metallurgy to such high northern latitudes. It is hard to think of any other areas in Northern Eurasia apart from the Ural Region that could have been the source of such impetus at that time.

It should also be noted that the spread of iron-making technologies to the north had its natural limits, too. Ust-Polui lies within a climatic zone where forest tundra passes into treeless tundra areas. Iron production could hardly develop at any point in time in tundra without charcoal fuel as a crucial resource. It was the borderline between forest tundra and tundra that became sort of a culture limit to the penetration of iron metallurgy. This ecological niche provided ancient people with all the necessary mineral sources: iron ores and fuelwood.

6. Conclusion

Summing up the results of a complex study of iron metallurgy at Ust-Polui, it makes sense to enumerate the major findings and hypotheses. Firstly, iron production and smithing technologies were born in the Circumpolar Region of Western Siberia as early as on the cusp of the eras. The ancient settlement-sanctuary of Ust-Polui is the most northern and the only point in the Arctic region where evidence of Early Iron Age iron metallurgy has been found. Secondly, ancient Ust-Polui blacksmiths built bloomeries using clay and stone walls, used charred animal bones as fluxes, and knew how to tap liquid slag. Thirdly, the identical geochemical composition of slag from different excavations indicates that the same technology was used all around the region and ores were mined from the same deposit. Limonites in the lower reaches of Ob River could be such sources of ores, but this hypothesis is yet to be verified in a separate study. Fourthly and finally, the development of ancient iron production in the Arctic regions must have been prompted by migrations of metal-producing cultures from the Eastern Urals, where iron metallurgy had developed long before it was transferred to the lower reaches of Ob River.

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EVGENY VODYASOV, Tomsk State University, 36 Lenin Ave., 634050 Tomsk, Russia; Vodiasov_ev@mail.ru

New light on old iron: recent work on Iron Age iron production, consumption and deposition in Britain

Staré železo v novém světle: nejnovější studie výroby, spotřeby a deponování železa v době železné v Británii

Peter Halkon – Zechariah Jinks-Fredrick

Over the last decade, there has been a noticeable increase in the number of projects and discoveries relating to Iron Age iron in the UK. These include the discovery of one of the earliest smelting furnaces at Messingham, North Lincolnshire, an extensive industry along the Thames Valley and finds of iron objects including swords and spearheads within the graves of the Arras culture of Eastern Yorkshire, for example at Pocklington. There has also been an encouraging increase of the number of PhD theses being undertaken in UK universities on early iron objects and their production and deposition, including those supervised and examined by the writer. This contribution will consider the origins of iron production in Iron Age Britain and the relationship between iron production, its uses and the deposition of iron artefacts within the landscape in the light of these recent discoveries.

iron – Britain – Early Iron Age – smelting – deposition

Během posledního desetiletí došlo k výraznému nárůstu počtu projektů a objevů souvisejících se železem doby železné ve Velké Británii. Patří mezi ně objev jedné z nejranějších tavicích pecí v Messinghamu v severním Lincolnshiru, rozsáhlá výroba tradičních nástrojů podél údolí Temže a nálezy železných předmětů včetně mečů a hrotů kopí v hrobech arrasské kultury východního Yorkshiru, například u Pocklingtonu. Došlo také k povzbudivému nárůstu počtu doktorských prací realizovaných na britských univerzitách (některé pod autorovým vedením), zabývajících se nejstaršími železnými předměty a jejich výrobou a deponováním. Příspěvek se zabývá počátky výroby železa ve Velké Británii a vztahy mezi výrobou železa, jeho použitím a ukládáním železných artefaktů v krajině ve světle těchto nejnovějších objevů.

železo – Británie – starší doba železná – tavení – deponování

This article aims to provide a review of recent work being undertaken on iron in Iron Age Britain, focusing on aspects of production, consumption and deposition. Some of the earliest iron objects yet discovered are socketed axe heads, replicating copper alloy examples (*fig. 1*; *Rainbow 1928*; *Manning – Saunders 1972*; *Boughton 2015*). These demonstrates considerable skill at this early period, as unlike copper-alloys, iron had to be forged and pieces welded together. The process of iron smelting, bloom refining and forging of artefacts is more complex than the manufacture of non-ferrous artefacts. The pattern of distribution of these axe heads is interesting as the majority were found south of a line between the Wash and Severn estuary, with a concentration along the River Thames and in South Wales (*Boughton 2015*; *Jinks-Fredrick 2017*). Further examples have been recorded through the Portable Antiquities Scheme (https://finds.org.uk/) in North Yorkshire (*Collins 2014*) and Norfolk (*Rogerson 2016*). Of the five Scottish examples recorded by *Boughton* (*2015*, 144, fig. 5.59) all are near rivers or the coast.

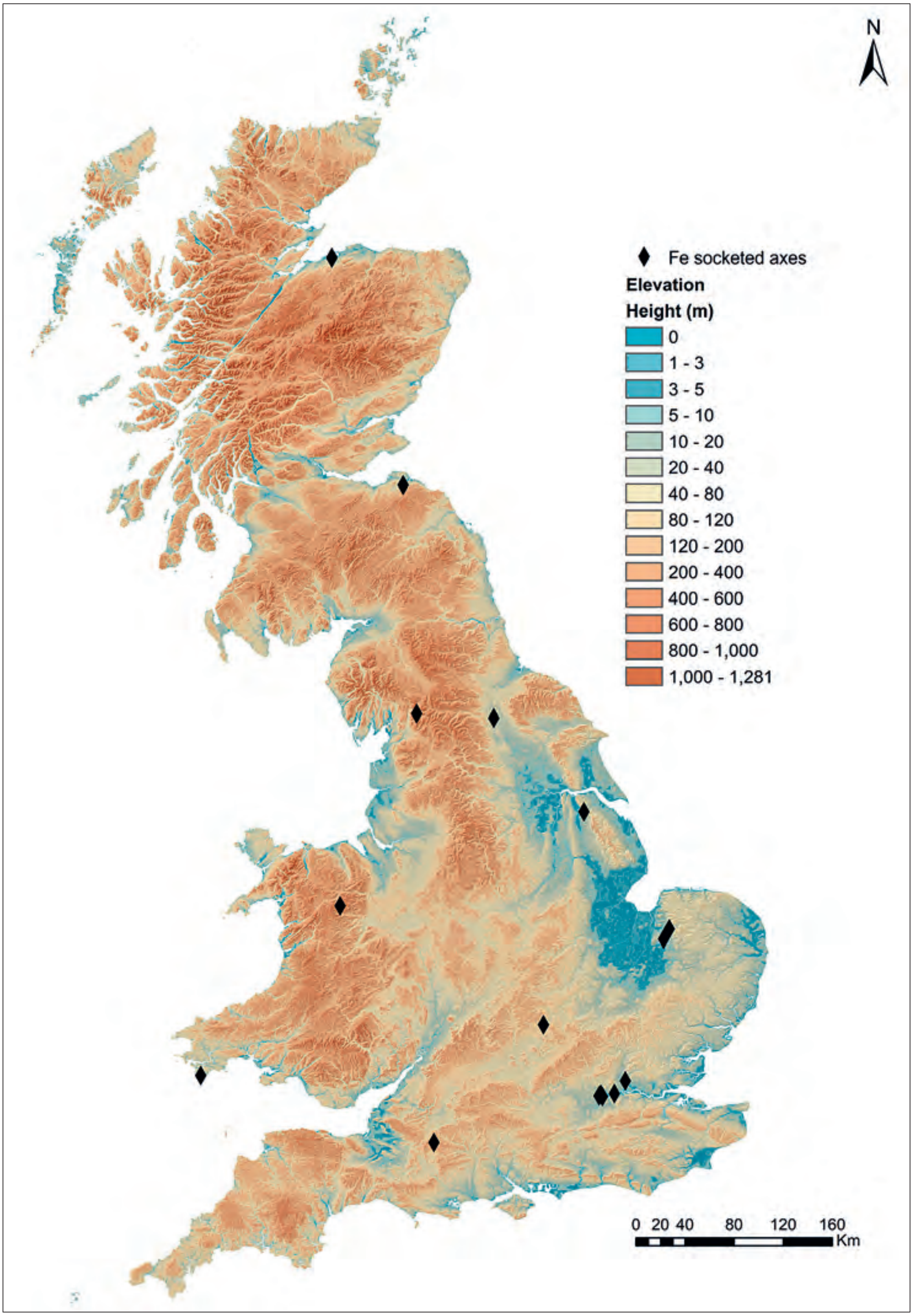

Fig. 1. The distribution of early Iron Age iron socketed axes (after Jinks-Fredrick).
Obr. 1. Prostorová distribuce nálezů železných sekerek s tulejkou ze starší doby železné.

Other items usually made in copper alloy include sickles and pins, like those found in the Llyn Fawr hoard, which was probably a ritual deposit in this south Welsh Lake around 750–600 BC, along with a range of copper alloy objects including cauldrons, weapons and horse trappings (*Fox – Hyde 1939*; *O'Connor 2007*; *Needham et al. 1997*). The Hallstatt C iron sword from Llyn Fawr is another example of the replication in iron of an item normally made from copper alloy and shows considerable skill on the part of the blacksmith responsible.

The earliest recorded iron objects from East Yorkshire are a pin or part of an iron loop and ring from Staple Howe (*Brewster 1963*) a small hill fort on the northern edge of the Yorkshire Wolds dating from Cal BC 753–402 (1 sigma) 765–350 (2 sigma) (*Dent 1995*; *2010*). Further to the East along the North Sea coast, at Scarborough Castle, pieces of iron rod were found with Ewart Park phase copper alloy objects in pits (*Smith 1928*; *Challis – Harding 1975*, 46). Iron fragments were also discovered in ditch fills at Grimthorpe Hillfort (*Stead 1968*, 166, 5–7) dating from 1150–400 BC.

A number of contenders have been proposed as the earliest place for the manufacture of iron in Britain (*fig. 2*). At Hartshill Copse, Upper Bucklebury, Berkshire (*Collard – Darvill – Watts 2006*) hammer scale was found in a late Bronze Age context dating from the 10th century BC. Other early iron production sites include Aldeby, southern Norfolk, where furnaces and slag were found during a watching brief along with later Bronze Age and early Iron Age pottery (*Trimble 2001*). At Shooter's Hill, London (*Dungworth – Mepham 2012*) 63 kg of slag from smelting was discovered in a ditch with later Bronze Age or early Iron Age pottery dating from c. 700–400 BC. At Broxmouth, East Lothian, Scotland, extensive evidence for iron production was found associated with a hillfort dated to 800–400 BC (*Armit – McKenzie 2013*).

In 2016, however, the earliest conclusive evidence for iron production in Britain so far was found in the shadow of the Scunthorpe steelworks at Messingham, North Lincolnshire, consisting of a furnace and 630 kg of slag. Charcoal samples from within the furnace structure and outside provided ^{14}C dates of c. 780–590 Cal BC (*Pitts 2016*).

These sites share a number of characteristics. Both Hartshill Copse and Shooter's Hill are situated relatively near to the Thames Valley, Aldeby lies close to the River Waveney, 10 km from the North Sea at Lowestoft, and Broxmouth is near the Firth of Forth in Scotland, and the North Sea. Further north, a cluster of Iron Age iron production sites has been identified around the Moray Firth (*Cruikshanks 2017*). Messingham lies close to the valley of the River Trent and 20 km south of the Humber estuary itself.

All these rivers are tidal and connected to the North Sea basin, albeit at some distance in the case of the Thames Valley sites. These locations provide access to already well established European communication networks and although independent insular innovation is possible, iron objects and perhaps iron production itself may have arrived by these routes and that 'connections across regions (are) implied by the sharing of new technologies and artefact types' (*Webley 2015*, 126). *Cunliffe* (*1995*) has proposed that the Atlantic seaways of western Britain may have been a conduit for the introduction of iron technology from the European continent, which appears to correlate with the distribution in Britain of later Bronze Age iron objects and Carp's tongue style swords (*Collard – Darvill – Watts 2006*). A cluster of such swords in north-western France also supports *Cunliffe*'s (*2005*, 72) idea of zones of influence and contact.

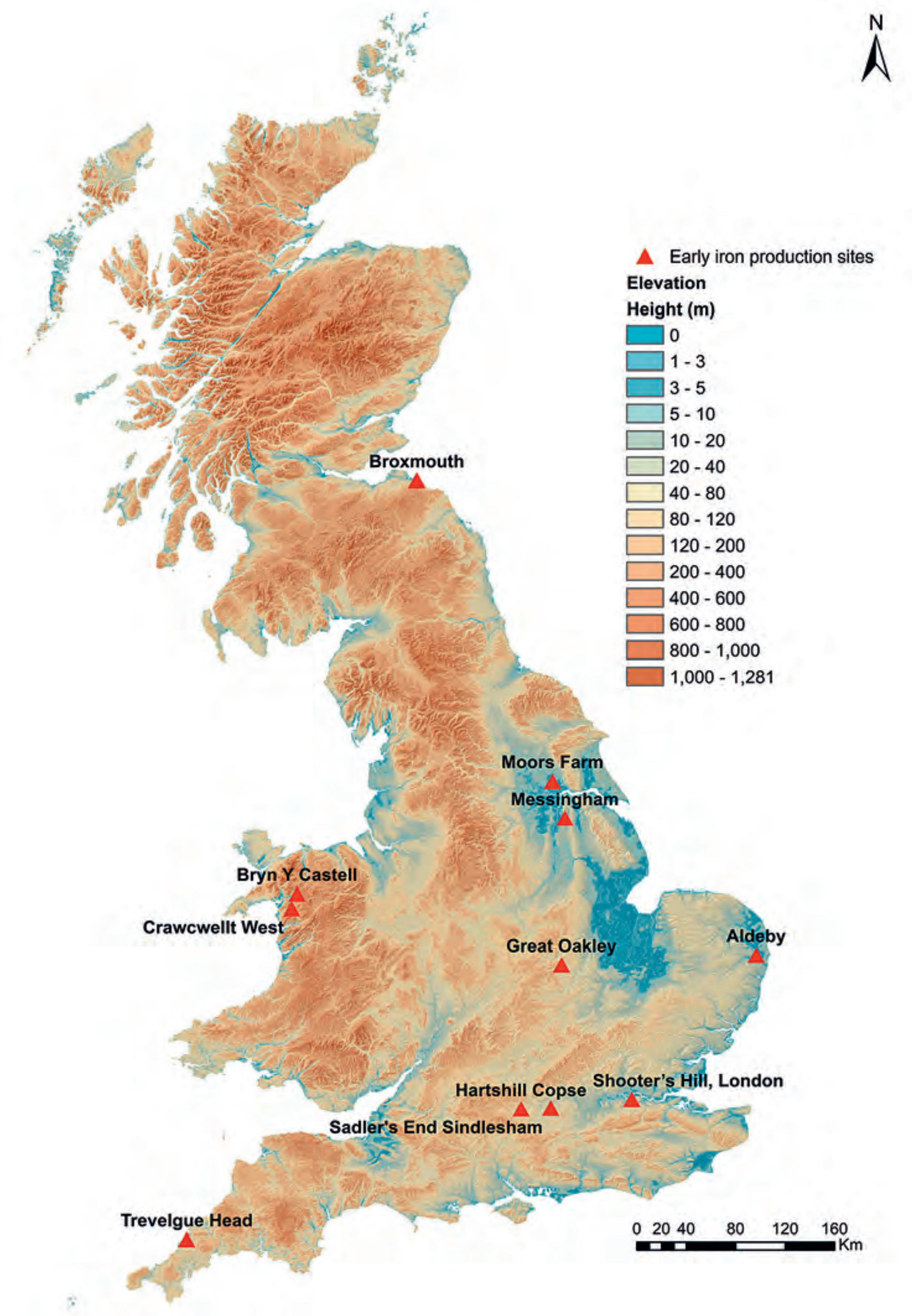

Fig. 2. Early iron production sites in the UK.
Obr. 2. Lokality s ranou výrobou železa ve Velké Británii.

Confirmation of the apparent relationship between early iron production sites and tidal river systems can also be seen within the Foulness Valley, East Yorkshire where long-term research has led to the discovery of a substantial industry (*Halkon 1997a*; *2012*; *Halkon – Millett 1999*). During a programme of field walking, 18 iron production sites were identified within an 8 × 8 km landscape block, the majority around the head of a tidal estuarine inlet of the River Humber. This inlet was created by a combination of factors including a tidal incursion somewhere between 800 and 500 BC and raised sea levels of around 0.7 m OD (*Halkon – Innes 2005*; *Coles 2010*). This opened up the region to trading networks established for a considerable time, as a number of Bronze Age and Neolithic items, including All Over Corded Beakers, are thought to be derived from continental Europe (*Manby – King – Vyner 2003*, 58).

The means by which such communication could be undertaken is well illustrated by the Bronze Age North Ferriby boats found on the northern shore of the Humber. These date from 1940 to 1680 Cal BC (*Wright et al. 2001*) and part of a similar vessel from Kilnsea, on the Holderness coast dated to 1870–1670 Cal BC (*Van de Noort et al. 1999*). So far, no Iron Age sea going vessels have been found in this region, although there is a cluster of log boats around the Humber Basin. These include the Hasholme boat, constructed from an oak with a felling date of 322–277 BC (*Millett – McGrail 1987*), the South Carr Farm log boat (*Halkon 1997b*) and Brigg boat in North Lincolnshire (*McGrail 1990*). The Hasholme and South Carr Farm boats sank in the tidal estuarine inlet and creek system mentioned above and may relate to iron production sites at Hasholme and North Cave.

At Moors Farm, Welham Bridge, a slagheap was found which contained over 5.3 tonnes of slag (*Halkon – Millett 1999*). Charcoal within the slag was radiocarbon dated to 400–200 Cal BC (68%) and 410–170 Cal BC (95%) (HAR 9234) and 520–390 Cal BC (68%) 770–370 Cal BC (95%) (HAR 9235). Further east along the Foulness Valley there were clusters of iron production sites at Bursea and Hasholme, Holme-on Spalding Moor (*Halkon – Millett 1999*) and to the east of the Walling Fen tidal inlet at North Cave (*Dent 1989*; *Halkon 2014*; *McDonnell 1988*).

To the east up the Humber estuary, Iron Age iron production was found along the River Hull at Thearne (*Campbell 2008*; *Halkon 2014*), and Arram (*Wilson et al. 2006*). At Elmswell, near the headwaters of the River Hull, a heap of around 1.5 tonnes of slag was excavated on a site with Iron Age, Roman and Anglo-Saxon activity (*Congreve 1938*) although it is not certain to which of these periods the heap belongs, the excavator's description implies that an Iron Age date is most likely.

The riverine and wetland distribution of these early iron production sites can also be explained by the availability of raw materials, particularly deposits of bog ore. In the case of the Foulness and Hull Valleys, recent analysis of smelting and smithing slag confirms the use of high phosphorus bog ores (*Hall 2017*). In many general books on Iron Age Britain the ubiquity of iron ores is referred to (e.g. *Harding 2014*, 90; *Cunliffe 1991*, 453) and the presumption made that any iron ore could be smelted using Iron Age technologies. Subsequent experimental archaeology, however, has demonstrated that iron production is much more complex than previously thought and some of the better-known 'modern' deposits were not fully exploited until the introduction of the Bessemer process. This is supported by *Schrüfer-Kolb* (*2004*, 16) who states, '… the economic assessment of ore sources is a complex undertaking and the simple plotting of chemical data against each

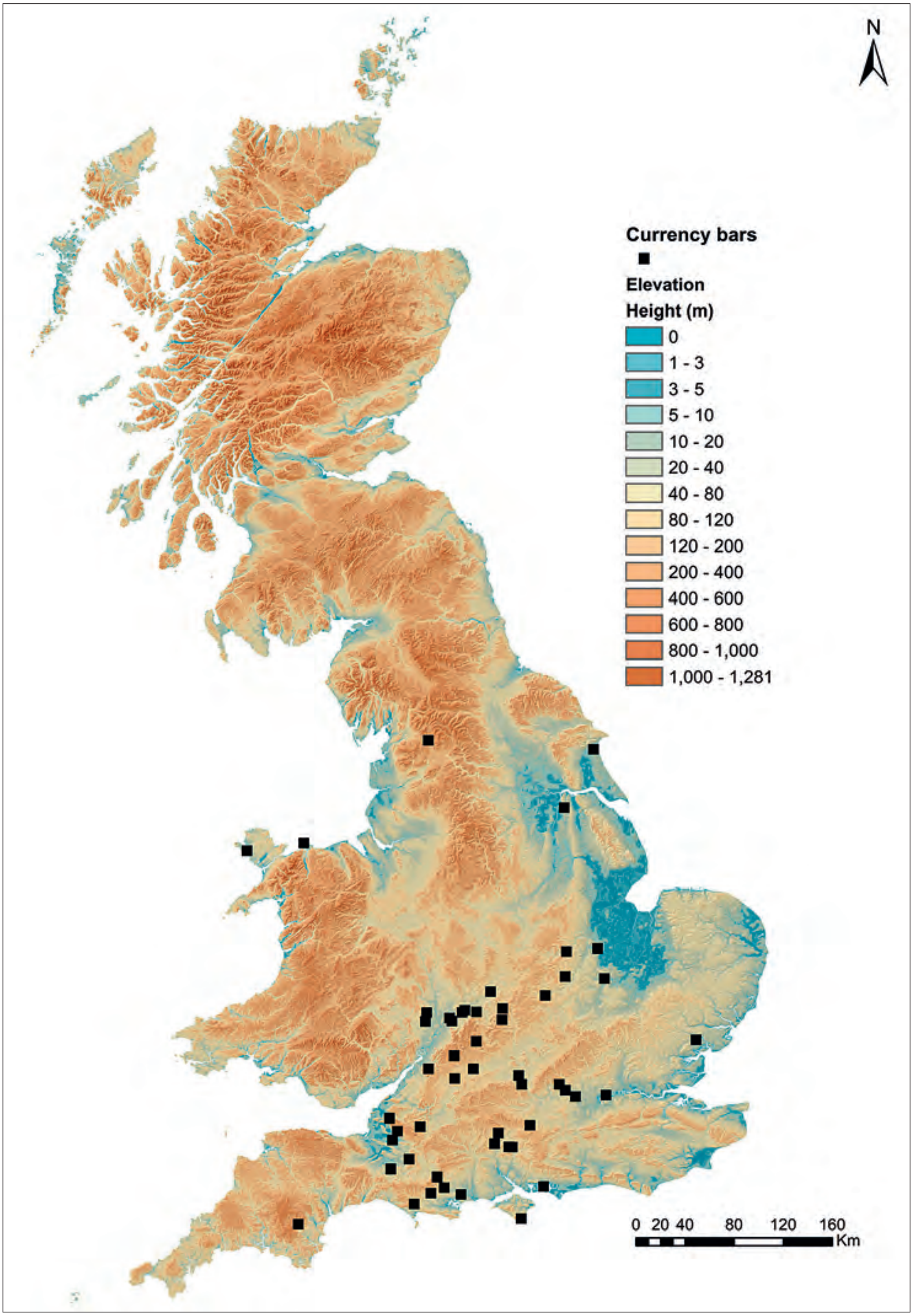

Fig. 3. The distribution of currency bars in the UK (after Jinks-Fredrick).
Obr. 3. Prostorová distribuce nálezů hřiven ve Velké Británii.

other is an over-simplification. Ancient resources must not be measured against modern standards'. Ore resources, particularly siderite ores from the Jurassic ridge, which runs from the Bristol Channel to the North Yorkshire Moors, were exploited during the Iron Age and Roman periods, particularly in the East Midlands in Northamptonshire, with a site at Great Oakley, near Corby, thought to be one of the earliest in this region (*Schrüfer-Kolb 2004*, 52; *Jackson 1982*). The area around the hillfort at Hunsbury is thought to have been a further centre for iron, although this is partly based on the concentration of currency bars there (*Schrüfer-Kolb 2004,* 105), artefacts which will be discussed later.

At Trevelgue Head, Cornwall, once thought to be the earliest large iron producing site in Britain, siderite ores, from a lode running through the headland, with surface deposits eroded to limonite and goethite, were exploited (*Dungworth 2011*) however the amount of slag found there is relatively small compared to more recently discovered sites.

It is noticeable that in these early stages of iron production, objects made of iron tend to be relatively small, and the full potential of the metal little understood. By the middle Iron Age, there appears to be a radical change, demonstrated most clearly by the contents of chariot burials, the earliest so far found in Britain being at Newbridge, Edinburgh, dating from 5th century BC (*Carter – Hunter – Smith 2010*). The shrinking of iron tyres onto wheel rims without nails represents a major innovation in blacksmithing. It had been suggested that this technique was developed in the Aisne-Marne region of France, arriving in the environs of Paris and East Yorkshire around the same time in the late 4th century BC (*Anthoons 2007*; *2011*). New radiocarbon dates, however, show that the seven chariot burials around Wetwang and the outlying Yorkshire example from Ferry Fryston (*Brown et al. 2007*), date from 'no more than a few decades around 200 Cal BC, some two centuries after the main phase of vehicle burial in northern France and the middle Rhine' (*Jay et al. 2012*, 182; *Hamilton – Haselgrove – Gosden 2015*). All but two of the 27 chariot burials known so far from Britain have been found in Eastern Yorkshire, most recently in 2017 at Pocklington (*Symonds 2017*) and on a site to the south of this region, between the Yorkshire Wolds and the Humber banks (Paula Ware pers. comm.).

Over the last two decades, experimental archaeology has provided insights into Iron Age iron production and demonstrated the considerable time and resources required for its production (*Crew 2013*). It has been estimated that the chariot fittings including the tyres would have needed around 36 kg of iron. Based on Crew's calculation this would have required a total of some 288 person days. A strong relationship between control of iron production and social status within Middle Iron Age society in this region may be possible. It may not be coincidental that the cemeteries with the most chariot burials at Arras and Wetwang are relatively close to the iron producing zones of the Foulness Valley and Hull Valley respectively.

Further south, the Thames valley remained important for the production of iron later into the Iron Age. At Sadler's End, Sindlesham, in Berkshire, the largest quantity of Iron Age smelting slag yet discovered in Britain was excavated, the majority in a 10 m spread weighing over 21,216 kg. This was estimated to be the residue from the production of 1.8 tonnes of iron, which could have been forged into c. 2000 currency bars (*Lewis – Crabb – Ford 2013*). According to Crew (pers. comm.), this appears to be a very low iron-slag ratio. Slag analysis showed that the raw material had been bog ore but not from the immediate vicinity. A ^{14}C date of 185–50 Cal BC was obtained from charcoal in Furnace 303.

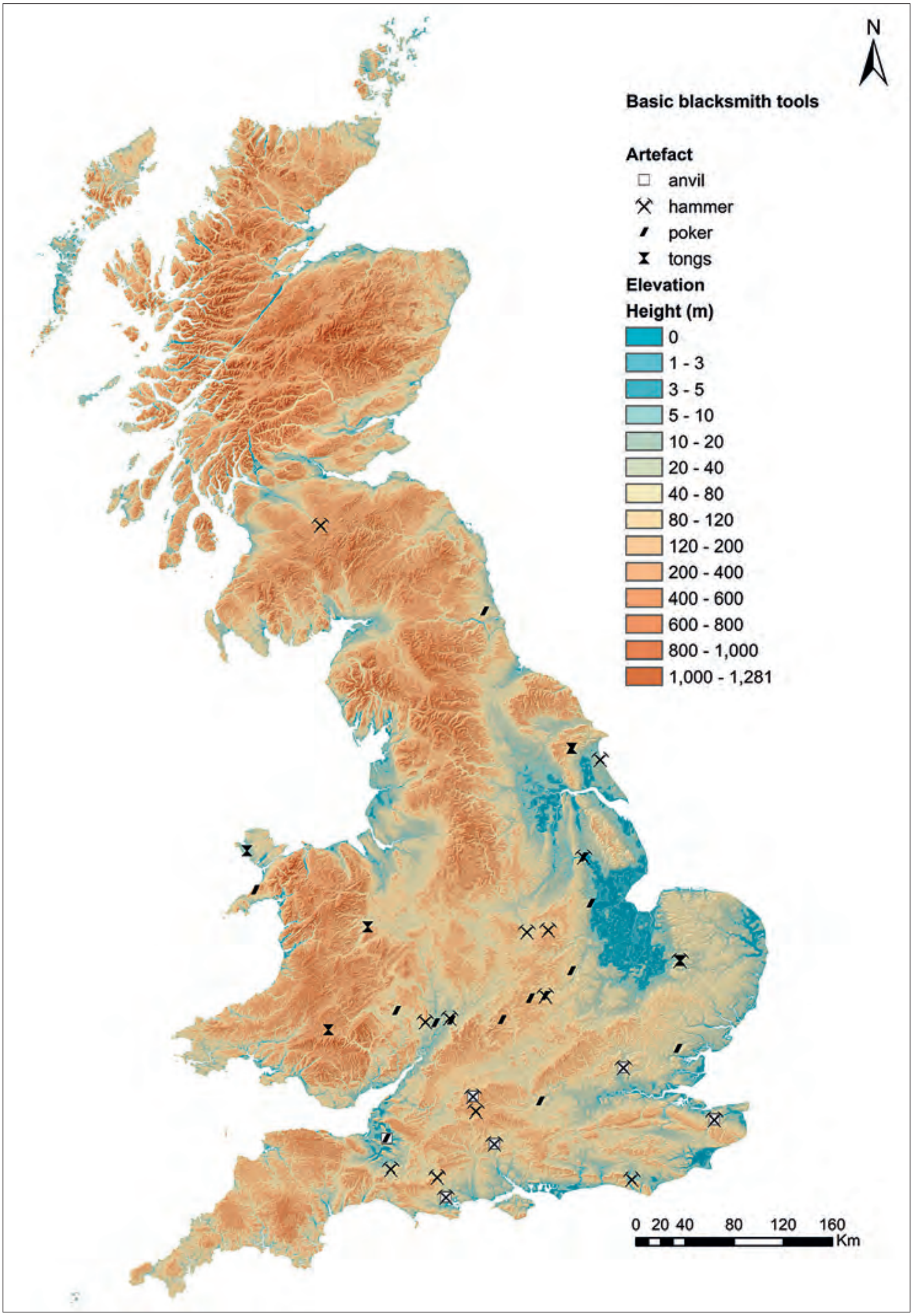

Fig. 4. The distribution of blacksmith's tools in non-burial contexts (after Jinks-Fredrick).
Obr. 4. Prostorová distribuce nálezů kovářských nástrojů z nehrobových kontextů.

The size of the Sadler's End slag heaps far surpasses what was until recently the largest amount of Iron Age slag from Britain, which weighed 6.5 tonnes (*Crew 1998*; *2009*), excavated 1990–1998 on a settlement with round houses at Crawcwellt West, Merioneth, North Wales, with iron production being undertaken c. 300 BC to 100 BC. At Bryn y Castell, a small hillfort near Ffestiniog, Merioneth, bog ores were smelted at around the same time, but the quantity of slag found here at 1200 kg was much less. A special feature of this site was a snail-shaped stone structure in which blacksmithing had been undertaken (*Crew 1987*; *2009*). The high quality research undertaken on these two sites remains pivotal in our understanding of early iron production and led to Crew's vital experimentation (*Crew 2013*).

So far, much attention has been paid to iron production. A feature of both the East Yorkshire and North Welsh production centres is the relative lack of 'currency bars', now generally accepted as a semi-product allowing the quality of iron to be assessed, rather than an early form of monetary exchange (*fig. 3*). Of around 1500 known examples, which can be divided into around 20 groups, few have been found in the north of England and Scotland (*Crew 1994*). Five bars were included in the hoard of iron objects from Llyn Cerrig Bach on Anglesey, which were of two types, one of which may be unique to North Wales (*Crew – Crew 2012*). In East Yorkshire the only bar known so far was found at Gransmoor near Driffield, close to the head waters of Hull Valley and the mouth of Wetwang/Garton Slack (*Halkon – Starley 2012*). The Gransmoor bar is of particular interest, as it comprised two smaller bars welded together. Analysis showed differences in quality between both sides of the join. The tip comprised heterogeneous phosphoric iron/low carbon steel and the socket section heterogeneous phosphoric iron/carbon below steel composition. It is almost certain that it was made from local bog ores. Considering the scale of the East Yorkshire industry there should be many such items and finished iron may have been traded in other forms.

The majority of currency bars have been found in hoards and the circumstances of their deposition is a matter of debate. *Hingley* (*1990*) argued that many were deliberately deposited as a form of structured deposition, particularly at boundaries and settlement and hillfort banks and ditches. A similar explanation has been put forward for other items made of iron or a combination of iron and copper alloys. A recent example is a 'special deposit' of the chariot fittings from several sets of harness found in a reused pit at Burrough Hill hillfort, Leicestershire. Here the fittings were laid in a box on a bed of chaff, which was then burnt and buried in a reused pit (*Farley et al. 2017*).

Current research on iron objects from non-burial context in Britain (*Jinks-Fredrick 2017*) is showing variations in the types of tools and weapons deposited, with certain locations preferred for specific object types (*fig. 4*). The distribution of all types of smith's tools, i.e. hammers, tongs and pokers, broadly matches that of currency bars, with a concentration in the Midlands between the Severn Estuary and the Wash (*fig. 5*). Iron objects, including currency bars, were deliberately deposited in the grain storage pits at Danebury (*Crew 1995*; *Hingley 2006*), and have been interpreted as some kind of offering in return for the successful preservation of grain, a pattern of deposition noted in other Wessex hillforts (*Sharples 2010*, 134).

An outlier from this distribution are the tongs, poker and possible forge spoon from a grain storage pit at Garton Slack in Eastern Yorkshire (*Fell 1990*; *1991*; *Brewster 1980*; *Halkon 2012*). Weapons, particularly swords (*Stead 2006*) are often associated with watery

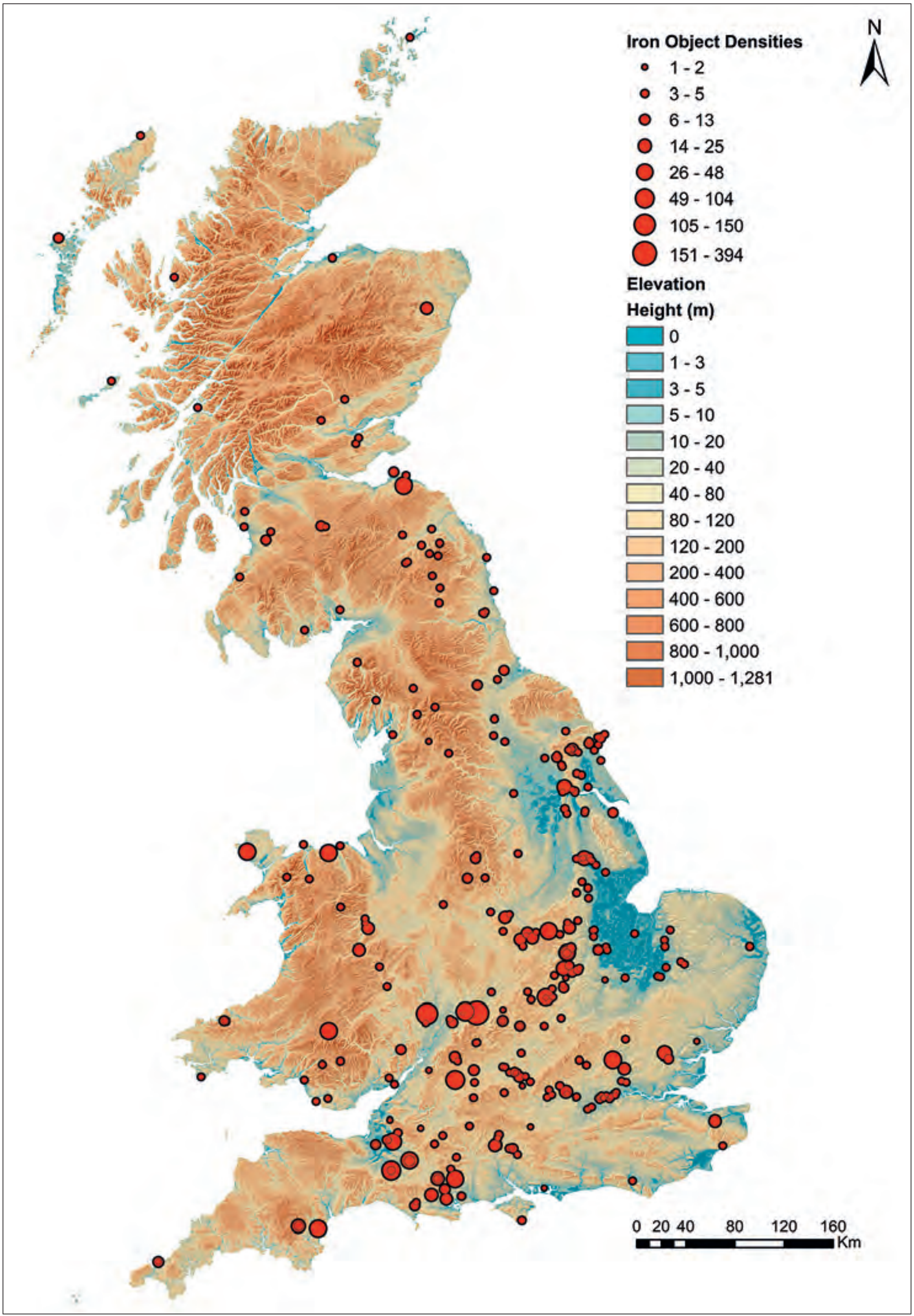

Fig. 5. The density of all iron objects in non-burial contexts in the UK (after Jinks-Fredrick).
Obr. 5. Hustota nálezů všech železných předmětů z nehrobových kontextů ve Velké Británii.

places following Bronze Age practices (*Bradley 1990*; *2016*), but by no means exclusively as in the case of the remarkable weapons cache from South Cave (*Evans 2006*; *Marchant – Halkon 2008*) which contained five swords in decorated sheaths and 33 iron spearheads, placed in a settlement ditch. Various interpretations have been put forward for its deposition. Carefully wrapped in organic material (long since decayed) and covered by sherds of Dressel 20 olive oil amphora, it may have been hidden ready for retrieval in a last act of resistance against incoming Roman forces around AD 70. Conversely, its location close to springs and overlooked by a possible hillfort at Mount Airey, may relate to some act of structured deposition (*Halkon 2008*; *2013*). Whatever the reason for disposal the swords, with their confident embellishment with exotic materials including enamel, sperm whale tooth, and elephant ivory, they mark a high point of metalworking in Iron Age Britain, following the expertise demonstrated in the earlier Kirkburn sword, which accompanied a burial in a large Iron Age cemetery in East Yorkshire (*Stead 1991*).

Given the probable size of Iron Age populations in Britain, the lack of inhumation burials is noteworthy, with other options chosen for the disposal of the dead in many regions (*Whimster 1981*; *Harding 2016*). Eastern Yorkshire has the largest concentration of inhumations, generally enclosed by small square or, in some cases, circular ditches. Iron in chariot burials has been referred to above. Of the less than 2000 burials in Iron Age Britain, excluding Eastern Yorkshire, only around 5 % of these contain iron artefacts, 30 % being weapons, with around 17 % being items of personal adornment and the same percentage of utensils. This contrasts greatly with Eastern Yorkshire were over 17 % of the around 1070 burials contained iron objects, most of which were brooches and spearheads (*Halkon 2012*; *Inall 2016*). Of around 80 burials with weapons in Iron Age Britain, more than half are in eastern Yorkshire (*Inall 2016*, 44) the most recently discovered by Northern Archaeological Associates between Burstwick and Rimswell in Holderness during an excavation prior to the laying of a pipeline (*Turner – Cooper 2017*, 10). This crouched burial resembled others in the Arras Culture tradition, as it included pig bones, a shield and more remarkably a sword, which had been deliberately bent almost double. It is not clear whether the spear in this and a burial close by followed the so-called 'speared corpse' ritual characteristic of eastern Yorkshire (*Stead 1991*; *Giles 2012*; *Halkon 2013*; *Inall 2016*).

So far two burials are recorded as containing blacksmiths tools, both accompanied by weapons, Burial 154 at Rudston, East Yorkshire (*Stead 1991*) and at Whitcombe, Dorset, which included a spearhead, a sword, a file and an iron hammer (*Stead 1990*). Not only finished artefacts were included as grave goods; at Pocklington (*Halkon 2017*), several burials contained iron slag, a phenomenon also noted in Ireland (*Williams 2015*).

In the space available it is only been possible to provide a brief overview. There is still much to be done. A priority, following recent French and German initiatives (*Dillmann et al. 2017*) should be trace element analysis to facilitate more precise provenance studies. Further characterisation and metallurgical analysis of slag is also essential (*Stetkiewicz 2016*). More controlled experiments particularly on slag-pit furnaces and assessment of the different qualities of iron objects are also needed. Above all, there needs to be better communication between archaeometallurgists and conventional Iron Age archaeologists to explain the complexity of iron production and its great potential for understanding past societies. Conferences such as 'Iron in Archaeology' at Prague will hopefully facilitate this process and continue the work of one of early iron's greatest pioneers, Radomír Pleiner.

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PETER HALKON, School of Histories, Languages and Cultures, University of Hull, HU6 7RX Hull, United Kingdom; A.P.Halkon@hull.ac.uk
ZECHARIAH JINKS-FREDRICK, School of Histories, Languages and Cultures, University of Hull, HU6 7RX Hull, United Kingdom; Z.A.Jinks-Fredrick@2014.hull.ac.uk

Milanówek/Falęcin – a settlement of iron-smelters from the Late Antiquity

Milanówek-Falęcin – sídliště hutníků železa z doby římské

Marcin Woźniak

The settlement at Milanówek/Falęcin is a part of large centre of iron production of the Przeworsk Culture, dating from the Late Pre-Roman and Roman Periods, and located in the western Masovia (central Poland). The site was discovered in the 1960s during surface surveys, and its area is estimated to 9–12 hectares. Over time, various non destructive archaeological methods have been employed at the site (e.g. aerial photography, geomagnetic surveys, advanced surface prospection), and excavations were carried out over an area of ca 1500 m^2*. There have been found remains of nearly 1000 slag pit furnaces, 4 lime kilns, 1 'horse-shoe-shaped' kiln, 2 buildings and several pits. The excavation yielded also a large set of artefacts, of which some were subjected to expert analysis (e.g. chemical composition of slags, mineralogical composition of clay of relic of shafts). On the basis of geomagnetic surveys and excavations it is presumed that the settlement at Milanówek Falęcin may contain remains of about fifteen thousand slag-pit furnaces.*

Przeworsk culture – iron metallurgy – Roman Period

Osídlení v Milanówek-Falęcinu bylo součástí rozsáhlého centra výroby železa převorské kultury, nacházející se v západním Mazovsku (střední Polsko) a pocházející z pozdního předřímského a římského období. Lokalita byla objevena v šedesátých letech 20. století pomocí povrchových průzkumů a její plocha se odhaduje na 9–12 hektarů. V průběhu času byla lokalita zkoumána různými nedestruktivními archeologickými metodami (např. letecké snímkování, geomagnetické průzkumy, povrchová prospekce), výkopové práce byly provedeny na ploše ca 1500 m^2*. Odkryty byly relikty téměř tisícovky pecí se zahloubenou nístějí, čtyři vápenické pece, pec ve tvaru podkovy, stopy dvou nadzemních staveb a několik jam. Výkopy přinesly také velký soubor artefaktů, z nichž některé byly podrobeny odborné analýze (např. stanovení chemického složení strusek a mineralogického složení hlíny reliktů šachet pecí). Na základě geomagnetických průzkumů a výkopů se předpokládá, že osídlení v lokalitě Milanówek-Falęcin může obsahovat pozůstatky zhruba patnácti tisíc pecí se zahloubenou nístějí.*

převorská kultura – metalurgie železa – doba římská

In the late 1960s and early 1970s, a cluster of settlements of the Przeworsk Culture dating to the Late Pre-Roman Period and the Roman Period (2nd century BC – 4/5th century AD) was discovered in the western Mazovia (central Poland). It was a result of a comprehensive field survey programme known as Archeologiczne Zdjęcie Mazowsza i Podlasia (Archaeological Map of Mazovia and Podlachia). A dense concentration of around 240 archaeological sites, spread across the area of approx. 300 km^2, where traces of an extensive iron production were uncovered, was registered in the eastern part of the cluster (*fig. 1*). This concentration is called the Mazovian Centre of Metallurgy.

Surface surveys allowed to determine territorial borders and structure of this phenomenon as well as to distinguish from within hundreds of newly discovered sites those of key importance for identifying the characteristic features of local settlement. A selected number

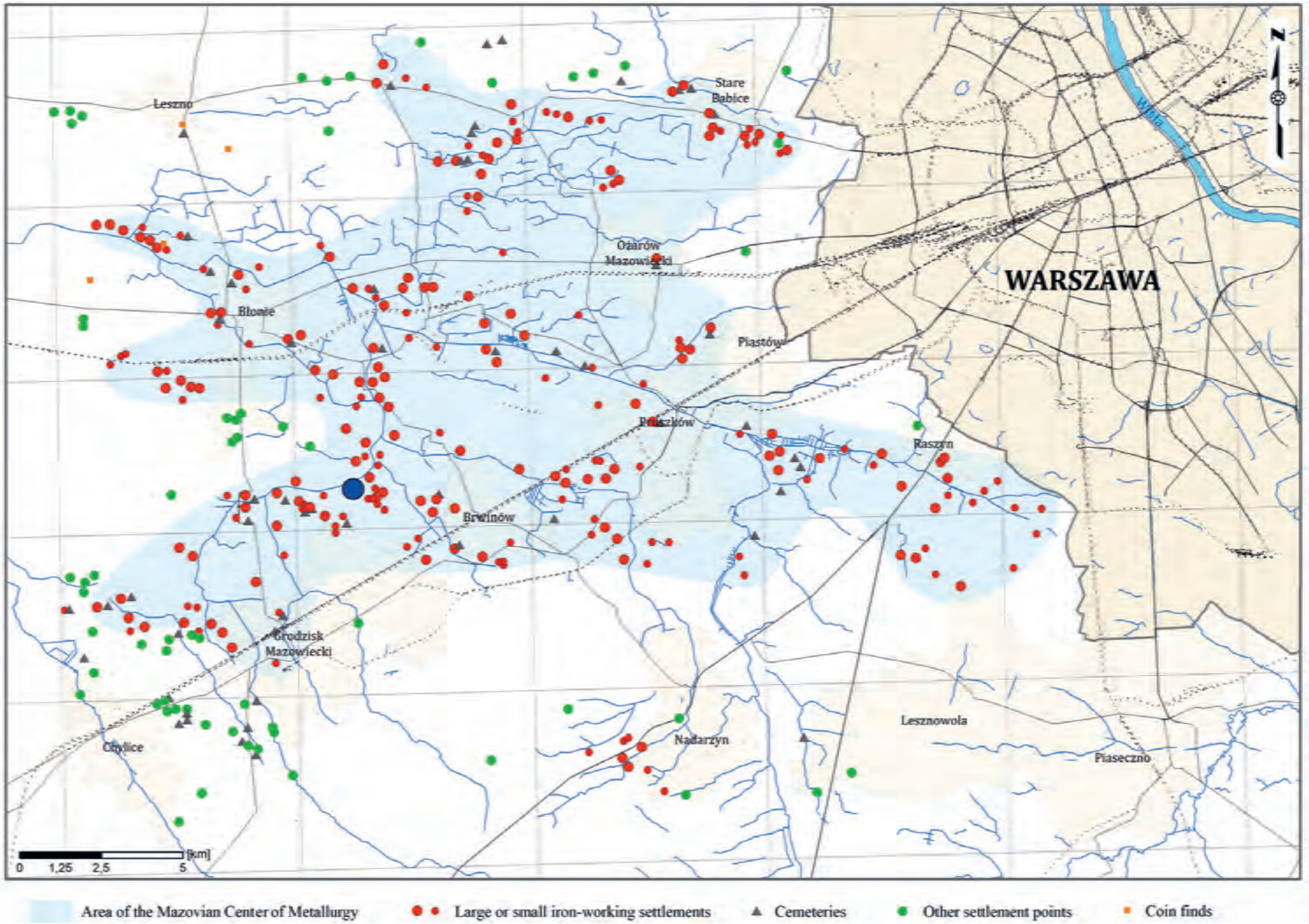

Fig. 1. A site in Milanówek/Falęcin (blue dot) on the background local settlement cluster of the Przeworsk Culture from the Late Pre-Roman and Roman Periods (acc. *Woyda 2002*, with modifications).

Obr. 1. Lokalita Milanówek-Falęcin (modrá tečka) na pozadí uskupení místních sídlišť převorské kultury z pozdně předřímského a římského období (podle *Woyda 2002*, upraveno).

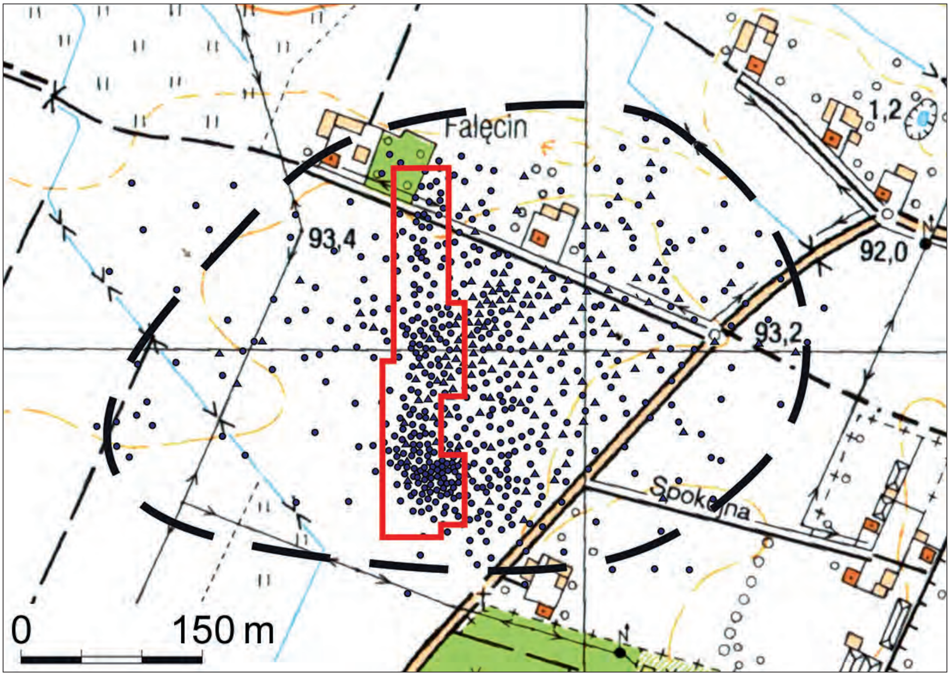

Fig. 2. Location of the settlement in Milanówek/Falęcin (black dotted line – presumed range of a site; dark blue dots and triangulars – fragments of slag and pottery shards on surface of ground; red outline – area of geomagnetic research).
Obr. 2. Poloha sídliště v Milanówku-Falęcinu (černá tečkovaná čára – předpokládaný rozsah sídliště; tmavě modré tečky a trojúhelníky – úlomky strusky a keramických střepů na zemském povrchu; červený obrys – geomagneticky prozkoumaná plocha).

of most promising sites was the object of a pioneer programme of non-destructive archaeological prospection[1], and the results were later verified during excavations. A vast settlement discovered at the border of Milanówek, Grodzisk Mazowiecki County, and Falęcin, Pruszków County, approx. 25 km south-west of Warsaw, was one of such sites. It is situated on a sandy hill bordered to the north and east by the wetland of the valleys of the river Rokitinica and its unnamed tributary and to the south by a gentle slope from where another small watercourse flows to the west. At the moment of discovery, the site was identified by numerous pottery sherds, pieces of daub and especially lumps of slag present on the surface of the ground. Based on the spread of the material, the size of the site was estimated at 9–12 hectares (*fig. 2* and *5: A*). The material was spread unevenly. Pottery dominated in the central part of the hill. Slag was predominant in the central-western and southern parts of the site. This particular spread of artefacts led to the idea of a dual – production/habitation – character of the settlement, with the production zone clearly separated.

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[1] E.g., aerial photography, electrical resistance, geomagnetic, thermal radiation, geological and geomorphological surveys, etc.

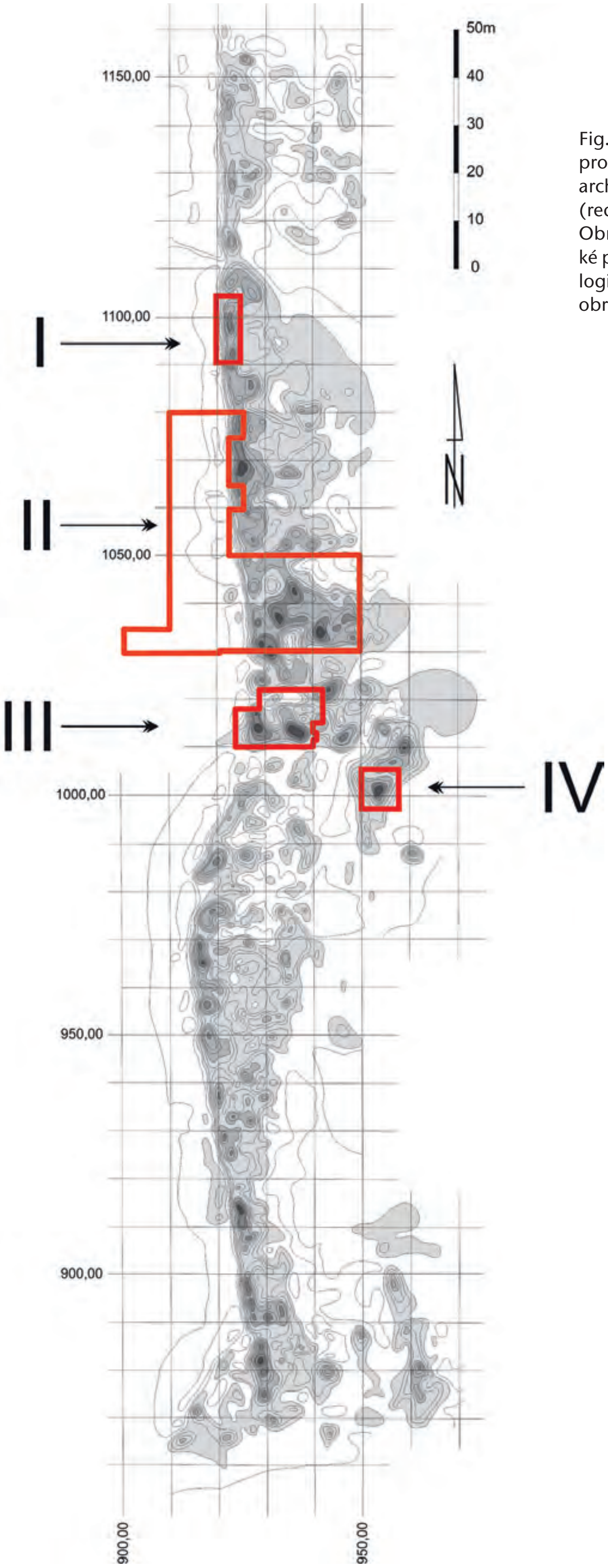

Fig. 3. Results of geomagnetic prospecting and location of archaeological trenches I–IV (red outline).
Obr. 3. Výsledky geomagnetické prospekce a poloha archeologických sond I–IV (červený obrys).

A large part of the settlement (3 ha constituting 20–30 % of the site) where the archaeological material was most dense on the surface was subjected to a geomagnetic survey (*fig. 2*). The goal of the survey was to detect possible anomalies which – as was assumed[2] – would be the indication of the presence of the remnants of bloomeries at the site. As a result of the survey, a magnetic anomaly about 300 meters long and 10–30 meters wide with clearly defined borders (particularly on its western side) was detected in the area (*fig. 3*).

The results of the prospection were then verified during the excavations conducted by S. Woyda in the years 1974–1975 and 1987–1988. The excavations took place in the central part of the site, slightly to the west of the hill peak, where the strongest anomalies were registered by the measurement equipment. It covered around 1550 m^2 of the surface (*fig. 3*). The biggest trench measuring 1240 m^2 was positioned across the length of the magnetic anomalies and alongside its western border. The rest of the excavation units, much smaller in size, were also situated within the range of the anomalies – in the centre or near its western edge. Excavations confirmed the results of the geomagnetic survey. In all of the units which were at least partially positioned within the field of the bigger magnetic anomalies, remnants of bloomeries – in form of pits containing lumps or blocks of slag – were found. In the areas were the equipment did not indicate significant anomalies, little to no remains of iron smelting furnaces were discovered. However, there were other features detected there, e.g., lime kilns.

The last excavation at the site took place in 2009. It was a rescue excavation preceding a construction of a water pipe meant to supply modern homesteads located within the borders of the site. The trench was almost 340 meters long and 0.8 meters wide – it dissected the NE part of the site (including the top of the hill) along the NW–SE axis (next to northern edge of road leading to houses lying in the area of site). In its NE part, several tens of pits divided into two groups by a small strip of empty land were discovered. A lime kiln was unearthed in the middle of the empty space. These features can be connected with the furnaces field registered during the geomagnetic survey. A ‘new’ furnace cluster consisting of more than 30 furnaces (registered over a 50-meter-long distance) was discovered in the SE part of the trench (to the SE of the hill peak), outside the area covered by the geomagnetic survey. Both clusters were divided by a 150-meter-long strip of land with no traces of iron smelting production. The furnace cluster newly discovered in 2009 is probably a part of a separate iron smelting workshop. Its shape and size, and, consequently, an estimation of a number of remnants of bloomeries to be found there, require a wide range of verification in the field. During all the excavation seasons, about 1000 traces of iron smelts were registered altogether.

All iron smelting furnaces discovered in Milanówek/Falęcin so far were one-time use units of the pit type. The majority of the features found within the range of the magnetic anomalies formed a vast slag-pit furnace cluster characteristic of the Mazovian Centre of Metallurgy: station of the so called ‘disorganized’ type, with an elongated and quite narrow shape. It was situated along the north-south axis. Its particular feature was a straight western border several hundred meters long (*fig. 4: II* and *5: B*). The highest density of

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[2] Based on the results of earlier surveys of bloomery sites discovered in the Holy-Cross Mountains (cf. *Bielenin 1992*, 44–48).

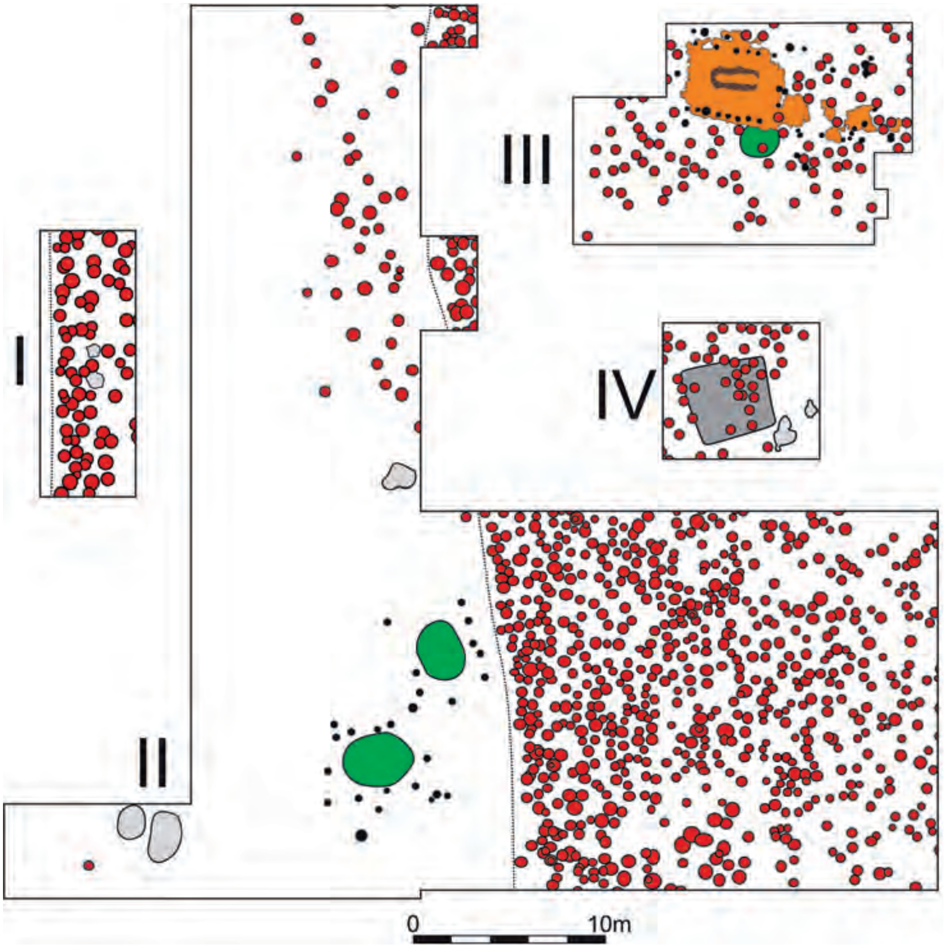

Fig. 4. Plans of archaeological trenches I–IV (red – slag-pit furnaces; green – lime kilns; black – postholes; orange – relics of house with 'horseshoe-shaped' furnace; dark grey – house; light grey – other pits; dotted line – western border of 'huge' cluster of slag-pit furnaces).
Obr. 4. Plány archeologických sond I–IV (červeně – pece se zahloubenou nístějí; zeleně – vápenické pece; černě – kůlové jamky; oranžově – pozůstatky domu s podkovovitě tvarovanou pecí, tmavošedě – další jámy; tečkovaná čára – západní hranice rozsáhlého shluku pecí se zahloubenou nístějí).

slag-pits, in places exceeding 180 items per 100 m^2, was registered along this border. The presence of such a distinct line with furnaces positioned alongside it is difficult to explain[3]. The most often used explanation points to the beliefs of the local population which might have been manifested in such a particular separation of the production zone from the rest of the settlement (*Woyda 2005*, 141–142; *Orzechowski 2013*, 219–220). Moving

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[3] Similar arrangement can be seen at other, better researched, iron smelting sites from Mazovia (*Woyda 2005*, 135, 137).

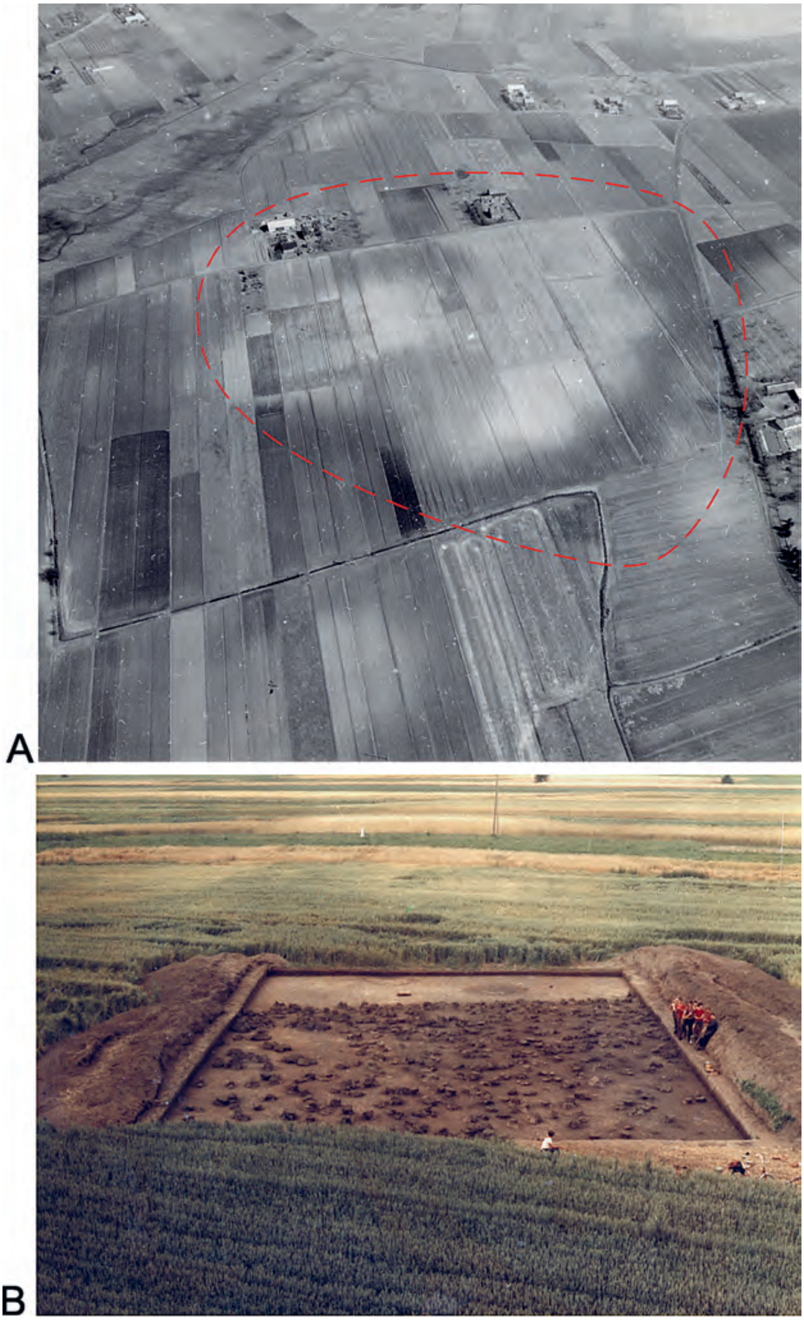

Fig. 5. Milanówek/Falęcin. A – an aerial view on site from the east, 1981 (photo Woyda); B – view on S–E part of trench II with well visible western border of 'huge' slag-pit furnace cluster (photo Woyda).
Obr. 5. Milanówek-Falęcin. A – letecký pohled na lokalitu od východu, 1981; B – pohled na jihových. část sondy II s dobře viditelným západním okrajem rozsáhlého shluku pecí se zahloubenou nístějí.

several meters to the east of the western border, the concentration of furnaces becomes noticeably less dense (fewer than 100 items per are). Unfortunately, the eastern border of the cluster was not registered during the excavations. Based on the excavations and geophysical prospection, it appears that several thousands of bloomeries could have been in use in the area of the 'huge' slag-pit furnace cluster.[4]

Another concentration of furnaces, much smaller and less dispersed, was situated next to the western border of the great slag-pit furnace cluster. The functioning of this station is difficult to interpret. Its location didn't follow the pattern according to which several thousand neighbouring furnaces were built. The main issue hindering any attempt at an explanation of this phenomenon (and not just this one, see below) is the inability to precisely indicate the time at which each furnace was constructed. This applies to both the furnaces lying within the great slag-pit furnace cluster as well as those outside its borders. It is possible that these two different clusters are an evidence of two unrelated, chronologically distinct phases of development of the settlement that functioned for at least two hundred years. More research into this matter is needed, and, above else, a better exploration of the site, beyond the metallurgical production zone, is required.

As mentioned before, the characteristic feature of the 'huge' slag-pit furnace cluster was a high density of bloomeries alongside its western border. The features discovered here formed complex, often multi-level stratigraphic sequences. Pits of the younger furnaces were dug into the older ones which in turn had also been dug into even older ones. Thus, the state of preservation at the time of discovery differs between features. The oldest features had often been almost completely destroyed. Their only remains are the bottoms of the pits – circular in shape, with black fill containing sparse pieces of slag. They were usually registered only after fully excavating the younger features. It is difficult to assess, however, if the features were destroyed on purpose, e.g., to prepare room for new units or if it happened by accident during the construction of new furnaces. Younger features were characterized by the presence of slag blocks. Some of the blocks were preserved in full, others were damaged to various degrees – either by the younger features or perhaps much later, e.g., by field cultivation in the modern times. In most cases, the outlines of the upper parts of the pits dug into the deep dark cultural layer were not visible. They could only be distinguished at their lowest part, i.e., at the level of the sandy sterile ground. Their construction was then mostly recreated based on the shape of the lateral surface of better preserved slag blocks which gave an inverted image of the walls of the pit. The pits usually measured 30–40 cm in diameter at the opening and were 40–60 cm deep. They were usually conical in shape, sometimes cylindrical. At times, they had an additional side channel. In many cases, the shape of slag blocks was irregular and disjointed at the top, possibly a result of a disturbance into the pit. It is speculated that this digging in was intended to enlarge the pit. A separate question is when it was done – before or after the smelting begun

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[4] Based on surface prospection, geophysical surveys and excavations, S. Woyda, who researched the Milanówek/Falęcin site, estimated the number of smelts at over 15,000. It should be emphasized that this estimation applies to the entire area of the site. In the parts of the site covered by the geophysical survey, that number was certainly lower. In the areas excavated in the 1970s and 1980s that lay within the range of the slag-pit furnace cluster, the number of furnaces per are differed from 180 (near the border) to 60 (several tens of meters from the western border of the cluster). Assuming a high density of around 90–100 furnaces per are in the entire area of the magnetic anomaly, the number of furnaces is unlikely to be more than 6–7 thousands.

(cf. *Woyda 2002*, 131; *Orzechowski 2013*, 103). No traces of any attempts at protecting the wall of the pit (e.g., with clay lining)[5], as can be observed in other regions (*Bielenin 1973*, 55–56; *Orzechowski 2013*, 97–98), were found during the excavations.

Fragments of fired clay from the broken down shafts were found in the area of the furnace cluster described. Some of them were found *in situ*, i.e., where they were at the moment of the shaft collapse after smelting had been finished. Others were found in the secondary deposit, mainly in the cultural layer. The preserved fragments allowed for a reconstruction of the shaft structure and for a specialist study into the subject. The aim of the research was to determine the methods of preparing the raw material, establish its composition and origin, and also to recreate the temperature in the shaft during the smelting process. Furnace shafts in Milanówek/Falęcin[6] were made of clay bands. Raw material used in their construction was tempered with shredded grass and/or straw and sand. Mineralogical analyses indicate that the material originated from clay outcrops situated near the site (*Kowalczuk et al. 1980*, 20–23). Clay bands measured approximately 10–20 cm in height and from 6–10 cm (at the bottom of the shaft) to 3–4 cm (near the top of the shaft) in thickness. The bottom clay bands contained small holes, through which air could flow into the shaft. They were usually vitrified on the inside. The bands in the upper parts of the shaft were only fired. Fragments from different parts of the shafts were included in a specialist study (*Daszkiewicz – Bobryk 1994*; *Daszkiewicz – Jelitto 1994*).[7] Two samples were obtained from the bands constituting the bottom of the shaft, one from the middle part and one probably from the vicinity of the top of the shaft. In order to determine the temperature affecting the interior walls of the shaft, the research material was divided into pieces that were then re-fired in different temperatures. The samples were compared with regards to colour and ceramic characteristics before and after firing. After firing, the fragments were also subjected to a derivatographic analysis, X-ray phase analysis and observation in the scanning electron microscope. As the result of the research conducted and with an assumption that shaft parts were used only once, a range of temperatures affecting the inner shaft walls during smelting was determined. For the top and middle parts of the shaft, the temperatures were 950–1000 °C and 900–950 °C respectively. In the case of the two samples from the bands at the base of the shaft it was determined that they were fired in the temperatures of 900–970 °C and 980–1000 °C. The latter two values are surprisingly low and raise doubts. The inside surface of the samples from the bottom parts of the shaft is vitrified, which was not observed in the samples from the upper parts of the shaft.

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[5] Contrary to *S. Woyda*'s (*2005*, 149) opinion, it was not necessary as clearly proved by the research conducted in the recent years by the friends and employees of the Muzeum Starożytnego Hutnictwa Mazowieckiego (Museum of Ancient Mazovian Metallurgy) in Pruszków. Their experimental research into the reconstruction of the furnace and the smelting process, based on the local archaeological material, showed that none of the several dozen experimental furnaces had been destroyed during the smelting process due to a collapse of unsupported pit walls.

[6] As was the case in other settlements of the Mazovian Centre of Metallurgy (*Woyda 2002*, 134, fig. 26).

[7] The research into the temperatures affecting the shaft walls of the Mazovian furnaces began in 1980. Two out of five shaft fragments that were analyzed back then came from the settlement in Milanówek/Falęcin. Based on the structural changes in the loamy materials, it was concluded that one of them was fired in the temperature of approx. 800–900 °C (*Kowalczuk et al. 1980*, 16). Unfortunately, there is no information from which part of the shaft the sample had been obtained, which limits further use of these results. It probably came from the upper parts of a shaft as indicated by the description of its structure which does not mention a liquid phase.

It is unlikely that fragments so different with regards to their morphology could form in similar conditions. This is supported by the results of a research[8] into materials discovered at a settlement site in Biskupice, Pruszków County, and situated approx. 3 km to the east of Milanówek/Falęcin. Four samples obtained from different parts of a shaft were analysed – all of them had their inside surface vitrified. The results achieved (1000–1100 °C; 1010–1100 °C; 1100–1200 °C and ca. 1200 °C) indicate visibly higher temperatures at the hearth level than could be observed based on the analyses of the samples from Milanówek/Falęcin. They are similar to the findings of *Hensel* (*1986*), who determined, based on the analyses of a slag block from Milanówek/Falęcin, that the temperature during the smelting approximated 1100 °C (see below). In this light, the results of the analysis of the shaft parts from the settlement discussed herein are disputable and should certainly be verified on a bigger sample of archaeological material.

The main goal of the previously mentioned physicochemical analyses of slag was to try and recreate the bloomery process that took place in the settlement in Milanówek/Falęcin, and the Mazovian region in general (*Hensel 1986*). The analysis was preceded by establishing the chemical composition of two iron ore fragments from the area near Milanówek. The samples were characterized by a high level of phosphorus content (P_2O_5 2.7–3.78 %) and low iron content (Fe_2O_3 23.0–30.0 %) (*tab. 1*, nos. 1, 2). Three slag blocks from the site in question were analysed. They were observed under a microscope and subjected to a thermal analysis. Their composition was also determined. Additionally, the melting point of slag in an argon and air atmosphere was measured. The analysed slag contained high levels of P_2O_5 (4–6 %) and slightly lower of CaO (2–4 %)[9] (*tab. 2*). The maximum melting effect when heated in the neutral atmosphere was achieved at the temperature of 1160–1180 °C, and when cooled in the neutral atmosphere – at the temperature of 1030–1080 °C. The values are lower than in the case of the slag from the Holy-Cross Mountains which melted in the temperatures between 1150–1220 °C (lately *Orzechowski 2013*, 76). According to *Hensel* (*1986*, 63, 78), low melting point of slag, and, consequently, the temperature of the smelt, in the furnaces from Milanówek/Falęcin, was a result of using ore with high phosphorus content and utilizing lime as flux. More so, Hensel saw lime as means to de-phosphorize the iron during the smelt (*Hensel 1986*, 63; cf. *Woyda 2005*, 146). However, the possibility to precipitate phosphorus with calcium oxide in an ancient bloomery has been questioned by other researchers (*Piaskowski 1981*, 439–444; see also *Orzechowski 2013*, 73–75). They emphasize that the presence of a few percent of CaO in the contents of the Mazovian slag could be attributed a specific composition of local ore rather than be an indication of an intentional action.

Geologists studying local ore have seen this problem slightly differently. An advanced field reconnaissance was undertaken in the area of the western Mazovia in the 1970s and the beginning of the 1980s, with a goal of identifying the supply network of the local iron

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[8] What is important, the analysis was done as a part of the same programme, by the same group of researchers and using the same equipment.

[9] Supplementing Hensel's research on the chemical composition of slag are the analyses done by E. Nosek on two slag blocks from Milanówek/Falęcin. First block contained 3.68 % CaO and 0.91 % P_2O_5 (averages based on 3 samples). The second one showed significantly higher content of phosphorus oxide – 2.69 % (average based on 2 samples); in this case CaO was not marked. Analysis report in the Science Department Archive of MSHM, inventory no. MSHM/ADN/221 (see also *Woyda 2002*, tab. 5).

No.	No. of sample	V_2O_5	SiO_2	FeO	MnO	Cr_2O_3	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	P_2O_5	NiO	CuO
1	R2	–	55.5	0.7	1.2	0.01	23.0	2.4	0.19	0.8	0.1	2.7	0.02	0.02
2	R3	–	24.0	0.7	13.5	0.01	30.4	3.4	0.15	2.2	0.3	3.78	0.03	0.01
3	5	indefinite	53.2	indefinite	2.75	indefinite	23.24	indefinite	indefinite	0.77	0.61	0.4	indefinite	indefinite

Tab. 1. Chemical composition of bog iron ore from vicinity of Milanówek/Falęcin (nos. 1–2 acc. *Hensel 1986*; no. 3 acc. *Kowalczuk et al. 1980*).

Tab. 1. Chemické složení bahenní železné rudy z okolí Milanówek-Falęcin (č. 1–2 podle Hensela (*Hensel 1986*; č. 3 podle *Kowalczuk et al. 1980*).

No. of sample	SiO_2	FeO	MnO	Cr_2O_3	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	P_2O_5	NiO	CuO
Block I												
1	18.6	49.2	1.6	–	18.7	1.2	0.04	2.9	1.7	5.0	0.04	–
2	21.5	46.1	1.8	–	17.4	1.4	–	3.9	0.6	7.1	0.03	–
3	15.3	51.6	1.4	–	19.9	1.6	0.08	2.7	1.1	5.5	0.03	–
4	18.7	48.2	1.7	–	18.9	1.5	0.02	4.0	1.0	5.5	0.06	–
5	23.6	45.1	1.7	–	13.8	1.7	0.09	3.9	1.0	7.4	0.06	–
6	25.9	46.6	1.5	–	14.5	2.9	0.23	3.0	1.0	5.4	0.08	–
7	14.8	35.5	1.2	–	35.3	2.1	0.18	2.3	0.8	4.6	0.08	–
8	18.1	49.8	1.7	–	18.2	1.3	0.18	3.1	0.6	5.9	0.07	–
9	21.0	49.7	1.7	–	13.5	1.0	0.14	4.3	0.8	7.3	0.08	–
Block II												
1	22.2	46.7	3.0	–	16.7	1.5	0.07	3.2	0.9	4.6	0.09	–
2	22.1	48.8	2.9	–	15.0	3.2	0.12	3.5	1.0	4.7	0.10	–
3	22.4	48.6	2.5	–	20.6	1.8	0.09	3.2	0.8	4.5	0.10	–
4	22.8	48.2	2.9	–	17.4	3.0	0.07	2.8	1.1	4.1	0.13	–
5	16.9	53.1	2.0	–	19.6	1.4	0.11	2.2	1.3	2.7	0.07	–
6	30.1	38.9	2.8	–	16.2	2.8	0.18	2.6	0.7	4.2	0.13	–
7	22.9	47.7	2.8	–	17.9	2.7	0.18	2.8	0.9	4.2	0.11	–
8	20.6	49.6	2.9	–	15.9	1.8	0.10	3.8	0.8	4.6	0.13	–
9	20.8	46.4	2.9	–	17.7	3.0	0.09	4.0	0.08	5.2	0.13	–
Block III (VI)												
1	16.6	38.3	0.68	0.02	32.1	1.7	0.16	1.4	0.2	2.56	0.05	0.02
2	21.0	48.4	1.10	0.02	12.7	1.7	0.16	3.7	0.3	6.78	0.07	0.02
3	20.8	44.9	1.07	0.02	15.8	2.2	0.16	3.4	0.03	6.87	0.05	0.02
4	19.2	30.0	0.94	0.01	30.7	1.7	0.13	3.2	0.3	5.43	0.06	0.02
5	25.6	39.1	1.13	0.01	18.2	1.8	0.19	3.4	0.5	4.40	0.07	0.02
6	12.9	55.0	0.88	0.01	19.9	0.9	0.09	2.4	0.2	3.82	0.05	0.02
7	22.8	43.1	1.10	0.02	17.0	1.8	0.03	4.8	0.22	6.6	–	–
8	21.0	50.0	1.10	0.04	14.0	1.8	–	3.6	0.23	5.8	0.03	–
9	20.3	50.2	0.90	0.02	14.8	1.2	–	4.1	0.15	6	0.02	traces

Tab. 2. Chemical composition of slag-blocks from a settlement in Milanówek/Falęcin (acc. *Hensel 1986*).

Tab. 2. Chemické složení struskových bloků ze sídliště v Milanówek-Falęcin (podle *Hensel 1986*).

smelting centre. Initially, the research encompassed the areas in the direct vicinity of the iron production sites (e.g. *Kowalczuk et al. 1977*, 13–22; see also *Leciejewicz 1978*). Next, the survey spread to the entire area covered by the local settlement cluster of the Przeworsk Culture. In the years 1979–1980, a team of geologists prospected an area close to 200 km^2, where they made multiple[10] test pits alongside almost all of the watercourses running in this region (*Kowalczuk et al. 1979*; *1980*). As a result, present day deposits of bog ore were localized and their size established.[11] A dozen samples of raw material were extracted in order to determine their chemical composition. The local bog ore consists of limonite. Presently, it creates vast outcrops sometimes covering many hectares. It is usually found in form of rocky concentrations or lumpy layers. Its characteristic feature is its high porosity. Individual deposits are internally varied, both in terms of morphology as well as chemical composition (composition of sample from vicinity of Milanówek/Falęcin – *table 1*, no. 3). On average, they contain 38 % of Fe_2O_3 and approx. 37 % of SiO_2 as well as low amounts of other oxides, e.g., CaO – 1.3% on average (0.7–6.45 %); P_2O_5 – 0.8 % on average (0.4–1.6 %). According to the researchers (*Kowalczuk et al. 1980*, 8–9), due to its high acidity – it contains less than 40 % of Fe_2O_3 and more than 30 % of SiO_2, – it would have been impossible to smelt iron from the local ore without using any type of flux (e.g., CaO).

What is mainly indicated when discussing the part lime played in the bloomery process in Mazovia is the presence of lime kilns registered in the local settlements. They were discovered at all of the better researched sites. Four features of this type were found in Milanówek/Falęcin. Two of them were located next to the western border of the great slag-pit furnace cluster (*fig. 4: II*; *6: C*). There were a dozen post holes registered around them which may be an evidence of some kind of a surrounding structure, e.g., a roof. Another kiln, partially destroyed by later features, was located in the central part of furnace sequence (*fig. 4: III*). The fourth kiln, only partially investigated, was registered during the rescue excavation in 2009. It was situated between the two furnace clusters. The first three features were oval or circular in shape, 2–2.5 m in diameter, with a semicircular cross-section, and depth of approx. 1.5 meters. Their construction consisted of a hollow with stone-lined walls dug into ground, and, most probably, of a clay dome towering over it, from which multiple pieces of daub were recovered. The kiln discovered in 2009 lacked any stone structure, which differentiates it from the rest. Layers of lime were found in the bottom parts of all these features. Raw material used for its production probably came from the local marl (marlstone) deposits (*Woyda 2005*, 146; see, e.g., *Palmirski 1880*, 534).

When considering the production and utilization of lime by the inhabitants of the settlement, one more feature connected with this matter should be mentioned here. It was discovered in the central part of the 'huge' slag-pit furnace cluster. Its remains indicate that it used to be a square building measuring 11 × 4 m with clay-covered walls constructed

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[10] The test pits were dug every 200–300 m, at the both sides of the watercourses, in the area of their floodplains. Once bog ore deposits were discovered in a given place, the number of open pits would be increased. 1080 test pits were dug in 1979. While no precise number is known for 1980, considering smaller scope of the survey, there were probably slightly fewer of them than the year before.

[11] Near the settlement in Milanówek/Falęcin, vast deposits of bog ore were found alongside the small tributary of the river Rokitinica, approx. 1 km east of the site, and – slightly smaller ones – alongside the river Rokitinica approx. 2 km west of the settlement. In the direct vicinity of the settlement, bog ore was found in only one of the test pits.

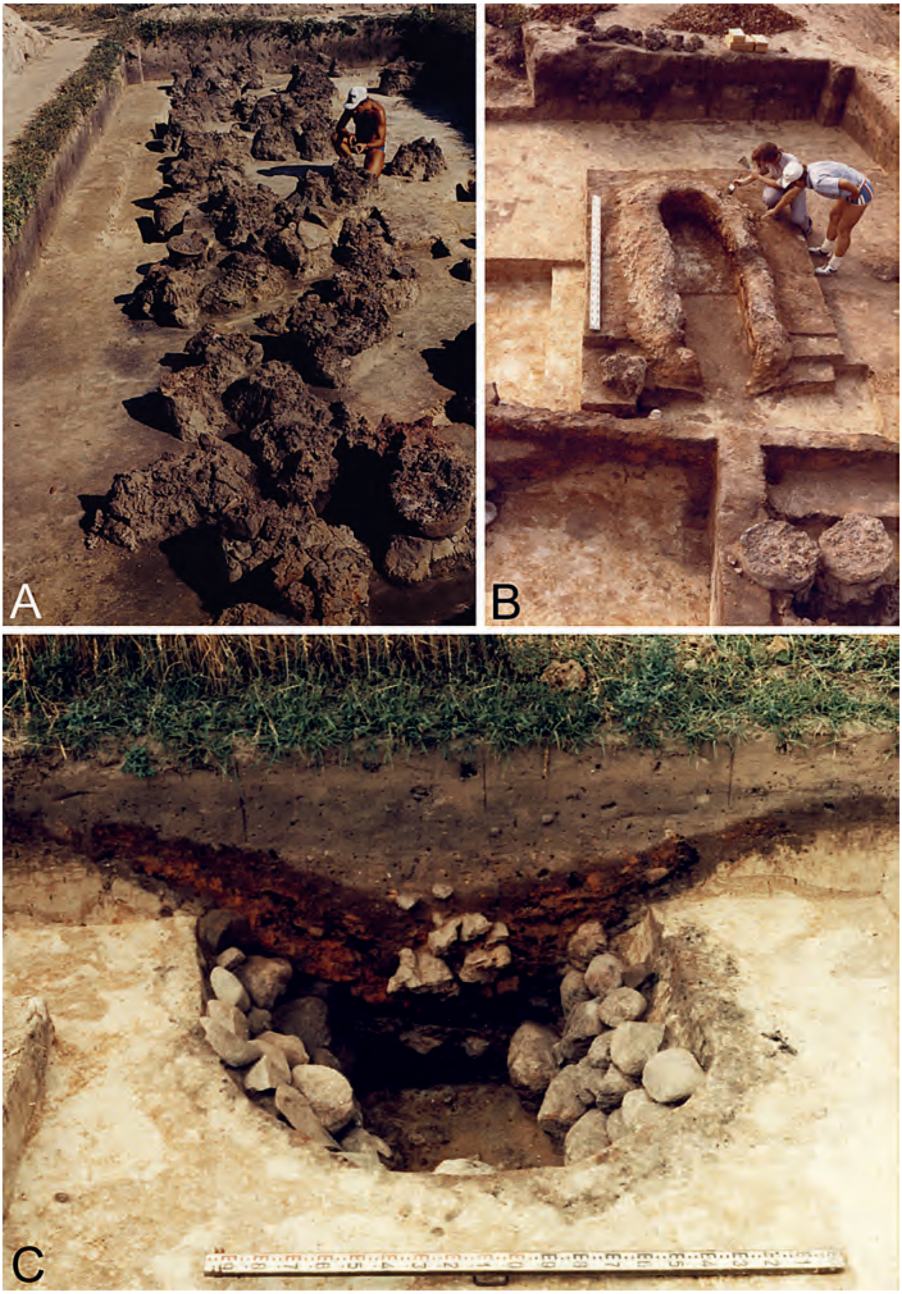

Fig. 6. Milanówek/Falęcin. A – view on trench I (photo Archive of MSHM); B – trench III – 'horseshoe-shaped' furnace during exploration (photo Archive of MSHM); C – trench II – lime-kiln during exploration (photo Woyda).
Obr. 6. Milanówek-Falęcin. A – pohled na sondu I (foto Archiv MSHM); B – sonda III – podkovovitě tvarovaná pec během průzkumu (foto Archiv MSHM); C – sonda II – vápenická pec během průzkumu.

from posts (*fig. 4: III*; *fig. 6: B*). A large, strongly elongated, slightly oval in shape furnace, 2.7 m long and 1.2 m wide, was situated in the western part of the building. It was dug slightly into the ground and was initially covered by a massive clay dome built over a wooden frame. At its base, the walls of the dome were 0.4 m thick. An opening in the eastern part of the dome allowed for the manipulation of the charge. After removing the remnants of the destroyed part of the dome, a uniform layer of lime about 10 cm thick deposited on clean, strongly annealed sand was discovered inside the furnace. Several pottery sherds and a single nodule of magnetic slag or iron were found in the top part of the lime layer. The function of the feature described is still unclear. *Woyda* (*2002*, 131; *2005*, 156) interpreted features of this type (most often called 'horseshoe-shaped')[12] as furnaces used to re-heat iron blooms in contact with lime. It is difficult to agree with this idea, more so that the author did not support it with any arguments. In the most recent literature on the subject, attention is drawn to the post-reduction phases of iron smelting (*Bielenin 1992*, 132; *Woyda 2002*, 136–137; *2005*, 154–158; *Orzechowski 2013*, 81–91). They included, among others, multiple re-heating and hammering of the raw bloom in order to remove the remains of slag and charcoal. It is assumed that hearths, where the smelted blooms were re-heated, were used for that purpose. Such hearths are characterized by the presence of distinctive lumps of slag, which dripped off the heated bloom, as well as of occasional iron flakes in their fill; however, no traces of lime have been found there. Conversely, no traces of activities related to iron metallurgy have ever been found in the features interpreted as 'reheating furnaces' by S. Woyda. However, traces of lime (or a similar substance)[13] have been observed in the better preserved of the so-named features. The remarks above indicate that furnaces from Milanówek/Falęcin as well as analogous features from neighbouring settlements cannot be directly associated with any of the phases of the iron smelting process. It would rather appear that they are a different type of a lime kiln.

The features discovered in Milanówek/Falęcin are evidence of a local production and utilization of lime. In the current state of research, however, it is unknown if the need for lime in the iron smelting was the reason for its production. The presence of lime kilns next to bloomeries may have different origins, e.g., it may be a result of separating the entire production zone, not just the metallurgical workshop, from the inhabited parts of the settlement. Lime production was an important part of the economy of that time, and shallow deposition of marl in the western Mazovia made it easy to exploit. Hence, the discovery of lime kilns in the local settlements should not come as a surprise. As it is, further research into the utilization of lime in the bloomery process is required. Small scale analytical research that has been conducted up to this moment on the randomly selected material should be complemented with a series of modern analyses. What would be of fundamental importance are the comparison studies of chemical composition between the slag blocks and

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[12] Similar features described also as 'reheating' or 'niche' furnaces were discovered in several other Mazovian metallurgical settlements, e.g., Reguły, Pruszków County, feature 1/are 27/2007; feature 1/are 29/2007, Biskupice, Pruszków County, feature 1/are 35/sector 10/1979; Stare Babice, Warsaw West County, feature 54/2006 – research by MSHM, documentation and artefacts in the museum collections.

[13] Only material from a feature in Biskupice (feature 1/are 35/sector 10/1979) was the subject of chemical composition analysis. The composition of the sample tested (39.1 % CaO) corresponds with that of the lime obtained from the four 'common' lime kilns discovered at the same site (CaO content in the range of 35.5–48.2 %) – analysis report W. Rusek and A. Żurada in the Archives of MSHM.

bog ore deposits found within the boundaries of the site, which, in theory, should be the closest match to the raw material utilized when the ancient settlement was in use. Fast regeneration of the local bog iron deposits means that starting material used for analyses was composed of samples that could have precipitated in the last several hundred years. Consequently, their composition might differ significantly from the raw material available in the ancient times.

Archaeological research in Milanówek/Falęcin was focused on the area of the production zone. Thus, the excavated area is dominated by production related features. Remnants of a building found in the trench IV, and several pits of undetermined purpose found next to this building and in the western part of trench II, are the only exceptions. The feature construed as a building was square in shape and measured around 16 m^2. Remnants of a stove made of stone, clay and pieces of slag blocks were found in its northern part. Numerous animal bone fragments, two weaving weights and a significant collection of pottery sherds, some of which – found in the vicinity of the stove – were re-fired, were recovered from the fill of the building. Ceramic material is mostly composed of sherds of thick-walled clay vessels with coarse surface. Scarce pieces of vessels with thick, non-facetted rims characteristic of the second ceramic phase of the Przeworsk Culture (e.g., *Dąbrowska 1973*, 499, 520; *1988*, 30–31; *2008*, 63–64; *Andrzejowski 2010*, 3) as well as pot sherds ornamented with incised lines made with a comb[14], date this feature probably to the late stage of the Late Pre-Roman Period. The time when the building was in use constitutes gives a *terminus post quem* for the bloomeries whose pits were dug into this structure.

This is linked inseparably with the matter of dating the Milanówek/Falęcin settlement and establishing the time period when its metallurgical workshop, manifested by the 'huge' slag-pit furnace cluster, was actually in use. Studying the chronology of the site is made more difficult by the small scope of the excavations limited only to the production zone. The next remarks are then based on a very humble collection of data, and as such can only be considered initial observations that must be verified in the course of future research. Pottery sherds discovered in a thick (20–40 cm in depth) cultural layer that was registered in all the excavated areas, as well as the ceramic material found in the building described above were the main source of material used for relative dating of the explored part of the site. The biggest collection is composed of highly fragmented sherds of big thick-walled clay vessels with a coarse body surface and a smoothed part near the rim, corresponding with the groups III and V of *T. Liana*'s (*1970*) classification. Some of the rims were thickened to a greater or lesser degree, others have edges that are indistinct or only slightly bent out. Such vessels can be encountered both in the Late Pre-Roman Period as well as in the Roman Period, usually in its early phase (*Liana 1970*, 439). Amidst the scarce examples of thin-walled pottery, vessels with thick rims, characteristic of the second ceramic phase of the Przeworsk culture dating to the phase A3 (*Dąbrowska 1988*, 30–31), are predominant. A small collection is composed of vessels showing characteristics of an even older style, namely vessels with thick facetted rims that appear in the phases A1-A2 as well as at the beginning of the phase A3 (*Dąbrowska 2008*, 8). What is peculiar in the ceramic

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[14] This ornamentation is seen as an imitation of the decorative patterns used by the people of the La Tène Culture (*Dąbrowska 2008*, 75).

material obtained is the small number of thin-walled vessels typical of the younger phase of the Early Roman Period and the beginning of the Late Roman Period such as vases and bowls with a biconical body, vessels with a distinct foot, etc. (see *Liana 1970*, 438–440, tables I–II). Only few fragments of wheel-made pottery were found either. Such pottery is encountered relatively often in local settlements from the Late Roman Period, e.g., Biskupice, Pruszków County (MSHM collection) or Izdebno Kościelne, Grodzisk Mazowicki County (*Machajewski 2016*, 235–244); Kraśnicza Wola, Grodzisk Mazowiecki County (MSHM collection). The data above indicate that the part of the Milanówek/Falęcin site studied so far was utilized in the Late Pre-Roman Period and the Roman Period. Small participation of vessels characteristic of the phases A1-A2 and the forms clearly typical of the Late Roman Period allows the dating to be narrowed to the latest phase of Pre-Roman Period to the beginning of Late Roman Period.

Trying to establish when the vast metallurgical workshop was formed is a separate matter. Woyda thought that the settlements in the area of the Mazovian Centre of Metallurgy were founded for the purpose of production. Thus, he dated the beginning of the local metallurgy to the same time as the oldest settlement horizon of the Przeworsk Culture people in this area (*Woyda 2005*, 122), i.e., at the end of the phase A1 or in the phase A2 (lately *Dąbrowska 2008*, 101–104). The idea of the contemporaneity of the developed metallurgical production and the solidification of the local settlement of the Przeworsk Culture was mostly based on the supposition that the clear division between the production and habitation zones must have been a result of a preconceived vision that directed the establishment of new settlements (*Woyda 2002*, 122; *2005*, 134–135; see also *Orzechowski 2013*, 216–217). In this light, the beginning of an intense iron smelting production in Milanówek/Falęcin should be placed in the phase A3 at the latest. The results of the research conducted at the settlement site do not fully support the above-mentioned statement. In the excavated area of the 'huge' slag-pit furnace cluster, most of the pits were dug into the cultural layer. The bottoms of many features did not even reach the sterile ground, and the top surface of the slag blocks, which would have been situated at the level of activity at the site at that time, were registered around 20–40 cm above the bottom surface of the said cultural layer. This also applies to the nethermost features situated alongside the sharp western border of the furnace cluster that were often preserved only in part and usually disturbed by later furnace pits. If *Woyda*'s (*2002*, 128) supposition – that the furnaces were constructed in straight rows in the first phase of metallurgical activity – is correct, then it should be stated that the oldest part of the excavated area of the furnace cluster was established in a place that must have been previously used by local population. However, the origin of this cultural layer is difficult to determine. Numerous pieces of slag and daub discovered in the layer indicate that it was mostly formed at the time when the furnace field was already in use.[15]

The presence of an anthropogenic layer older than the furnaces raises doubts about the simultaneous beginning of habitation and metallurgical centre at this site. However, this

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[15] Archaeological material from the, mostly uniform, cultural layer is divided into collections obtained from the consecutive ares. At this moment, it cannot be stated which of the artefacts come from the lower and which from the upper levels of the layer. It makes it impossible to determine the characteristics of the oldest level of the layer into which the pits had been dug.

matter requires further in-depth studies. Attempts at absolute dating (e.g., radiocarbon dating[16]) of the remnants of the furnaces will be of key importance. The inability to date even relatively, using classic methods, the majority of the furnaces themselves is the reason that the rhythm of the metallurgical production is being closely connected with the pace of the settlement development at this site. As it is, at the present state of research, the beginning of the intensive iron production in Milanówek/Falęcin can be seen in the Late Pre-Roman Period, and its peak in the Early Roman Period. It corresponds to the situation registered in the other, better researched, settlements in the region of the Mazovian Centre of Metallurgy (*Woyda 2005*, 131).

The site presented here is one of the most important settlements of the Przeworsk Culture people in the western Mazovia. The results of the research conducted at the site are, in many places, a reference point for the studies of the economy of local populations, especially with regards to the iron metallurgy in the region. They have also confirmed the validity of non-destructive prospection of iron smelting sites. A complete study of obtained materials, and, in long term, resuming the large-scale archaeological exploration of the site will be of crucial significance to further research. Excavations so far have only covered a limited area focused solely in the production zone of the settlement, a result of a drive to explore this newly discovered phenomenon – a local iron smelting centre. The favourable location of the site, situated away from the rapidly expanding infrastructure of small suburban towns near Warsaw, protects it from severe devastation. The presence of a cultural layer partially situated below the present-day field cultivation level is also of great significance. Features located in or under the layer are all well preserved. By employing modern technology not available several decades ago, future studies at the site will let us examine it more thoroughly and verify if any of the previously stipulated theses have in fact been true.

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Abbreviation: MSHM – Muzeum Starożytnego Hutnictwa Mazowieckiego (Museum of Ancient Mazovian Metallurgy) in Pruszków

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[16] In the late 1970s and early 1980s, two samples were dated by calculating levels of the isotope C-14: one obtained from a lime kiln and one from a slag-pit furnace. The results indicating the 6th century B.C. indeed differ from the chronology established based on the artefactual material and have been stated as dubious (*Woyda 1981*; cf. *Pazdur 1990*, 98–99, tabs. 1: 17–18; 3).

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MARCIN WOŹNIAK, Muzeum Starożytnego Hutnictwa Mazowieckiego im. S. Woydy, plac Jana Pawła II 2, PL-05-800 Pruszków; marcin.wozniak@yahoo.pl

Before or after? Stratigraphic relations of Iron Age slag-pit furnaces in the Mazovian Centre of Metallurgy

Před nebo po? Stratigrafické vztahy pecí se zahloubenou nístějí z doby železné v Mazovském metalurgickém centru

Robert Janiszewski

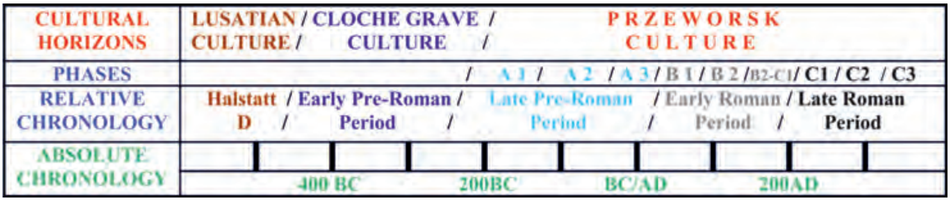
Chronology of the bloomery fields of the Iron Age is a very complex and interesting subject. Usually it can be established by radiocarbon analysis of the organic debris, mainly charcoal fragments, found at the bottom of slag-pit furnaces or by dating archaeological material collected from the sites during excavations. Both methods however, based on very limited material, often provide only broad time frames for the occupation of the sites. In Mazovian Centre of Metallurgy, where several large bloomery fields were located very close to or even within the Iron Age settlements, frequently a number of slag-pit furnaces were recorded in stratigraphic relations with other archaeological features. The chronology of those features could be established more precisely by analysing their archaeological contents. The aim of this paper will be to discuss the chronological implications for the slag-pit furnaces found in such relations. The results of this assessment will be compared with series of radiocarbon measurements from the Mazovian Centre which haven't been published so far.

Late Iron Age – Przeworsk Culture – Mazovia – iron production – slag-pit furnaces

Chronologie železářských hutí doby železné je složité téma. Obvykle ji lze stanovit radiokarbonovou analýzou organických zbytků, zejména úlomků dřevěného uhlí ze dna zahloubených nístějí nebo datováním dalšího archeologického materiálu. Obě metody, založené na velmi omezeném materiálu, však často poskytují velmi široký časový rámec osídlení lokality. V Mazovském metalurgickém centru, kde bylo několik velkých železářských hutí umístěno velmi blízko, nebo dokonce v prostoru sídlišť doby železné, bylo často zaznamenáno mnoho pecí se zahloubenou nístějí ve stratigrafických vztazích s jinými archeologickými objekty. Chronologii těchto objektů lze přesněji stanovit analýzou jejich archeologického obsahu. Cílem tohoto příspěvku je diskutovat dopady na chronologii železářských pecí nalezených v takovýchto souvislostech. Výsledky tohoto hodnocení budou porovnány s řadou dosud nezveřejněných radiokarbonových měření z Mazovského centra.

pozdní doba železná – převorská kultura – Mazovsko – výroba železa – pece se zahloubenou nístějí

One of the biggest challenges for archaeologists interested in iron production during the Pre-Roman and Roman Periods of the Iron Age is to indicate precisely when such activity took place within the time span which lasted for more than 500 years (*tab. 1*; *Andrzejowski 2010*). The radiocarbon analyses of organic samples, mainly charcoal fragments from bottoms of slag-pit furnaces or found stuck in slag fragments usually produce results with rather broad timeframes, often insufficient for the study of these periods and frequently inconsistent with the chronology of archaeological material collected from the sites (*Pleiner 2000*, 162; *Orzechowski 2013*, 174). Such a chronological gap between the radiocarbon measurements and archaeological material is well known as the so called 'old wood' effect (*Bowman 1990*, 51–53). Therefore the chronology of iron production is based primarily on comparative analysis of datable artefacts, mainly ceramics. On many occasions however,



CULTURAL HORIZONS	LUSATIAN CULTURE / CLOCHE GRAVE CULTURE / PRZEWORSK CULTURE
PHASES	/ A 1 / A 2 / A 3 / B 1 / B 2 / B2-C1 / C1 / C2 / C3
RELATIVE CHRONOLOGY	Halstatt D / Early Pre-Roman Period / Late Pre-Roman Period / Early Roman Period / Late Roman Period
ABSOLUTE CHRONOLOGY	400 BC 200BC BC/AD 200AD

Tab. 1. Archaeology and chronology of the Iron Age in Western Mazovia.
Tab. 1. Archeologie a chronologie doby železné v západním Mazovsku.

when both occupational zones, production and residential, were distant from each other researchers face additional difficulty to convincingly set the chronology of iron production. In such situations archaeological material coming from the bloomery fields is quite rare, often with its chronology difficult to assess. Frequently, when scholars deal with the sites occupied for a long time it is also difficult to link firmly production activity with any of the chronological phases within the wider period of occupation. Such dating problems are familiar to the archaeologists focused on the phenomenon of iron production in the Mazovian Centre of Metallurgy, one of the largest iron production centres in the Barbarian Europe during the Iron Age.

The Mazovian Centre of Metallurgy was identified relatively late, during the 1960s and 1970s, as a result of a large scale archaeological survey project initiated and carried out by S. Woyda who held the position of the Heritage Officer for Warsaw Voivodeship at that time. The Centre is located in central Poland between Vistula River and Bzura River which is one of its left bank tributaries in the western part of the Blonie Plain, geographical region of approximately 1,500 km^2. This, mainly flat, land stretches between the valley of Bzura River on the west and the Vistula Valley on the east. In the northerly direction it is limited by the edge of the glacial formation of the Warsaw Depression and from the south by the elevation of the Rawa Plateau. This limited area consists of many bottom terraces of numerous named and unnamed tributaries of the Bzura River and is characterized by a mainly flat form of terrain with rare elevations of small height differences. Prior to the research undertaken by S. Woyda only about 20 sites dating to the Iron Age were known from the region (*Niewęgłowski 1966*, 149–164). As an outcome of his project, that number of sites multiplied by nearly twenty. In the late 1970s, due to S. Woyda efforts the Museum of Ancient Mazovian Metallurgy (MSHM) was established in Pruszkow town as an institution designated for protection and evaluation of the Centre.

According to its finder, the Mazovian Centre of Metallurgy occupied a compact area of approximately 300 km^2 with over two hundred settlements (*fig. 1*). These sites were divided into two types: permanent or seasonal self-sufficient settlements and other places of occupations linked to these settlements, characterized by traces of short-lived working activity, not exclusively dedicated to iron production. The size of the major sites varies from hundreds of square meters to several acres of land. It is estimated that total production of the Centre was more than a hundred thousand smelts. In S. Woyda opinion, mass scale production begun in the Late Pre-Roman Period, had its peak during the first two centuries AD and collapsed with the end of the Early Roman Period, by the beginning of the 3rd century AD (*Woyda 2002*, 121–154; *2004*, 129–166). This short characteristic of the Mazovian Centre

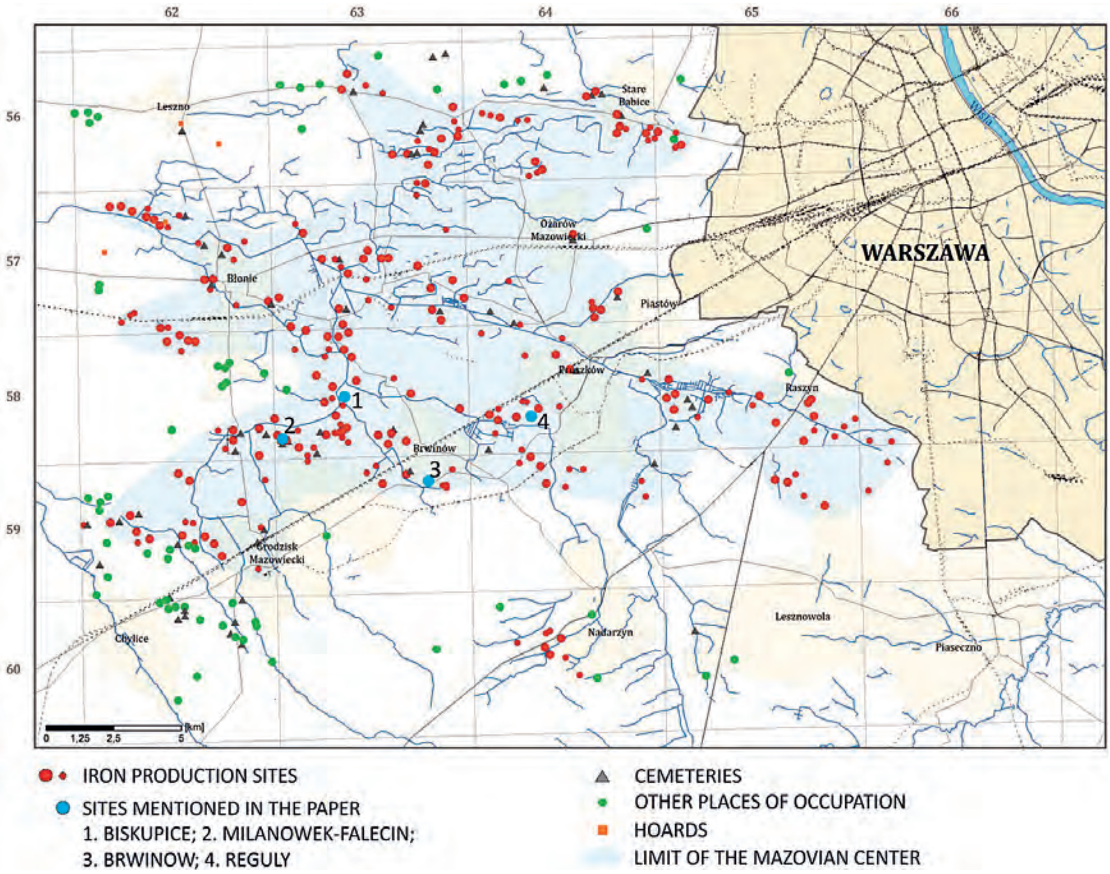


Fig. 1. Mazovian Center of Metallurgy (after *Woyda 2004*, 130, il. 2).
Obr. 1. Mazovské metalurgické centrum (podle *Woyda 2004*, 130, il. 2).

of Metallurgy and estimation of its production was based mainly on the material and observations gathered during the survey phase and slightly corrected when more advanced archaeological examination in form of research or rescue excavations were carried out. The latter type of investigation however, was done only on a few out of over a hundred major sites assigned to the relevant periods. In addition, no results of these excavations have been published fully so far.

It is distinct for the Mazovian Centre that organization of iron production was arranged in large production zones – bloomery fields consisted of hundreds or even thousands single-use slag-pit furnaces. Although, generally speaking, production was arranged in the so called ‘unorganized’ fields there was in some instances very clear tendency to shape the iron production, at least at some stage, in linear formations. Traces of such attempts have been recorded on a few sites during the geomagnetic survey (Milanówek–Falęcin, Parzniew) and confirmed to some extent by the excavations which followed (Milanówek–Falęcin, Reguly). During the initial survey phase it was also noticed that on some sites production zones were located close to the residential sectors, sometimes even occupying parts of the same area. In several instances it created situations, confirmed during the excavations, that slag-pit furnaces were in stratigraphic relations with other archaeological features, which often contained datable artefacts. Detailed analysis of such situations would allow us to establish stratigraphic sequence and relative chronology for single slag-pit furnaces or its clusters found in such positions. Cases of these relations were recorded on several sites excavated by the MSHM's staff and this paper will discuss examples from four of them. Lack of publications permits only to review a limited number of features with clear and relatively precise chronology, although the base for such research is potentially much broader. The results of this assessment will be confronted and combined with series of radiocarbon measurements secured for three of these sites which haven't been published so far. Generally speaking there are three situations when slag-pit furnaces or their debris could be in stratigraphic relations with other archaeological features:

1. Archaeological features were destroyed or truncated by slag-pit furnaces – in such cases archaeological material coming from these features gives a *terminus post quem* for the furnaces.
2. Slag-pit furnaces were destroyed or interrupted by other archaeological features – in such situations archaeological material coming from these features provides a *terminus ante quem* for the furnaces.
3. Debris of iron production, mainly slag blocks or fragments thereof, were re-used as a packing material during construction of other archaeological features. In such instances, we are not able to identify which specific furnaces these remains came from, but it justifies the observation that the iron production phase was earlier or contemporary to the time of construction of those features.

The first group of such examples comes from the Biskupice site (**AZP No 58-63/5**). It was a large multi-period settlement occupying an elevated area near a small creek called Zimna Woda. During several summer campaigns between 1976 and 1992 approximately 8 acres of the site was unearthed. During the excavations both residential and production zones were documented, confirming observations based on surface and geomagnetic surveys made prior to the excavations. The former zone, oval in shape, occupied a lozenge plateau in the central part of the site, while the latter was divided into two parts located on opposite (western and north-eastern) sides of the residential sector. Both production units were connected by an almost straight line of slag-pit furnaces which crossed the residential area in its northern part. More than 3,500 slag-pit furnaces, in the form of slag blocks preserved *in situ* or circular furnace pits with secondary fills, were recorded on the unearthed area. The first of the examples from that site, the oval hearth filled with stones (**S2/A4/Feat. 3a**) had its southern half partially destroyed by the slag-pit furnace with a slag block preserved *in situ*. Datable artefacts in form of pottery sherds included a pot (reconstructed) which was in use during the Early Pre-Roman Period, before the Przeworsk cultural horizon emerged. Another feature, possible hearth (**S2/A5/Feat. 4**), was also stratigraphically earlier than smelting furnaces represented by two oval pits with secondary fills. Again, its chronology can be assessed by pottery sherds found in its fill. Black coloured examples of a bowl with an ear handle and wide opening and fragments of a pot with faceted rim indicate that that feature was in use during the A2 to the beginning of A3 phases of the Late Pre-Roman Period. In the Biskupice site also the opposite situation was documen-

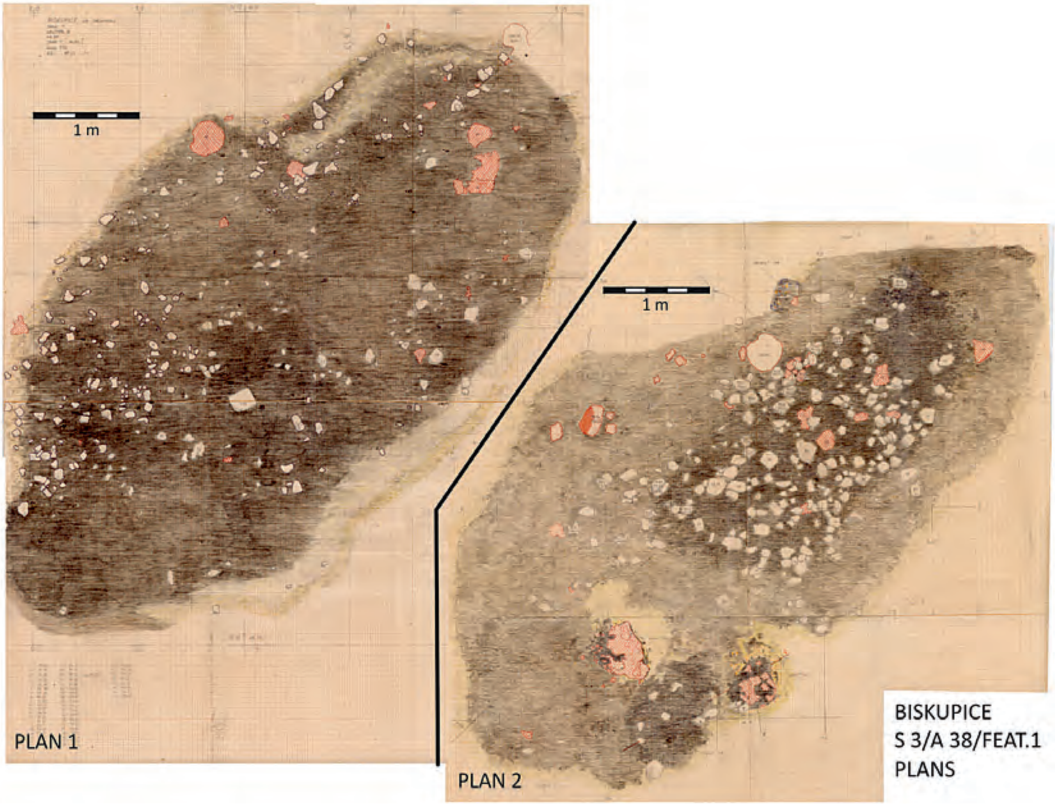


Fig. 2. Biskupice S3/A38/Feat. 1: Plan 1 (2), Plan 2 (4). After: Dwgs # Bs. 236/82, Bs. 238/82, unsigned.
Obr. 2. Biskupice S3 /A38/objekt 1: Plán 1 (2), plán 2 (4). Podle: Dwgs # Bs 236/82, Bs. 238/82.

ted, when archaeological features were constructed later than the iron production phase. One such example is a large, oval hearth filled with a layer of burnt stones (**S3/A38/Feat. 1**), which clearly was set on top of a few slag-pit furnaces (*fig. 2*). These furnaces apart from their bases were almost completely destroyed by construction of the hearth. Among numerous pottery sherds there were examples of wheel-thrown ceramics, production of which could be placed not earlier than the beginning of phase C1 of the Late Roman Period. A third situation from the list of possible cases is exemplified by remains of the square-planned well (**S3/A36/Feat. 28**) with lining made of wooden planks preserved in the bottom part of the shaft. During construction a number of fine stones and small slag fragments were clearly used as packing material. Layers of secondary deposit within the well's shaft contained only a few pottery sherds, including a wheel-thrown piece. Lack of clearly Pre-Roman and very Early Roman material might suggest that the well was in use during the later phase of the Early Roman Period. More precise chronology of the well's construction could be provided by dendrochronological analysis of the preserved planks. The last example from the site of Biskupice would also be one of the most intriguing. In northern part of the western production zone an alleged ritual horse burial, surrounded by slag-pit furnaces was

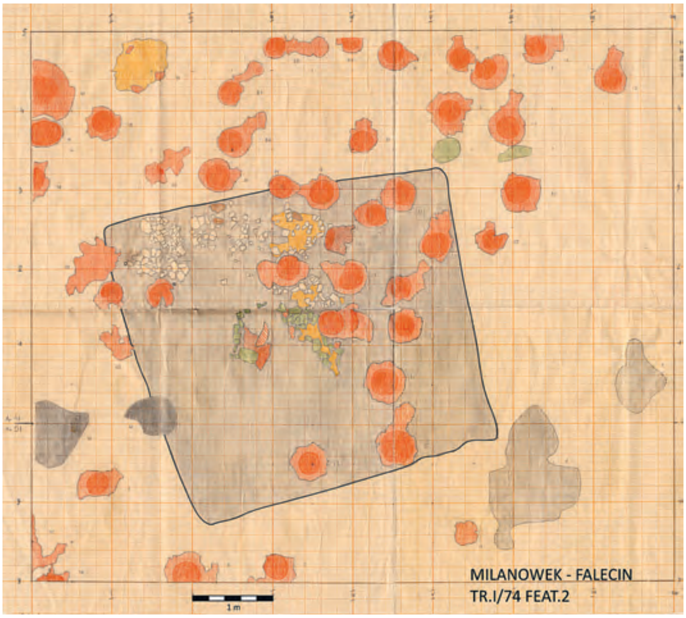


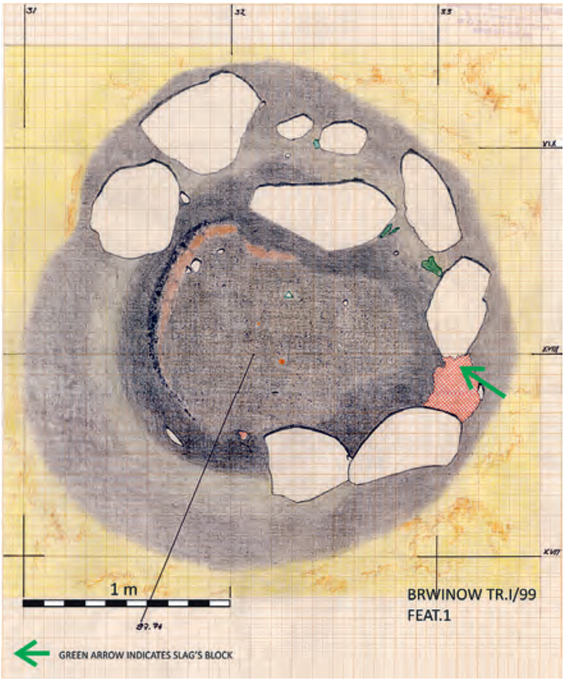
Fig. 3. Milanówek–Falęcin Tr.I/74/Feat. 2. Plan. After: Dwg # M-F I/74/1, author: S. Woyda.
Obr. 3. Milanówek–Falęcin sonda I /74/objekt 2: Plán. Podle Dwg # M-F I/74/1, autor: S. Woyda.

recorded (**S2/A15/Feat. 1**). Its dramatic setting was emphasized by a block of slag deposited intentionally on animal's skull (*Woyda 2004*, 141–143). However, in absence of any datable artefacts associated with that burial and lack of radiocarbon analysis of skeletal remains its direct connection with iron production remains speculative.

Another important site investigated by the MSHM's staff was Milanówek–Falęcin (**AZP No 58-63/14**). A few seasons of research excavations in 1970s and 1980s took place along the western limit of the site, mainly within its production zone, and test trench locations were based on the results of surface and geomagnetic surveys. During four seasons of excavations just over 1,500 m^2 of the site was unearthed and approximately a thousand smelting furnaces and their remains along with dozens of other archaeological features were recorded. During the first season, in 1974, one of the most interesting examples of stratigraphic relations between slag-pit furnaces and other features was recorded (*fig. 3*). Small scale excavations in a rectangle trench of just 56 m^2 yielded about 40 slag-pit furnaces of which nearly half was set on the top of a square dwelling, preserved in its bottom (**Tr. I/74/ Feat. 2**). Fills of hut remains contained four conical ceramic loom-weights and pottery sherds typical for final phases of the Late Pre-Roman Period. Another interesting feature from that site, excavated during the following season, was a lime kiln (**Tr. II/75/ Feat. 1**), common on Iron Age sites, oval in shape with steep sides lined with stones. This kiln was sealed in its eastern half by a group of four slag-pits furnaces. The kiln contained a very small amount of uncharacteristic pottery sherds but its bottom layer, rich in charcoal, produced radiocarbon date of 2450 (± 180) BP (**Gd-448**).

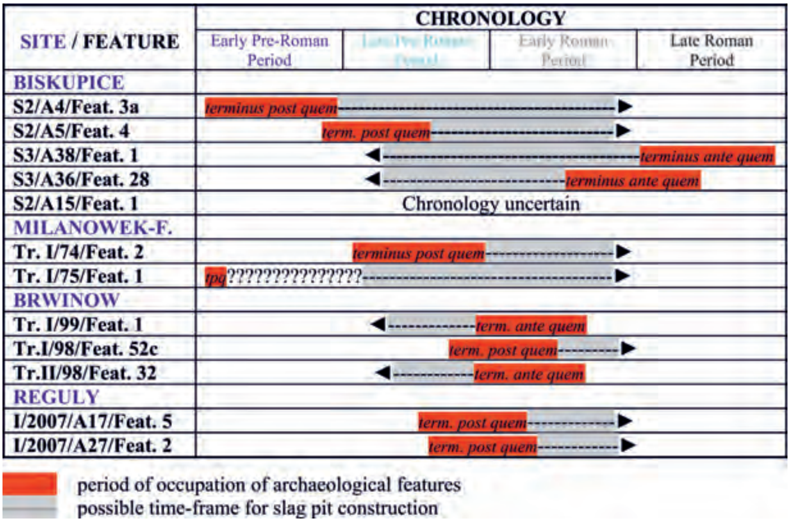
Another site discussed in this study is located under the present day town of Brwinow (**AZP No 58-63/11**). As far as existing conditions permit its interpretation, it also was split into two distinct zones: residential and production, the latter situated in the western part of

Fig. 4. Brwinow Tr.I/99/Feat. 1. Mid-ex plan. After: Dwg # Br. 3/99, author: P. Holub.
Obr. 4. Brwinow sonda I/99/objekt 1: plán objektu po částečném odkrytí. Podle: Dwg # Br. 3/99, autor: P. Holub.



the site. Several small scale rescue excavations took place mostly within the production zone and resulted in the recording of just over a thousand slag-pit furnaces along with several other archaeological features. Among these features was a well (**Tr. I/99/Feat. 1**), circular in plan with a wide layer of packing deposit consisted of stones in shaft's upper half (*fig. 4*). Among large stones, forming a ring situated on the top of the packing layer, one block of slag was also deposited. Backfilled material from the well's shaft included pottery sherds dating from the B1 phase of the Early Roman Period and, hence, suggesting early disuse of the well. Another feature from the site, an oval hearth with black charcoal-rich layer (**Tr.I/98/Feat. 52c**), was cut through by a slag-pit furnace (**Tr.II/98/Feat. 45)** situated in its central part. The fill of the hearth contained pottery sherds pointing to the Early Roman Period as the time of its formation, but in this case artefacts mark a *terminus post quem* for the construction of that slag-pit furnace. The last interesting structure from the site of Brwinow, presented in this paper, is a cluster of three slag-pit furnaces (**Tr.II/98/Feats. 29, 30, 31**) with a pavement stretched between them (**Tr.II/98/Feat. 32**), consisting of a layer of fine stones and a layer of burnt clay acting as a cover. Very limited ceramic material suggests that the structure was set in the Early Roman Period. Stratigraphic relations within this group were clarified by one of the sections showing that in order to construct the stony floor of **Feat. 32** an exit channel of one of slag-pit furnaces (**Feat. 31**) was terminated below the ground level. Thus in this case, smelting furnaces were formed prior to the pavement and served as its corners.

The last archaeological site included in this study is Reguly (**AZP No 58-65/14**), located just out of Pruszkow town. Parts of the site were unearthed in series of rescue excavations



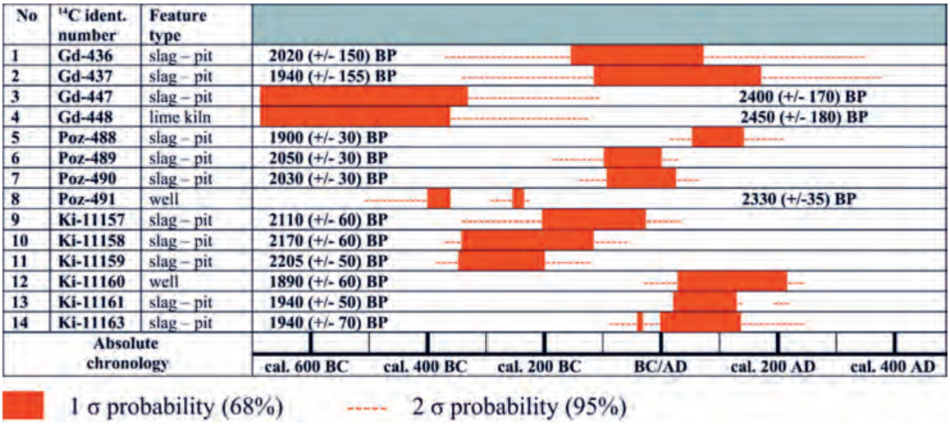
SITE / FEATURE	CHRONOLOGY			
	Early Pre-Roman Period	Late Pre-Roman Period	Early Roman Period	Late Roman Period
BISKUPICE				
S2/A4/Feat. 3a	*terminus post quem*------------	----------------------------	----------▶	
S2/A5/Feat. 4		*term. post quem*----------	----------------▶	
S3/A38/Feat. 1		◀--------------------	--------------------	*terminus ante quem*
S3/A36/Feat. 28		◀--------------------	------*terminus ante quem*	
S2/A15/Feat. 1	Chronology uncertain			
MILANOWEK-F.				
Tr. I/74/Feat. 2		*terminus post quem*	------------------▶	
Tr. I/75/Feat. 1	*tpq*???????????????	--------------------	----------------▶	
BRWINOW				
Tr. I/99/Feat. 1		◀------------	*term. ante quem*	
Tr.I/98/Feat. 52c			*term. post quem*---------▶	
Tr.II/98/Feat. 32		◀------------	*term. ante quem*	
REGULY				
I/2007/A17/Feat. 5		*term. post quem*	------------▶	
I/2007/A27/Feat. 2		*term. post quem*	------------▶	

🟥 period of occupation of archaeological features
▨ possible time-frame for slag pit construction

Tab. 2. Chronology of archaeological features and their stratigraphic relations with slag-pit furnaces.
Tab. 2. Chronologie archeologických objektů a jejich stratigrafické vztahy s pecemi se zahloubenou nístějí.

in advance of the phases of residential expansion of the present day village. The first of the analysed features (**Tr.I/2007/A17/Feat. 5**), a pit with circular plan and a single black fill, was sealed by two slag-pit furnaces (**Tr I/2007/A17/Feat. 10** and **A27/Feat. 5**) with both slag blocks partially destroyed but with very clear cuts and distinct fills layers. Regardless of whether the pit's fill was primary or secondary it was formed before both smelting furnaces were constructed and material from that fill, again solely in the form of pottery sherds, suggests formation time during the final stages of the Pre-Roman Period or slightly later. Another feature from that site, the last example presented in this assessment, was a possible hearth (**Tr.I/2007/A27/Feat. 2**) heavily affected by later iron production activity and disrupted by a cluster of slag-pit furnaces, out of which three had slag blocks still preserved *in situ*. Ceramic material from the hearth's layer suggests it was in use at the beginning of the Early Roman Period.

Having discussed examples of stratigraphic relations between slag-pit furnaces and other archaeological features from the Mazovian Centre some general observations can be drawn. The overall picture suggests that results of this assessment correspond with the chronology of iron production suggested in S. Woyda's papers. Several slag-pit furnaces were set on remains of various features dated by archaeological material, mainly pottery, to the Late Pre-Roman or Early Roman Period. No slag-pit furnaces were stratigraphically later than features dated to the Late Roman Period (from phase C1 onwards) while some structures dated to that period clearly destroyed existing remains of iron production activity (*tab. 2*). It has to be mentioned however, that there was no investigation carried out on the sites which, according to the surface survey reports, contained pottery of the Late Roman Period and frequent iron slag debris. Among the analysed examples there are also cases which prove early production of iron; they are in the form of slag blocks or slag fragments, which were re-used during construction of other archaeological features, mainly wells, or



No	^{14}C ident. number	Feature type	
1	Gd-436	slag – pit	2020 (+/- 150) BP
2	Gd-437	slag – pit	1940 (+/- 155) BP
3	Gd-447	slag – pit	2400 (+/- 170) BP
4	Gd-448	lime kiln	2450 (+/- 180) BP
5	Poz-488	slag – pit	1900 (+/- 30) BP
6	Poz-489	slag – pit	2050 (+/- 30) BP
7	Poz-490	slag – pit	2030 (+/- 30) BP
8	Poz-491	well	2330 (+/-35) BP
9	Ki-11157	slag – pit	2110 (+/- 60) BP
10	Ki-11158	slag – pit	2170 (+/- 60) BP
11	Ki-11159	slag – pit	2205 (+/- 50) BP
12	Ki-11160	well	1890 (+/- 60) BP
13	Ki-11161	slag – pit	1940 (+/- 50) BP
14	Ki-11163	slag – pit	1940 (+/- 70) BP

Tab. 3. Radiocarbon results from Mazovian Centre of Metallurgy.
Tab. 3. Radiokarbonové výsledky z Mazovského metalurgického centra.

which were disrupted by their construction. Datable material retrieved from the fills of features suggests the Early Roman Period as time of their use. This might indicate an early phase of iron smelting in the Masovian Centre, a phase which preceded the culmination of the production during the Early Roman Period.

These provisional conclusions can also be compared with the results of radiocarbon analysis of the samples from the sites discussed above. Although only four results, analysed in the late 1970s have been published so far (*Pazdur 1990*, 98–99) in fact there have been in total 18 results of carbon dating from the Mazovian Centre (*archives ADN/254*), and 14 of them might be useful for this review (*tab. 3*). These samples came from three major sites discussed in this study: Milanówek–Falęcin (*tab. 3: 3–4*), Biskupice (*tab. 3: 1–2*) and Brwinow (*tab. 3: 5–14*), and were mostly taken from charcoal debris collected from the bottoms of the slag-pit furnaces (11 cases) or from other features (3 cases: 1 lime kiln and 2 wells) allegedly associated with iron production. The analyses were performed between 1976 and 2004 in three different laboratories: in Gliwice (**Gd-436**, **Gd-437**, **Gd-447**, **Gd-448**), Poznan (**Poz-488**, **Poz-489**, **Poz-490**, **Poz-491**) and Kiev (**Ki-11157**, **Ki-11158**, **Ki-11159**, **Ki-11160**, **Ki-11161**, **Ki-11163**). More than a half of the results from slag-pit furnaces (7 out of 11) seem to be in line with the general view on the chronology of iron production in the Mazovian Centre and belong to the final phases of the Late Pre-Roman or Early Roman Periods, while another one can be placed slightly earlier but still within the Pre-Roman Period (*tab. 3: 9*). The results from Milanówek, samples from slag-pit furnace and the lime kiln (*tab. 3: 3–4*), have been questioned since its publication as both were dated to the beginning of the 5th century BC (*Woyda 1981*, 95–96). However, such early dating will be less surprising when stratigraphic relations of both these features are re-assessed. The lime kiln, mentioned in the study (**Tr.I/75/Feat. 1**), clearly preceded phase of iron production as it was sealed by series of slag-pits and a smelting furnace chosen for charcoal sampling (**Tr.I/75/Feat. 41**) was part of that cluster. In such a situation the mixing of fills and its organic contents was quite possible and sample contamination with earlier material is a likely explanation for such a premature date for a smelting furnace. Two other early results secured from slag-pit furnaces from Brwinow could mark a very early phase of production in the community before the Przeworsk Culture emerged or, in author's opinion more likely, could exemplify the 'old wood' effect. Measurements from other archaeological features recorded on these sites offer various results. The case of the lime kiln from Milanówek has been discussed above while results from timber samples collected from two wells, recorded in Brwinow and located not so far from each other gave different dates. While the younger one (*tab. 3: 12*) fits comfortably within the period of intense iron production, the other well *(tab. 3: 8*) was probably in use before production on the site started. This example, together with the lime kiln from Milanówek, might suggest also that not all archaeological features found on sites interpreted as iron production centres should simply be linked with metallurgical activity.

Therefore, it can be concluded that in the case of the Mazovian Centre of Metallurgy where both zones, production and residential, frequently coexisted on many sites, analysis of stratigraphic relations between slag-pit furnaces and other features may provide useful information on the relative chronology of iron production during the occupation of each site. However, this information might be more effective and could provide better results only with full publication of these sites. For future research it would be very helpful if chronological conclusions based on stratigraphic relations could be combined with the results of radiocarbon or dendrochronological analysis in order to verify research findings with scientifically proved chronology.

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ROBERT JANISZEWSKI, Museum of Ancient Mazovian Metallurgy, T. Pelczynskiego 32c, Apt. 33, PL-01-471 Warsaw; janiszewski_r@op.pl

Socio-economic determinants of iron production on Polish lands during antiquity

The phenomenon of metallurgical smelting centres of the Przeworsk culture

Socioekonomické determinanty výroby železa na polských územích v době římské

Fenomén hutnických center převorské kultury

Szymon Orzechowski

Metallurgical activity of the peoples living in the area known as Germania Magna is characterized by an extensive and ad hoc nature which clearly is different from the centralized Roman production model. In the so-called Barbarian parts of Europe however, there were regions where there was a specialized and identifiably large mass production of iron. On Polish lands three such centres were active – in the Holy Cross Mountains, in West Masovia and in some regions of Silesia. The presence within a single cultural unit of several large metallurgical centres functioning on the basis of different organizational patterns is a unique phenomenon and warrants reflection upon the causes of their creation and the meaning of production for their neighbouring areas. These enormous logistical projects indicate the existence of yet unknown to us interdependent social structures of large work teams in the population, evident over a period of several generations. Their reconstruction can help us understand at least some aspects of the social and economic life on Polish lands towards the end of antiquity.

ancient metallurgy – Przeworsk culture – metallurgical centres – social structures

Hutnická činnost lidí žijících v oblasti známé jako Germania Magna se vyznačuje rozsahem a ad hoc charakterem, který se jasně odlišuje od centralizovaného římského modelu výroby. V tzv. barbarských částech Evropy však existovaly regiony, kde probíhala specializovaná masová výroba železa. Na polských územích působila tři taková centra – ve Svatokřížských horách, v západním Mazovsku a v některých oblastech Slezska. Přítomnost několika velkých metalurgických center v rámci jedné kulturní jednotky, fungujících na základě různých organizačních vzorů, je jevem výjimečným a opravňuje k úvahám o příčinách jejich vzniku a o významu výroby pro sousední oblasti. Tyto obrovské logistické projekty naznačují existenci dosud neznámé vzájemně závislé sociální struktury velkých pracovních týmů po dobu několika generací. Jejich rekonstrukce nám může pomoci pochopit alespoň některé aspekty společenského a ekonomického života na polských územích v době římské.

starověké hutnictví – převorská kultura – metalurgická centra – sociální struktury

Enormous progress that has taken place in archeo-metallurgical research in recent years, has also led to a very worrying phenomenon which is associated with the gradual dehumanization of the discipline. Fascinated with the opportunities offered by natural sciences, we gradually lose sight of man and the complex socio-economic and political processes which created the reality surrounding him, and decided about the development of the field of economy that interests us – metallurgy. The archaeological community has ceased to understand us, which results in alienating our discipline from the mainstream of archaeology. I do not oppose analytical research and I consider it to be an indispensable element of modern science. We have to remember, however, that devoid of a broader cultural context, our findings can become merely a set of empty technical data.

In the area of the so called European Barbaricum we have encountered two organisation models of iron production. The first is represented by small workshops fulfilling the immediate needs of local communities (*Pleiner 2000*, 45–47). The other trend in production was realised by specialised metallurgical centres operating to satisfy the demands of external markets. In Poland among those there were the Świętokrzyskie Mountains and Masovia. Despite popular knowledge of those technologies, Silesia represents a rather extensive production model. Only the Brzeg region alludes to the aforementioned regions of specialised metallurgy (*fig. 1*).

It is generally believed that the skill of iron smelting was commonly known and practised among the Przeworsk culture people. It is to be confirmed by the presence of slag found on a relatively large number of sites of the culture. It should be remembered, however, that the majority of such finds has not been unequivocally defined and assigned to a smelting stage, and it cannot be ruled out that at least some of them were related to the so-called post-reduction phase of the metallurgical process, which comprised activities involving purifying iron and its further processing. An unclear chronological context of a considerable part of those finds could result in manifestations of metallurgical activity from other epochs being included in that group. It is symptomatic that discoveries of bloomery furnaces have become relatively rare, and on many systematically researched sites no traces of any metallurgical activity have been found. More evidence seems to support the idea that metallurgical production in Polish territories was distinctly regionalised. Besides the already mentioned centres of specialised metallurgy, production activity in this respect was conducted in some larger and several smaller clusters, both in the Przeworsk culture area, e.g. in Greater Poland – in the central and upper river basin of the Warta, Prosna and Obra; in Kuyavia – in the valleys of the rivers Zgłowiączka, Bachorza, Noteć and Parchań; in central Poland on the Pilica and Radomka rivers; but also of the Wielbark culture – in the Gniezno Lake District and further north on the River Drwęca, and in Pomerania and Powiśle (*fig. 1*). It is symptomatic that there are practically no metallurgical sites on the upper Vistula River and in the Lublin region, in the areas of intensive settlement of the Przeworsk and Wielbark cultures (*Orzechowski 2013*, 271–277). In the west, the clearly outlined metallurgical region in the vicinity of Żary on the Bobr River should be associated with the Luboszyce culture, as it alludes to a larger cluster of that culture in Lower Lusatia (*Spazier 1996*; *2007*). There remain small production complexes associated with the Bogaczewo culture in Masuria and the post-Zarubintsy culture on the Narew River.

Because of the character of this study, I will limit it to the general characteristics of the largest metallurgical mass-production regions, taking into account the scale and specificity of the production carried out there. I will also recall elementary data concerning the Przeworsk culture whose people were the creators of those immense production undertakings.

The people of the Przeworsk culture inhabited the area of southern and central Poland between the turn of the 3rd and 2nd century BC and the mid-5th century AD, and belonged to the largest and longest-lasting political systems in the regions. In Roman records they

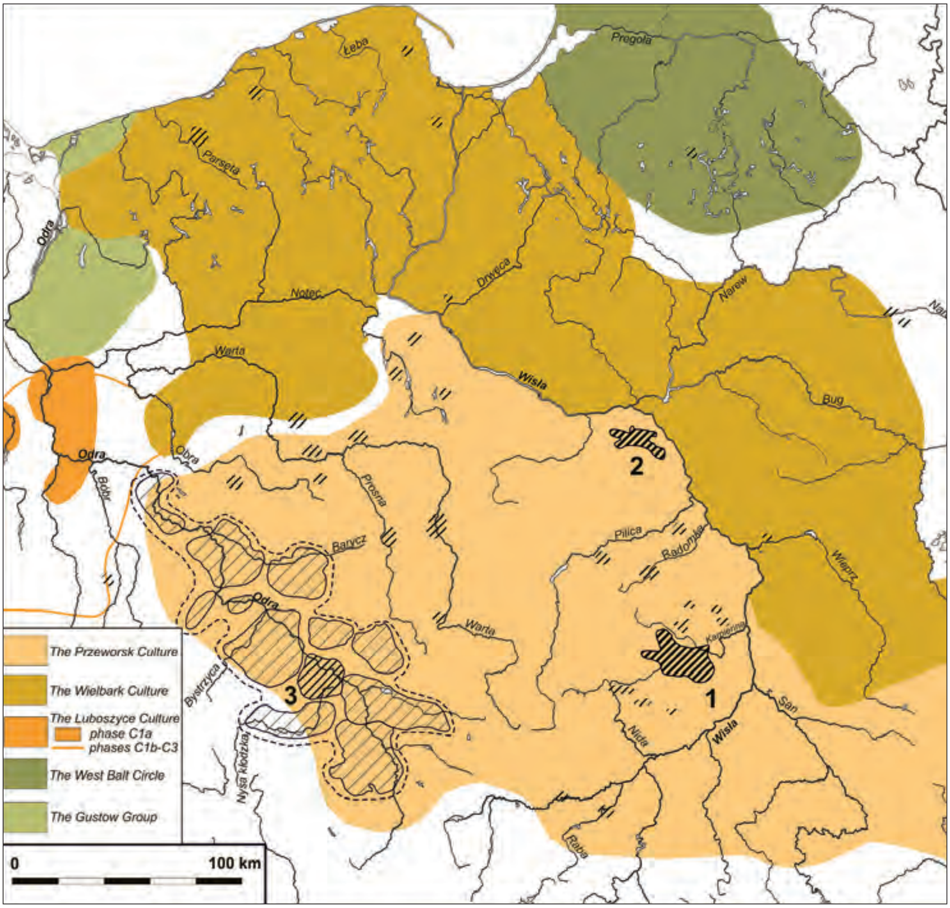

Fig. 1. Bloomery centres (1, 2, 3) and smaller smelting centres (marked with a small hatching) operating in Polish territories within the Przeworsk culture and neighbouring cultural units. 1 – Świętokrzyskie Mountains metallurgic centre and its potential enclaves; 2 – Mazovia centre; 3 – metallurgic regions in Silesia (3 Brzeg area).

Obr. 1. Hlavní (1, 2, 3) i menší hutnická centra působící na polských územích v rámci převorské kultury a sousedních kulturních jednotek. 1 – hutní centrum ve Svatokřížských horách a jeho potenciální enklávy; 2 – Mazovské centrum; 3 – hutní regiony ve Slezsku (oblast 3 Brzeg).

are known as the Lugii (*Lugiorum nomen*), and later they can be at least partially identified with Vandal tribes (see *Andrzejowski 2010*).

Among many original elements of these people's culture, particular attention needs to be paid to their achievements in black metallurgy. Apart from the economic aspect of this production, one can say they had a special preference for iron, which was used for producing not only the indispensable tools and weapon but also some elements of clothing, traditionally made from other metals. Iron fulfilled its basic function in grave furnishings, where its amount implied the symbolic significance of this metal. All the above features led to giving the Przeworsk culture the name of 'the culture of iron' (*Orzechowski 2007a*).

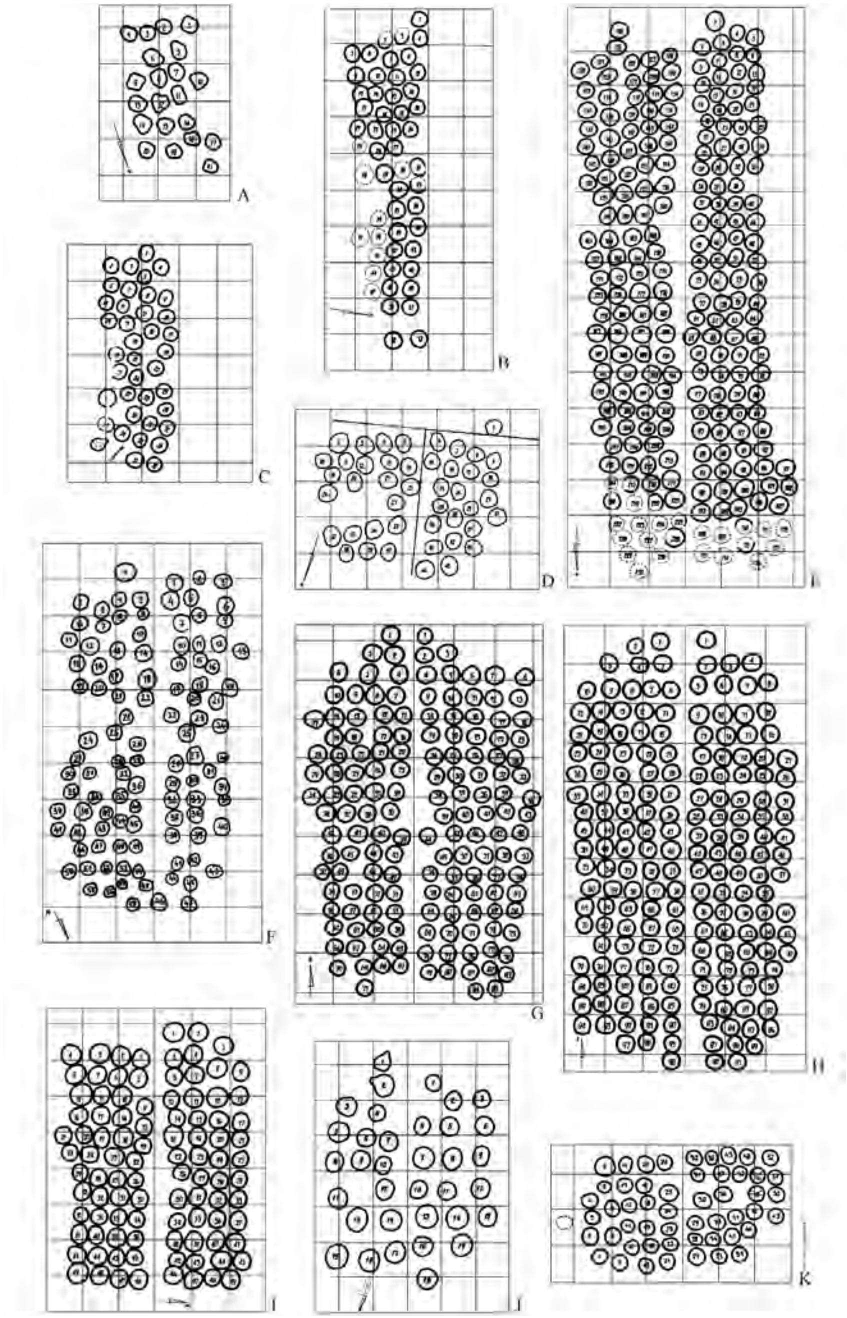

Fig. 2. Plans of various types of organised slag-pit clusters from the Świętokrzyskie Mountains (acc. to *Bielenin 1992*).
Obr. 2. Plány různých typů organizovaných seskupení zahloubených nístějí ve Svatokřížských horách (podle *Bielenin 1992*).

It has already been mentioned that besides a few traces of iron smelting in the settlements which satisfied local needs, the Przeworsk culture people organized some huge production centres geared towards producing huge amounts of the material to be exported. The huge smelting centres operating in the Świętokrzyskie Mountains area, in Western Masovia and in Silesia might have fulfilled this function.

The Świętokrzyskie Mountains metallurgical centre undoubtedly holds a special position. Approximately 8,000 metallurgical workshops with over 550,000 furnaces worked in the area of almost 1,000 km^2. Jointly they could have produced about 11,000 tonnes of iron, and the heyday of its activity was in the mid-2nd century AD (*Bielenin 1992*, 190–197; *Orzechowski 2013*, 245–250). The other large metallurgical region of the Przeworsk culture located in the western Masovia comprised the area of about 300 km^2. It is estimated that from the 1st to the mid-2nd century AD there worked here between 120 and 150 thousand furnaces which jointly produced about 1400–1800 tonnes of iron (*Woyda 2002*, 123–125).

Each of the above mentioned production regions worked out its own methods of organising labour and production technologies. For the Świętokrzyskie Mountains area, a typical form was so called ‘organised’ bloomery ironwork containing two furnace clusters of almost identical layout, usually located outside the area of permanent settlement (*fig. 2*). In Masovia, on the other hand, there were created enormous production settlements which grouped from a few to several thousand of bloomery furnaces, located on the outskirts of the dwelling area. Frequently, the furnaces here were inexplicably set in ideally straight lines, 200 to 300 metres long (*fig. 3*). In the biggest settlement recognised so far, in Milanówek–Falęcin, there could have operated up to 15,000 bloomery furnaces.

In turn, in the Brzeg region in Silesia metallurgical workshops created ‘nest’ complexes consisting of several sites, remote from the settlement zone. Most frequently, they included a metallurgical workshop, a forge and less often a settlement serving as a traditional dwelling place. According to *S. Pazda* (*1994*, 168), in the 4th and 5th centuries about 130 tonnes of iron were produced here.

It is worth noticing that centres of specialised metallurgy, operating in various regions occupied by the Przeworsk culture people, were present throughout practically the whole period of its existence, for almost six hundred years. At the earliest that trend in production shaped in Masovia where, already towards the end of the younger pre-Roman period (1st century BC), huge settlement-production complexes began to emerge. The apogee of that activity occurred mainly during the Early-Roman period and distinctly slowed down only towards its end. It is surmised that the phenomenon was directly related to the appearance of the Wielbark culture settlements, identified with the Goth migration in eastern Masovia in the mid-2nd century. However, it did not mean a complete abandonment of that activity. It was indeed “moved” outside the settlements and was considerably fragmented, yet on some sites it might have developed even until the beginning of the 4th century (phase C2; *Woyda 2002*, 122, 123, 140).

In the Świętokrzyskie Mountains, the beginnings of organised metallurgy date back to as late as the end of the early-Roman period, though the majority of organised slag-pit clusters functioned mainly in the 2nd and possibly at the beginning of the 3rd century (phases B2 to C1b) Also in this case, after that period the activity did not disappear completely, but might have survived in the form of fragmented manufacture further into the late-Roman period (*Bielenin 1992*, 167–179; *Orzechowski 2007b*, 72–91).

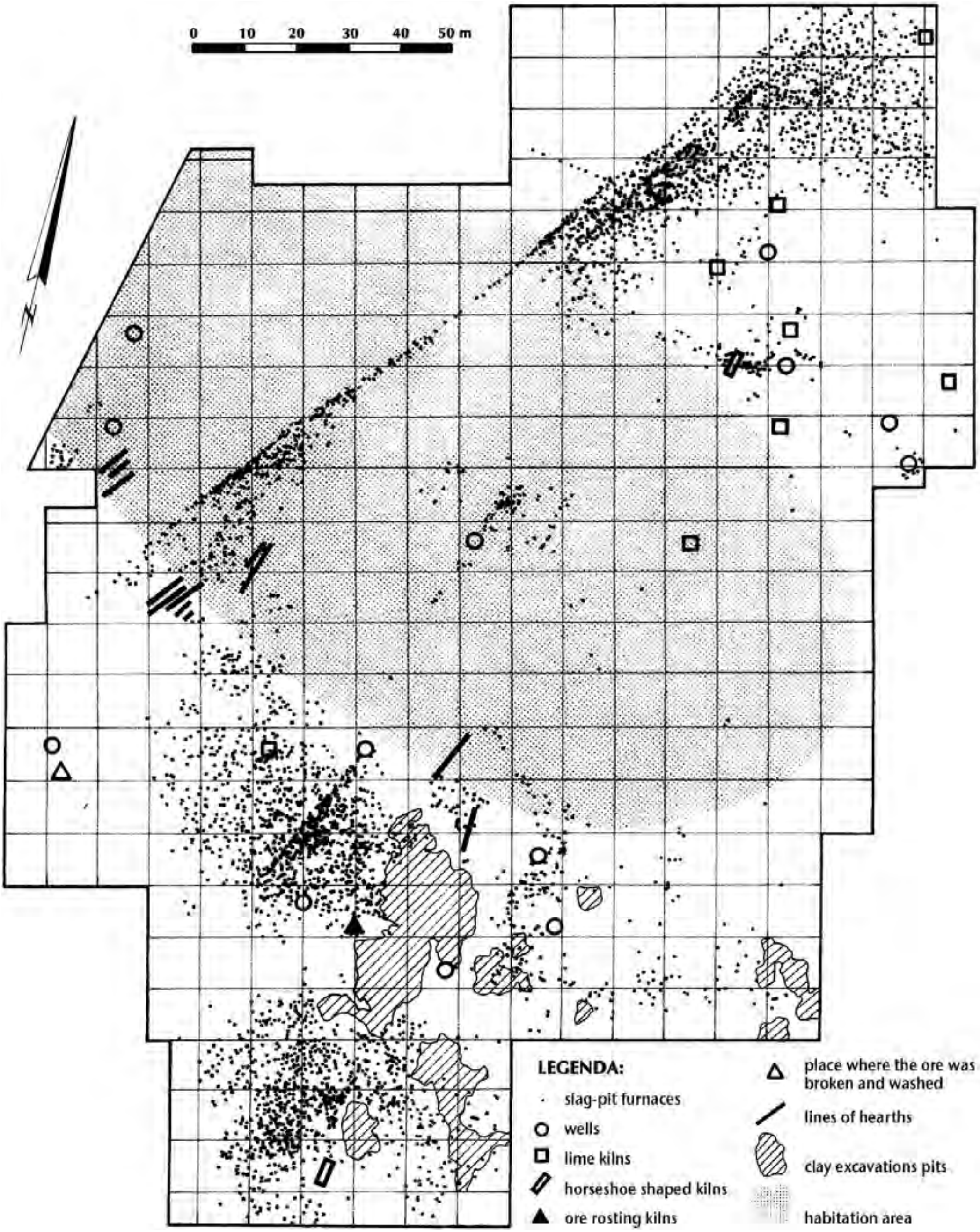

Fig. 3. Plan of the examined section of the settlement in Biskupice with a characteristic borderline along which the furnaces were concentrated (acc. to *Woyda 2002*).
Obr. 3. Plán zkoumané části sídliště v Biskupicích s charakteristickou hranicí, podél které byly pece koncentrovány (podle *Woyda 2002*).

Slightly later than the beginnings of mass production in the Świętokrzyskie Mountains region, some metallurgical regions in Silesia also started to operate whose heyday occurred mostly during the younger and Late-Roman period. More than 50 % of all smelting sites in this region are associated with the phase C of the Roman period (mid-2nd – beginning of the 4th c.). The end note of organised production was the so-called Brzeg metallurgic region dating to the phase D (second half of the 4th – mid-5th century; *Madera 2002*, 66, 67).

We do not know, however, whether they were created as a result of single decisions of strategic character, or by evolution – as a result of increased demands for iron needed by developing settlements. In the former case, one would have to assume the existence of a thriving headquarters that would be responsible for it and find a motivation for making such decisions. In the latter, one would have to explain how such specialized forms of team-work organization could have spontaneously emerged in agricultural environments and, what is more, in the domain so remote from pre-industrial economy?

The key to explaining the origin, the principles and the time when mass production functioned is the issue of potential markets for the iron produced here. Indicating consumers for the metallurgical regions in Silesia poses the least problems. One can see here a clear correlation between the settlement development and the increase in metallurgical production. The Brzeg region must have had the largest range of influence, though it worked mainly to satisfy the needs of the Brzeg–Oława settlement region, but might also have supplied lands on the Widawa River, and between the Oława and the Nysa Kłodzka rivers (*Pazda 1994*, 171, 172). Upper Silesia was rather self-sufficient in this respect.

The centre in Masovia, operating mainly during the Early-Roman period, was at the time the only region producing large surplus of the material within the Przeworsk culture area. Among its direct consumers there must have been the neighbouring settlement region on the Bzura River and through it probably also the central-Poland settlement cluster in the vicinity of Łodz (*Skowron 2006*, 26, 162). The presence of early-Przeworsk sites in the Vistula River valley might also indicate close ties between that region and the Sandomierz Upland. One might assume that iron from Masovia stimulated the economic development of the Przeworsk culture in its older stages of development.

Naturally, the intended purpose of the immense production of the Świętokrzyski region excites most controversy. If we assume that the time of functioning of the so-called organised slag-pit clusters where mass production was carried out was relatively short, i.e. was enclosed between the end of the 1st and the beginning of the 3rd century AD, then the issue acquires a completely new dimension.

The idea of the iron export to Roman provinces should naturally be ruled out, but its occurrence within the limes zone (Roman borderland) is more likely. The thesis that increased production in the Świętokrzyskie Mountains might have been related to the Marcomanni wars seems very attractive (*Woyda 1982*, 112–116; *Urbańczyk 1996*, 7; *Bielenin 2002*, 19; *Olędzki 2008*, 165; *Orzechowski 2013*, 255–256). It seems to be indicated by numerous premises, such as the inflow of Roman imports into metallurgical areas, the chronology of the organized furnace clusters, and the political situation in the Roman borderland zone. Cassius Dio (*Historia Romana* LXXI, 12) mentions an alliance from the year 171 between the Romans and the Cotini who previously traditionally supplied that market with iron. In the year 173 the *foedus* was already broken, and the rebellious Cotini were relocated probably to the south bank of the Danube. It cannot be ruled out that after the end of the war and the fall of the Cotini in Slovakia, a new ready market opened in this area. It is also possible that even earlier, at the height of the Marcomanni power, some amounts of iron from the Świętokrzyskie Mountains might have arrived there as trade goods or a tribute for that tribal union (compare *Modzelewski 2004*, 438–439).

However, if we assume that the whole of the enormous production was left on the site, then we also have to accept that it must have triggered certain economic processes within the Przeworsk culture itself. After all, ‘pumping’ such large amounts of strategic material into the economy must have affected its development. Perceived at the turn of the early and younger Roman period, acceleration of settlement processes within many regions of the Przeworsk culture, as well as its expansion southwards might have been related to the mass production of iron (compare *Godłowski 1985*, 81–87, 129–131).

Analysing the phenomenon of mass production of iron in the Przeworsk culture, one has to ask the question how economic enterprises, the running of which exceeded the possibilities of individual manufacturers, or even of organisational structures such as family or neighbourly community, might have functioned in the social conditions existing at the time? The political system of the barbarian world towards the end of the antiquity created a multi-stage social structure, defined as segmentary lineage (*Modzelewski 2004*, 349). Besides a family and a territorial-neighbourly community identified with districts known as *pagus* mentioned by Tacitus (*Germania* 6, 12, 39) and Caesar (*Commentarii de bello Gallico* IV, 1; VI, 23), there also existed superior units, namely a tribe *civitas*.

The majority of questions related to everyday functioning of those small communities, such as undertaking economic activities, observing traditions, as well as social order, must have been resolved at the level of those units. A community of a higher order, consisting of many such organisations, namely a tribe *civitas*, operated mostly in the face of a threat of warfare, or when undertaking migration. Social integration within that highest segment was based on a variety of relationships: family ties, neighbourly, ethnic but also on a common tradition and cult. The permanence of such ties must also have been influenced by a form of administrative constraint. Tacitus (*Germania* 7) mentioned limited royal power which can serve as evidence that the binder and executor of obligations were not only privileged individuals.

It is assumed, that at least during the older periods they were egalitarian societies, and the superior authority was limited to the issues of cult and warfare (*Wolfram 1996*, 72; *Kolendo 2008*, 124–125; *Heather 2012*, 70). Who, therefore, made social and political decisions and who enforced obeying certain decisions important for the society? According to some researchers, the assembly served that purpose at the level of neighbourly, but also tribal relations. How could huge metallurgical centres of the Przeworsk culture function in such realities, and how can one explain the stability of economic activities they conducted?

Commodity production of iron in the Przeworsk culture reflects social interrelations, unknown to us nowadays, connected to team work of large groups of people subordinate to the superior idea, and realized for a period of at least a few generations. It is curious, that metallurgic centres were generally located in areas previously undeveloped, with poor settlement traditions, or on the proverbial *cruda radice*. One has to assume, that already at the moment they were established, particular components of the created settlement network were adjusted to realising specific production tasks on the above-regional scale. At the same time, they were in direct vicinity of large settlement clusters.

Activities relating to iron-smelting production were carried out on the considerable area covering – as was the case of the Świętokrzyskie Mountains centre – almost 1,000 km^2. The metallurgic zones in western Masovia and between the Odra, Oława and Nysa Kłodzka rivers – Brzeg region – were much smaller, yet even they occupied the area of 300 km^2 each. Though not the whole area had to be excluded from agricultural use, a part of it suffered natural degradation which made it useless for food production. The belief that large areas of 'no-man's land' existed within the already settled areas at the time is more and more frequently challenged. All farmland, including pastures and woods, as well as land lying fallow temporarily belonged to neighbourly communities and access to them must have been restricted (*Modzelewski 2004*, 257–259; *Rodzińska-Nowak 2012*, 117–123). It seems that locating metallurgical activity in wasteland or zones of dispersed settlement was largely related to the restricted access to 'free' plots of land within the already developed zones. Thus the threat already signalled by ancient authors, of conflict between miners, smelters and farmers, caused by pollution of water, soil and air was postponed.

Let us look at the team work phenomenon in metallurgy, which had inevitable consequences for the order and social relations existing at the time. In primitive communities that were generally characterised by an egalitarian structure, aims requiring joint efforts of large groups of people were fairly rare. Apart from defending the shared territory or seizing new lands, it is difficult to find activities – especially of economic character – triggering the need of cooperation on a larger scale. In the region of our interest one can point out only two undertakings that required integrated activities of larger groups of people. The first was associated with 'servicing' the Amber Road, the other with production of iron in large metallurgical centres (*Urbańczyk 1996*, 4–8). In a certain way, though on a much smaller scale, sites producing the so-called manufactured ceramics within the Krakow region allude to that model. It was also there that production settlements specialising in mass manufacturing of pottery for sale were established.

In the case of such large logistic enterprises as those encountered while mass-producing iron, there appears the question concerning the principles of its supervision and division of profit. After all, it is generally known that those regions were not exceptionally affluent. In settlements and burial grounds found in the specialised iron-smelting zone one cannot see the wealth of the material produced here. If we observe a certain accumulation of luxurious commodities, they are usually outside the production zone and bear evidence of profits concentrated in the hands of a narrow privileged group. An excellent example here is the valley of the Kamienna River, where large monetary deposits and numerous imported objects were found (*Orzechowski 2000*). In this context it is difficult to agree with the belief stating there was no fully hierarchical society during the first two centuries after Christ, when the largest Przeworsk culture metallurgical centres operated. Another model seems more likely, which assumes that already at the turn of the eras at least some tribal organisations possessed clearly distinguished power structures in the form of the elders, as well as 'kings' who did not limit themselves merely to representing and serving a cult (*Heather 2012*, 56, 58, 61). It is confirmed by information documented in the sources, that the Suebian people who arrived in Gaul, but also the Marcomanni, Quadi, or Cherusci were led by rulers with a strong position. If we assume that the model of making decisions important for particular communities was based only on the system of the assembly acclamation, then how can one explain the stability of the discussed economic enterprises realised throughout the period of several generations and their perfect organisation? Only strong executive authority could guarantee running such large economic undertakings.

Considering those conditions, it is also worth looking closer at the distribution of regions of centralised metallurgy on maps of the Przeworsk settlement. We can see that they were generally located outside the large stabilised settlement clusters (see *Godłowski 1985*, maps 1–6, 9). However, it does not mean that they operated in complete isolation from main settlement regions. The Świętokrzyskie slag-pit clusters from the Łysogóry range area obviously leaned towards the great settlement macro-region in the Sandomierz Upland, while western Masovia must have had various connections with the settlements on the lower and middle Bzura River, and possibly also with the area of eastern Masovia. Similarly the Brzeg region was established between two largest clusters of the Lower and Upper Silesia and, as has been mentioned before, might have served an ancillary part in relation to the Bystrzyca-Oława region regarded as the largest tribal territory in this area.

A close relationship between metallurgical centres and strong territorial organisations was fully justifiable, or even necessary. Considering the then level of agriculture and its low effectiveness, even temporary releasing a part of the population from the duty of acquiring food and transferring them to production tasks in metallurgy, required primarily large demographic reserves and appropriate economic stimuli, but also certain coercive measures. If we accept, after *K. Czarnecka* (*1990*, 115), that about 30 % of the population at the time were small children and elderly people who did not participate in the production process, the problem of workforce for that very demanding branch of economy becomes even more acute.

Respecting certain organisation principles by direct producers in such a vast territory during a period of probably a few generations, indicates the existence of stable social and political relations in the mass production regions. Only strong territorial organisations might have legitimised and supervised such activity. Even if we assume, that iron produced by the discussed metallurgic centres was distributed only in the Polish lands, iron trading must have been approved of and protected by above-regional political structures. In the context of the existence of stable roads for trading amber which had to travel even further from its source to its purchaser, such an assumption appears highly likely. In the Przeworsk culture area the freedom of such trade might have been guaranteed by the Marcomanni rulers. The time of its decline partially overlaps abandoning the mass production and its fragmentation, and consequently popularisation of the technologies in the whole area of the Przeworsk culture.

With such a large-scale production, requiring collective efforts of specialists from various fields – such as mining, preparing raw materials, smelting and iron processing – there must have been diverse problems connected to storage, distribution and transport of large amounts of that strategic material. Family institutions, and even neighbourly communities, were too weak to ensure continuity of production with insufficient workforce, or the safety for producers. Considerable food surplus must also have occurred, which allowed teams of smelters and ore miners taking care of production to be, at least temporarily, excluded from farming the land or animal husbandry.

There is much evidence of the long-distance iron trade, and not only in the organised and centralised Roman world (*Straube 1996*; *Bielenin 1999*, 209–212; *Serneels 2004*, 206–213). Despite internal political division in pre-Roman Gaul, metallurgical regions of the Senones, Bituriges-Cubi or the Cenomani supplied iron to even very remote areas where no traces of native metallurgy were found. It was possible thanks to the supervision of the powerful Aedui tribe, who controlled more important trade routes between central and eastern Gaul at the time (*Orzechowski 2007c*, 256, 257). In the Przeworsk culture lands the freedom of such trade might have been guaranteed by the Marcomanni state. The time of its decline partially coincides with abandoning the mass trend in production and its fragmentation and, consequently, popularisation of those technologies on the entire area influenced by the Przeworsk culture.

Finally, it is worth drawing attention to yet another social aspect of conducting production activities on a scale exceeding everyday needs of local communities. It is believed, that iron metallurgy was one of the first crafts to emerge from the trends of natural economy. Specialist and arcane knowledge and technical skills, as well as expensive tools caused it to be an occupation for a specialised professional group. A complicated and multi-stage process of iron production made it necessary to split competence. The size of production carried out within large metallurgical centres finally must have influenced establishing specialised groups of manufacturers providing production workshops with sufficient amounts of raw material, or realizing subsequent stages of the metallurgic process. If we assume that only one large organised slag-pit cluster in the Świętokrzyskie Mountains needed almost 20 tonnes of iron ore, and at least as much of charcoal, and its production capacity might have equalled even 2 tonnes of iron, then we must also assume that the appropriately numerous and prepared staff of ore miners, charcoal burners, smelters and blacksmiths must have been delegated to man it (*Bielenin 1992*, 190–197; *1999*, 201–203). Only such organisation of work, based on advanced job specialisation, might have manages such a challenge and ensure continuity of production.

Iron production in the Przeworsk culture is a phenomenon of particular significance for the history of Polish territories towards the end of the antiquity. An analysis of the creation and functioning mechanisms of the mass trend of this activity is indispensable for understanding the complicated social-economic and political processes occurring at the time, not only within the Przeworsk culture but also in the whole central and eastern Europe. Without a thorough analysis of mutual relations and references between that extremely important sphere of productive activity and the cultural development of the peoples inhabiting the Polish lands at the time, we will not create a credible image of that realty. In view of the lack of written records and limited significance of classic archaeological sources from that period, determining economic indicators and organisation requirements needed for the functioning of those enormous production enterprises would allow for answering several questions concerning the character of the then existing social structures and their mutual relations. The image of independent, but at the same time lazy, pleasure-seeking and belligerent Germani, evoked in written sources, does not match their achievements in the field of metallurgy which required enormous workload and abiding by the rules of teamwork. Broadening the range of research on the prehistoric iron metallurgy by examining the previously neglected social-economic and political aspects of such activity, can contribute new data to the image of a broadly understood cultural model of barbarian communities of the so-called Barbarian Europe, we are trying to recreate.

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SZYMON ORZECHOWSKI, Institute of History, The Jan Kochanowski University in Kielce, ul. Świętokrzyska 21d,
PL-25-406 Kielce; simon@ujk.edu.pl

Early medieval iron bloomery centre at Zamárdi (Hungary)
Complex archaeometrical examinations of the slags

Raně středověké hutnické centrum v Zamárdi (Maďarsko) Komplexní archeometrický průzkum strusek

Béla Török – Zsolt Gallina – Árpád Kovács – Ferenc Kristály

Archaeological excavations at Zamárdi (Hungary) revealed one of the largest early medieval iron smelting centres in Central Europe with about a hundred ore-roasting pits, twenty bloomery furnaces, reheating furnaces and a forge. In addition, a related Avar settlement dating from the 7th to 9th centuries was also unearthed, with remains of carriage roads, about twenty houses with stone furnaces and a number of open-air furnaces. The bloomery remains fit into the series of furnaces of the 7th and 8th centuries found previously on other sites in former Pannonia. As a part of a complex research project, more than a hundred slag samples from Zamárdi were examined by XRF, ICP, XRD and SEM-EDS. Different slag types and their metallurgical roles were identified. We concluded that the nature of archaeometallurgical sites can be confidently determined by the typological examination of several kinds of slag.

Avars – iron smelting – bloomery – slag – archaeometry

Během archeologických výzkumů v Zamárdi (Maďarsko) bylo odkryto jedno z největších středověkých středisek hutnictví železa ve střední Evropě s asi sto jámami na pražení rudy, dvaceti železářskými pecemi, vyhřívacími pecemi a kovárnou. Kromě toho bylo objeveno související avarské sídliště z 7.–9. století s pozůstatky vozových cest, asi dvaceti domy s kamennými pecemi a řadou venkovních pecí. Pozůstatky železářské výroby zapadají do série nálezů pecí ze 7. a 8. století, které byly objeveny na jiných místech někdejší Panonie. V rámci komplexního výzkumného projektu bylo analyzováno více než sto struskových vzorků ze Zamárdi, a to pomocí XRF, ICP, XRD a SEM-EDS. Identifikovány byly různé druhy strusky a jejich vztah k hutnímu pochodu. Dospěli jsme k závěru, že základní rysy archeometalurgických lokalit mohou být spolehlivě stanoveny typologickou klasifikací několika druhů strusky.

Avaři – hutnictví železa – železářská pec – struska – archeometrie

1. Introduction – historical background

There is no evidence for siderurgy on a vast scale in Roman Pannonia. Currently, there is no archaeological evidence of furnaces associated with iron reduction and as few as one and a half dozen of smithy workshops are known from this period (*Gömöri 2000a*, 220; *Rupnik 2014*, 273). The smithy workshops in Pannonia might have been supplied with raw material from the metallurgical centres of Noricum, Dalmatia and Siscia (*Gömöri 2000b*, 220). The iron metallurgical centres in Dacia Ripensis province (East Serbia) were founded at the end of the 3th century, and were abandoned due to the attack of the Huns in 411. These centres were reorganized by Imperial orders in the 5th and 6th centuries and might have operated until the end of the 6th century or the beginning of the 7th century (*Gömöri*

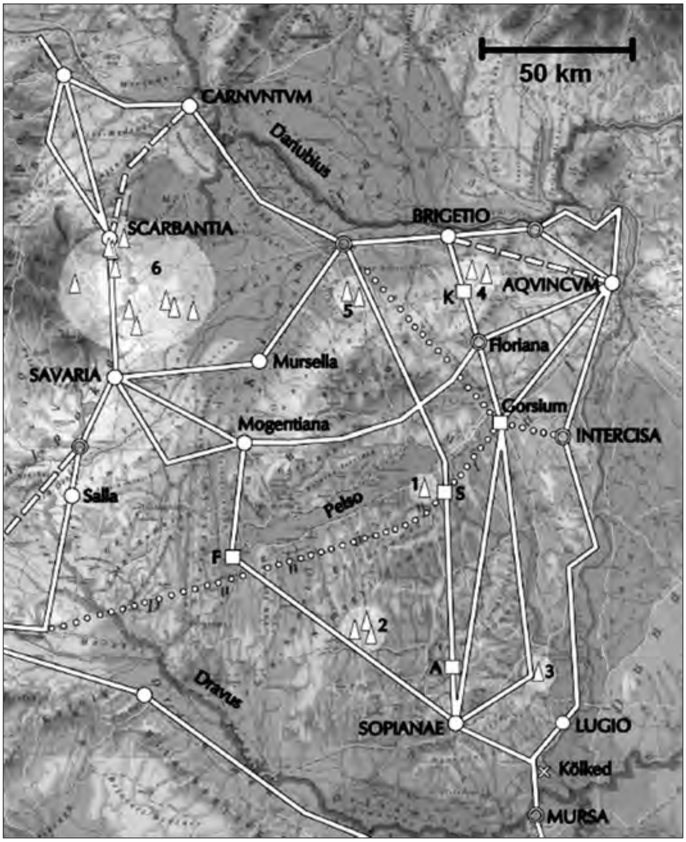

Fig. 1. Roman routes and Avarian iron working sites in Pannonia – 1 Zamárdi, 2 Kaposvár, 3 Bátaszék, 4 Tatabánya (Avarian smithy?), 5 Tarjánpuszta, 6 Surroundings of Nemeskér and Zillingtal, K, S, F, A Roman fortresses (*Gömöri 2012*, 28).
Obr. 1. Římské komunikace a avarské železářské lokality v Panonii – 1 Zamárdi, 2 Kaposvár, 3 Bátaszék, 4 Tatabánya (avarská kovárna?), 5 Tarjánpuszta, 6 okolí Nemeskéru a Zillingtalu, K, S, F, A římské pevnosti (*Gömöri 2012*, 28).

2012, 26–27). Nevertheless, in the relevant iron reduction sites near Pannonia, the volume of iron production was not consistent from the Late Antiquity through the Middle Ages. It is notable, however, that the Avarian iron smelting sites commonly were established in the areas of Roman settlements (*vici*, *villae*), which raises the possibility of continuity (*fig. 1*; *Szentpéteri 2009*, 237; *Gömöri 2000a*, 223; *Gömöri 2012*).

Beyond the borders of the Roman Empire in the Carpathian Basin, in the territories of the Sarmatians and Imperial Period Germans, archaeological data concerning iron smelting is meagre. However, remains of smithy workshops have been recovered from Sarmatian and German sites (*Kulcsár – Jakab 2009*, 59; *Lönhardt 2012*).

After the fall of the Roman Empire, an identical situation seems to have occurred regarding iron production; that is, evidence of iron reduction is poor while iron working evidence is common. Although fairly numerous iron objects are known from the 5–6th-century burials of the Migration Period Germans in the Carpathian Basin (primarily Gepids and Langobards), German bloomery furnaces have not been found in Hungary. As a result, it is ambiguous whether the iron smelting technology of the Avars, who took over former Pannonia succeeding the emigration of the Langobards in 568, is related to previous local or western influence to any extent.

A common feature of the iron and metal production culture of the Gepids and the Avars, who moved to the Carpathian Basin during the final decades of the 6th century, is the presence of smith burials. The artefact inventories from these graves are very similar in relation to the shape and amount of tools as well as for their weapons (*Beninger 1966*, 177–178; *Tejral 2008*, 71; *Rácz 2009*, 75–80). A certain degree of correlation may be assumed about iron working between the Germans and Avars, but the same cannot be proposed for iron reduction. Additionally, some of the tools of the Avarian iron smiths, including anvils of truncated pyramidal shape, hammers and flat pliers (*Rácz 2009*, 79, fig. 13), follow German types that had widely been used since the Roman Period (*Rácz 2009*, 75, 79–80).

By tracking down the migration of the Avarians from the eastern steppe region to the Carpathian Basin, as well as the movement of their various ethnic components over time, it becomes clear that for several hundred years they could have been in contact with peoples and empires having a sophisticated iron metallurgy, such as the Juan-juan Empire in the 4th–6th centuries and the succeeding Turkic Empire (552–745) (*Gömöri 2008*, 65–68; *Vásáry 2009*, 21, 34–37). The antecedents and analogies of the Avarian iron smelting furnaces (*Semykin 2015*, 13, fig. 31) are evident at Volga Bulgarian sites (*Fjodorov-Davidov 1996*, 15) and in villages and iron reducing centres dating to the 6th and 7th centuries in the Podolian Upland, located to the East of the north-eastern Carpathians (*Gömöri 2000b*, 179). Extensive iron metallurgy, indicated by the regular occurrence of smithy workshops and iron reduction furnaces, also was pursued in the settlements of the Khazar Empire (7th–10th centuries; *Fodor 2009*, 52). Their characteristic underground furnaces, supplied with two subsurface tunnel-like bellows, do not occur either on Avarian or on later, Hungarian Conquest Period sites in the Carpathian Basin (*Pleiner 2000*, 188, 190, fig. 51).

The population of the Avarian Kaganate became even more heterogeneous in the second part of the 7th century. It was the Onogur group, settled around 670, who started exploiting the bog iron deposits of the Carpathian Basin for the first time. The culture of the newcomers presumably led to important changes in the lifestyle of the already heterogeneous local Avarian population. During the second half of the 7th century, they might have established iron working settlements exclusively on the territory of the Avarian *tudun* (*Princeps Pannoniae*, western proconsul), in former Pannonia, in the territories of Roman *villae* and *vici*, and, for easier transport, along Roman roads (*fig. 1*). The development of these iron working settlements reached a peak in the 8th century and, as the available data indicate, they survived the fall of the Avarian Empire. Their technological heritage lasted up to the end of the 9th century, with influences extending even to the Hungarian Conquest period (*Gömöri 2000a*, 221–239). Their iron working activities were centred in two main regions, in northern Transdanubia of today's western Hungary (mainly the Prealpine region) and in southern Transdanubia, mainly of the territory on today's Somogy County (*Gömöri 2012*, 29). In some workshops south of Lake Balaton, e.g. Zamárdi and Kaposvár, iron workers and smelters might have lived and worked together. Although Avarian iron production decreased if compared to the Roman period, it was still significant, since they succeeded in reducing iron import dependency (*Gömöri 2000a*, 221–239).

The Avarian iron working technology stemmed from territories to the east of the Carpathian Basin. In addition to their ancient eastern roots, the influence of the Onogurs in the Carpathian Basin is important as well and interactions with the Bavarians and the Moravians also may have played a part too (*Pleiner 2000*, 276–277, figs. 13, 49). After the fall of the Avar Kaganate, lasting about 250 years, the territories north of the Rába River were annexed by the Carolingians to the Frank-Bavarian zone of influence under the name of Pannonia Superior in the 820s. The local Avarian smelters were divided in several *comitates* by the Bavarians, and were forced to pay their taxes in iron (*Gömöri 2008*, 74).

2. Archaeology of the Avarian Age ironmaking in the Carpathian Basin

The highly developed ironworking skills of the Avarians are indicated by the burial inventories and by the vast amount, great complexity and wide variety of Avarian Age iron artefacts. *Gömöri* (*2000a*, 222–223) listed 33 archaeological sites related to Avarian iron working, among which 26 are located in Transdanubia; their amount has increased during the past twenty years. As a result of the significant earlier excavations of Avarian bloomery workshops in Hungary (*Gömöri 2000a*, 102–126, 210–216, 185–196,) and of the archaeometallurgical studies, the historical background and main operating stages of the bloomery process in the period were successfully outlined (*Gömöri 2000a*, 221–256).

Among the early medieval iron working sites in Central Europe discovered in the past few decades, the workshops at Kaposvár, Zamárdi and Bátaszék are most important. In 2001, the excavation at Kaposvár-Fészerlak unearthed more than 400 Avarian Age features associated with iron working across a total of 17,500 m^2 area (*Gallina 2002*). This is the second largest known Avarian ironmaking sites in Europe, featuring the most characteristic structures recorded on iron reduction sites of the same period. The peculiarities of the site include wells with well-preserved wooden constructions; the source of water for iron working (*Gallina 2002*, 80–82). The adjacent late Avarian Age cemeteries and settlements and the sizeable bloomery workshops, presumably owned through special rights, shows that the site was a regional centre. The recovered bloomery workshops, found in a single archaeological layer, might have operated over the course of a surprisingly short period, between the end of the 7th century and the mid-8th century (*Gallina 2002*)

At Bátaszék-Nagyorros, Avarian bloomeries (a total of 25 features in an area of 1,000 m^2) were better preserved than those at Kaposvár, thus their structures could be easily reconstructed. Several types of furnaces of the 8thand 9th centuries were found in this site. They forecast important changes in the previously somewhat rigid typology (*Gömöri 2000a*, 242) and also show transitions to the furnace types of the Hungarians (*Czövek 2010*, 213–241). Traces of a furnace type were found that is structurally transitional between the so-called ‘Avarian type’ (*Gömöri 2000a*, 242, fig. 157: 1: more or less free-standing bloomery, with a subsurface base) and the 10th-century Hungarian ‘Fajsz-type’ furnace (*Gömöri 2000a*, 240, 242, fig. 157: 4: fully built in the wall of the workshop). A 3D theoretical reconstruction of this transitional type is shown in *fig. 2*.

Two Avarian bloomery furnaces and their related workshop pits were unearthed recently at Zillingtal (Austria), near the Hungarian border. According to *Mehofer* (*2010*, 229) these features also represent a transitional type between the free-standing and the built-in types. Based on the recovered tuyere fragments and the amount of slag, the workshop served the local iron market only.

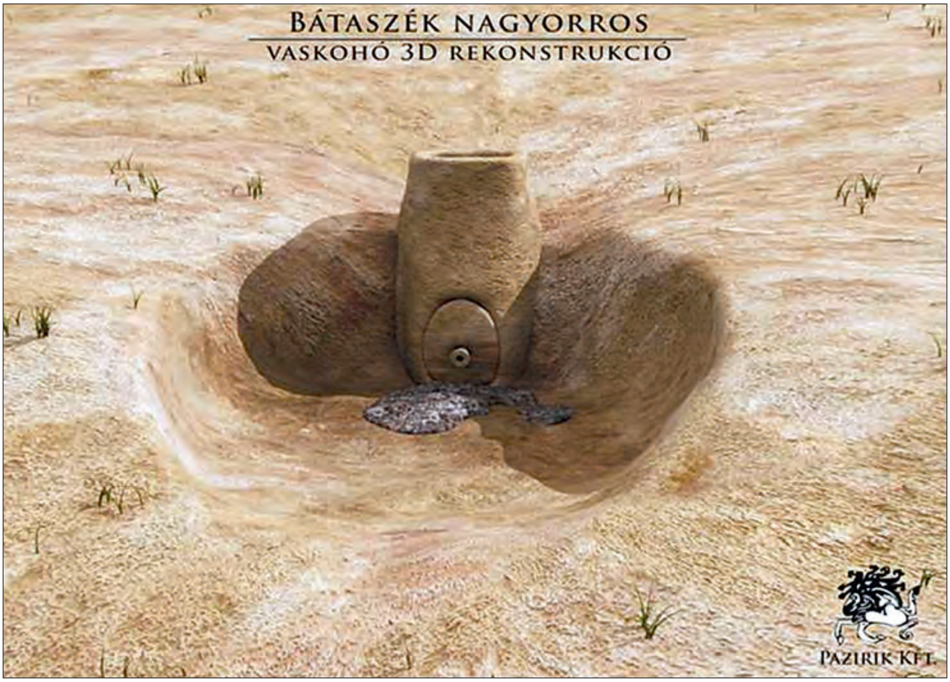

Fig. 2. Theoretical reconstruction of a transitional type bloomery at Bátaszék (*Czövek 2010*, 239).
Obr. 2. Teoretická rekonstrukce přechodného typu železářské pece v Bátaszéku (*Czövek 2010*, 239).

At Zamárdi, on the southern bank of Lake Balaton, four sites were excavated in 2005 and 2012. The nearly 1,500 archaeological features recovered from a total area of 27,700 m^2 date to six periods. The Avarian Age is represented by 580 features, including nearly 100 ore roasting pits, around 20 bloomery furnaces, as well as additional traces of a half-dozen demolished bloomeries. Two reheating fireplaces and a smithy workshop also were unearthed. Beyond smelting-related features, 20 houses with built-in fireplaces and over 100 outdoor fireplaces were found too. The excavations revealed an iron working centre and settlements of outstanding importance in the Avarian Age that stretched more than 1 km in length (*fig. 3*).

The various workshops and settlements at Zamárdi occurred sequentially; since more workshops were added southward, all the finds and features related to iron metallurgy found in the southernmost area date exclusively to the late Avarian period. The settlement features are only partially associated with the smelters' centre, and were partly found in younger archaeological layers. The complex of bloomery workshops and settlement, 1,100 m in length and 150–200 m in width, was in used from the middle of the 6th century to the end of the 9th century (much more longer period than that of Kaposvár), ranging from the Langobard era to the Hungarian conquest (*Gallina – Hornok – Somogyi 2007a*, 153–168; *2007b*, 71–81; *Gallina 2011*, 179–198).

The importance of the excavation at Zamárdi is highlighted by the 2,500 graves found just 400–500 m away from the settlement. They form one of the largest known early and

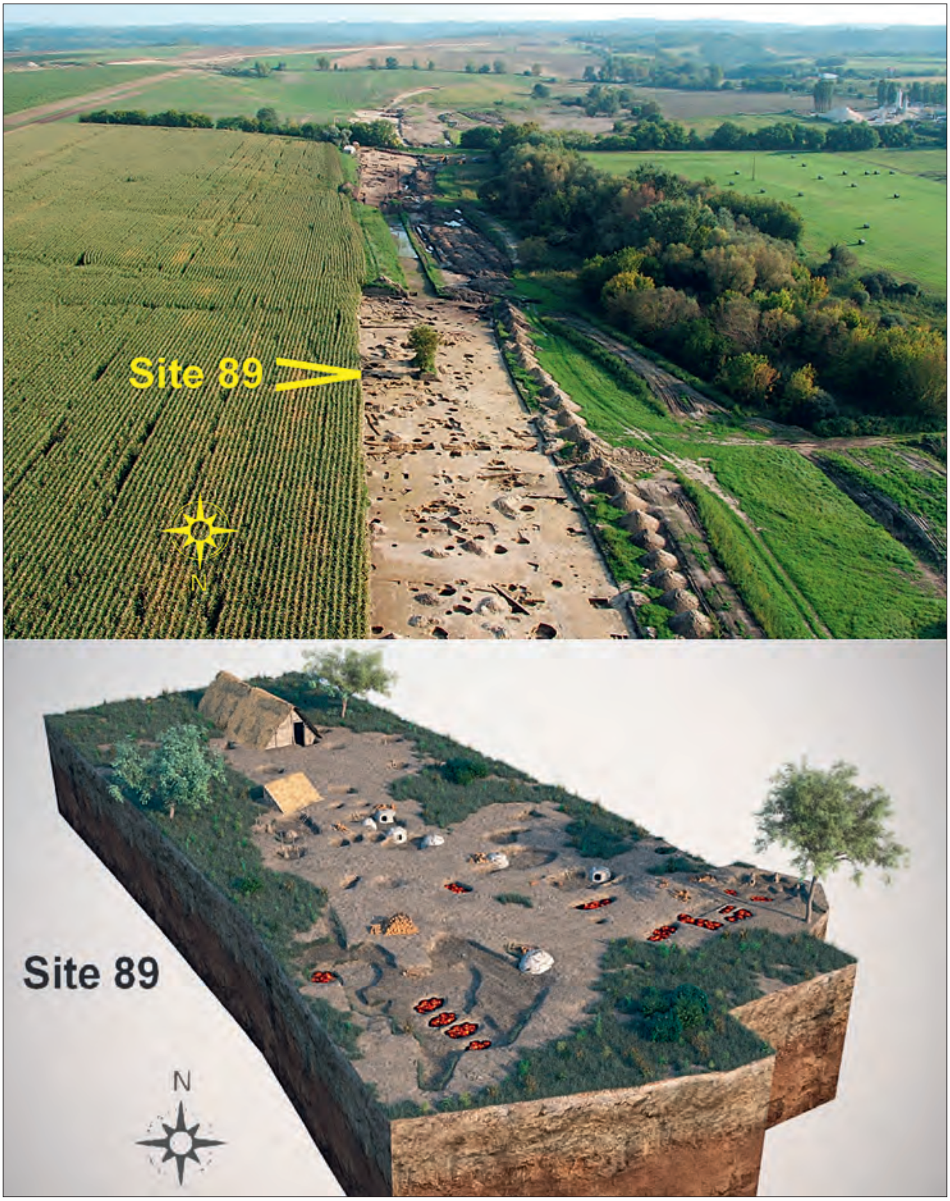

Fig. 3. Aerial photograph of the excavation sites at Zamárdi and 3D-reconstruction (made by Pazirik Kft based on Zs. Gallina's instructions) of the southern part of site 89. Photos in figs. 3–5 by Zs. Gallina.
Obr. 3. Letecká fotografie výzkumu v Zamárdi a 3D rekonstrukce jižní části lokality 89.

late Avarian Age cemeteries in the Carpathian Basin (*Bárdos 1992*, 55; *1996*, 48). In this cemetery, Germanic influences may be recognized, such as the characteristic sealed pottery. Some researchers suppose that the seat of an Avar *kagan* was located at Zamárdi

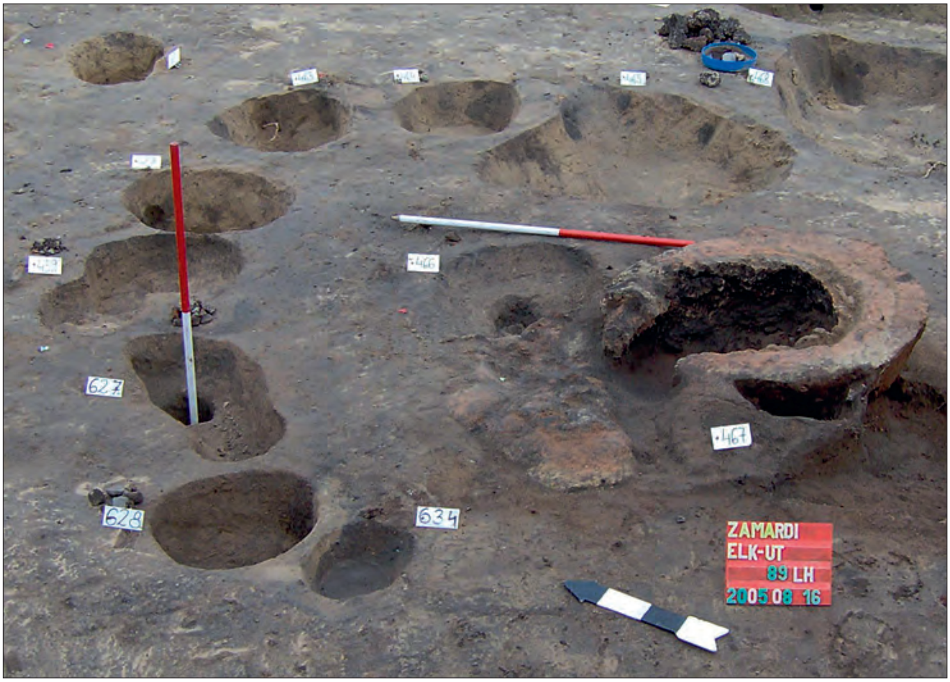

Fig. 4. Traces of a bloomery workshop covered by a roof.
Obr. 4. Stopy zastřešené železářské dílny.

(*Szentpéteri 1995*, 242–243) or at least the capital (*ordu*) of a high-status individual from the closest entourage of the kagan (*Bóna 1986*, 14), while others do not share this opinion (about this subject see *Gömöri 2000a*, 221–223).

The remains of operational processes preceding the smelting at Zamárdi are the round hollows (workshops) with a diameter of 2–3 m and a depth of 20–35 cm. They can be found in a relatively small area in a great number in groups. The bloomeries in the workshops, with circular, oval or horseshoe-shaped bottom, were built with thick walls. Their hearths had a foundation of finely polished clay that was mixed with sand. The diameters of the hearths vary largely between 30 and 95 cm. The outer arc of the hearths reddened for 10–20 cm in thickness and their inner part turned into grey by the heat 5–10 cm in thickness. On some occasions, larger slag blocks were found inside the furnaces. It was possible to reconstruct their form which was cone-shaped or bottle-shaped, i.e. larger at the base with a narrow upper section. It might reach a height of 70–80 cm. Large variations are evident in the shape and position of their slag holes and breast-wall holes. The air blowing was performed by using probably one bellows through a clay tuyere embedded in the middle of the breast-wall. Sometimes these furnaces were restored and restructured. Among iron working features, superpositions also occurred (*Gallina – Hornok – Somogyi 2007a*, 164). The bloomeries are often found in groups of various size. At Site 89, two complex workshops covered by a roof with the ore roasting pits under it were unearthed (*fig. 4*; *Gallina – Hornok – Somogyi 2007a*, 160).

Semi-subterranean bloomeries with only their hearths dug in the ground, classified as 'Avarian type', were found at Magyaratád (*Gömöri 2000a*, 109–110), Zamárdi (*Gömöri 2000a*, 211–213) and Tarjánpuszta (*Gömöri 2000a*, 187–193; *Pleiner 2000*, 171, fig. 44: 1). These sites date to the late Avarian Age. The Avarian furnaces at Zamárdi, Kaposvár and Bátaszék were sunk into the ground, a substantial part of their height was built into the wall of the workshop, equipped with breast-wall and tuyere (*Czövek 2010*, 213–224; *Gallina 2011*, 179–198). Thus, these features were somewhat similar to the 10th-century Hungarian furnaces found at Somogyfajsz, 50 km from Zamárdi (*Pleiner 2000*, 173, fig. 45).

The outcrops of near-surface bog iron ore with limonite concretions used for smelting were probably along the neighbouring stream at Zamárdi (*Gömöri 2000a*, 258, fig. 159: a). In the fill of some features large amounts of roasted iron ore were found. On the basis of the investigation of related finds and the smelting experiments it can be presumed that ore and charcoal were broken to a grain-size of 1–2 cm. The furnace was dried before processing with wood and charcoal, then it was heated to a constant high-temperature-profile. The quantity of ore for one smelting process reached 10–15 kg. During the continuous air blowing, the charcoal was further added in order to maintain the furnace temperature (1150–1350 °C in the hearth) and reducing atmosphere. The use of slag forming materials could not be detected but it cannot be excluded. The relatively high quantity of slag is a characteristic feature of the bloomeries at Zamárdi. A great number of large pieces of tapped slags flowing into the slag-pit in front of the open tap hole on the bottom of breast-wall and of furnace slags taken out of the furnace at the end of smelting were found. After completing the metallurgical process, the bloom of a weight of 1–3 kg drawn through the opened breast-wall was heated on the round mildly dished reheating fireplaces near the furnaces and compacted and purified by hammering out the slag inclusions and gathering ups by using a wooden hammer (*Török – Kovács – Gallina 2015*, 236).

Surprisingly only one forge was unambiguously identified at Zamárdi (*fig. 5*). The reason could be, according to *Gömöri* (*2000a*, 278), that these structures were timber-framed constructions that tend to decay relatively quickly. Nevertheless, semi-subterranean forges had been built at Tarjánpuszta already in this period and remained in use until the 12th century.

Zamárdi was both a settlement and an iron working site. The volume of iron production was considerably larger on this site, with significantly larger furnaces and workshop pits as well as many ore roasting pits, than at the shorter lived Kaposvár smelters settlement. However, if compared to the amount of furnaces only, a small number of breast-walls and tuyeres were recovered. The approximately 100 outdoor ovens for baking and meat smoking, renewed several times, indicate daily activities connected with the smelters centre. Large numbers of millstones were also found (*Gallina – Hornok – Somogyi 2007a*, 160). The long period of continuous site use may imply the vicinity of a strong power centre; this assumption seems to be supported by the above mentioned large cemetery. By contrast, at Kaposvár the scale of production was lower as indicated by smaller furnaces and fewer roasting pits but aided with relatively high numbers of tuyeres and breast-walls. Additionally, only a few residential buildings were unearthed on the smelters' settlement or in its vicinity at Kaposvár. Thus, it may be assumed that this site was specialized in iron production. This also gives a hint about the different work management strategies in the period (*Gallina 2002*, 75–86).

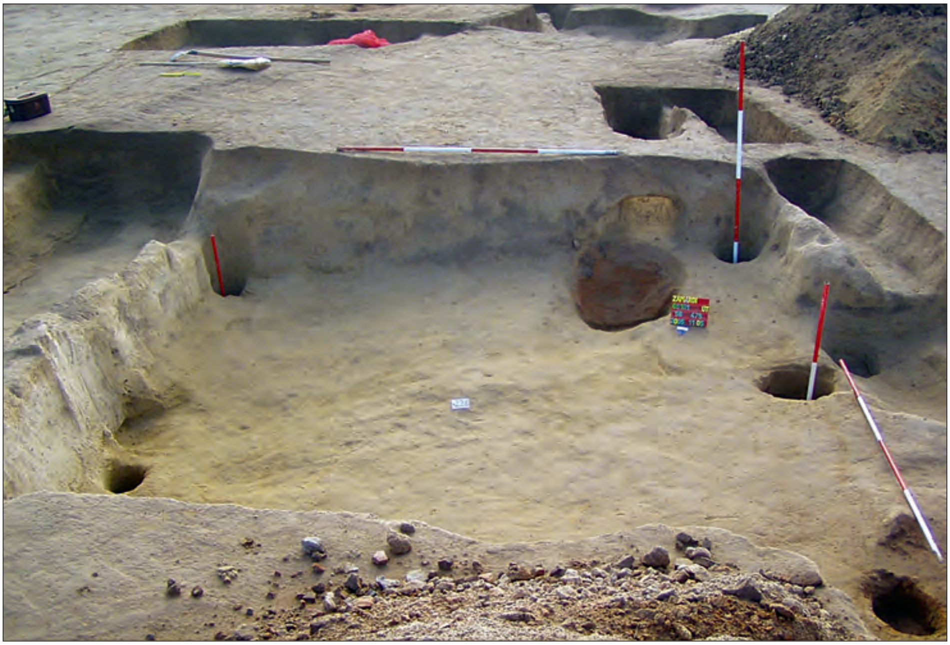

Fig. 5. Smithy workshop of site 56 at Zamárdi and its theoretical reconstruction (made by Pazirik Kft based on Zs. Gallina's instructions).
Obr. 5. Kovářská dílna v lokalitě 56 v Zamárdi a její hypotetická rekonstrukce.

3. Archaeometrical examinations of slag samples

3.1. Methods and materials

A complex research project coordinated by the Archaeometallurgical Research Group of the Univesity of Miskolc (ARGUM) has been running for a number of years. The general goal of this research is to gain deep insight into the technical, technological and environmental knowledge of Avarian Age ironworking in the Carpathian Basin. As one of the main objectives of this research project, about 100 slag samples were analysed from Zamárdi and other Avarian Age sites related to iron metallurgy. Different slag types and their chemical and mineralogical compositions, microstructures as well as their metallurgical roles were identified. By studying the properties of slag finds, the results can offer useful information to determine the technological level of local methods and the quality of raw materials and products.

The main analytical techniques include chemical analysis with ICP-OES (Varian 710-ES), supplemented by using titration for separating the Fe^{2+} and Fe^{3+} (the importance of the relative proportions of Fe^{2+} and Fe^{3+} was demonstrated by *Bachmann 1982*, 8), textural-chemical investigations with SEM-EDS microanalysis performed on both polished and fracture surfaces (Zeiss EVO MA10 equipped with EDAX EDS, Amray 1830 I and Jeol 8600 JXA Superprobe) and mineralogical analysis (XRD Bruker D8 Advance diffractometer with Bragg-Brentano and Göbel mirror for parallel beam, Cu-K_α source) performed predominantly on powder specimens. In some cases chemical investigations can be supplemented by WD-XRF (Rigaku Supermini 200) analysis on powder pellets or fused beads as well as by portable ED-XRF (XMET8000 Expert) on the sample surface.

In one of our previous studies related to the Zamárdi sites (*Török – Kovács – Gallina 2015*, 229, 232), two different groups of slag were identified: tap-slags flowing out of the furnace and furnace slags (cinder); *Pleiner* (*2000*, 257) used this term only with regard to the unreduced ore grains embedded in this slag remaining in the bloomery up to the end of smelting. However, in many cases significant difficulties may arise in distinguishing the different kinds of slag from different steps of the bloomery process. Considering other kinds of residues (purification slag, reheating and forging slags), which often have similar chemical and mineralogical compositions, their investigation is even more difficult. There are numerous scientific papers dealing with the analyses of late Antiquity and Medieval iron smelting slags. Referring to those studies, *Pleiner* (*2000*, 252–253) provided a comprehensive explanation for the relatively wide ranges of chemical components and the typical mineralogical constituents of bloomery slags. *Pleiner*'s (*2000*, 258) extensive survey has a schematic representation of the different slag types and of the furnace zones of their occurrence inside and outside the two kinds of bloomeries (slag-pit and flat-hearth tapped furnaces). Similarly to the majority of previous related works (e.g. *Oelsen – Schürmann 1954*, 599), *Pleiner* (*2000*, 259–264) classifies the bloomery slags into two groups (tapped slags and furnace slags) and distinguishes the slag-pit blocks formed inside the bottom of the hearth or gathered in a subterranean slag-pit. However, *Pleiner* (*2000*, 257) underlines that the different slag classifications are usually based on the authors' archaeological, investigational and/or experimental experiences acquired by exploring finds of a given period and site(s) as well as by using specific techniques.

Buchwald's (*2005*, 92, 96) comprehensive work gives also detailed descriptions of the different types of iron smelting slags, as "production slags". In addition to these materials, the characteristics of the so-called purification and manufacturing (forging) slags, formed typically in oxidizing atmosphere, are discussed as well (*Buchwald 2005*, 92, 97, 100, 138, 196).

3.2. Discussion and conclusions

As a preliminary step of the complex examination, the slag samples from Zamárdi and the other Avarian Age sites were divided into several groups. Based on their external features, a part of the studied slag assemblage was classified as tapped-slag or furnace slags from the smelting. Numerous furnace slags and slag-pit blocks were discovered *in situ* on the sites and some slag pieces were found in specific, well-definable contexts, e.g. were stuck to a fragment of furnace lining or to a tuyere. A few examined samples were classified as purification slags or were considered as forging slags. The remaining slag pieces had unclear or transitional characteristics.

A relatively low weight ratio (~10 %) of the unearthed slag finds can clearly be identified as tapped-slag. This kind of slag, heavy, compact and completely melted, usually has a shiny black surface and sometimes bizarre forms due to their flowing. Minor gas bubbles are found in their dark-grey fractures otherwise their inner structure is relatively homogeneous. The chemical composition of the analysed tapped-slag samples shows that the two dominant components are SiO_2 (on average 27–30 wt%, however, in some cases it may reach 60–65 wt%) and FeO (iron-oxide with Fe^{2+}) generally 40–45 wt% (*Török – Kovács – Gallina 2015*, 232) but in numerous cases only 4–5 wt% FeO could be detected. In general, the CaO-content was low (2–5 wt%). Based on their chemical composition, a typical SEM-image of a tap-slag displays three phases: fayalite laths often having a distinctive pattern in the middle, iron-oxide (wüstite) dendrites and pyroxene network (or glassy parts) around them. In some cases, wüstite dendrites were not observed or just in the form of very small crystals. Very similar micrographs of this kind of microstructure are presented by *Buchwald* (*2005*, 97, 127, 136)

In our tapped-slag samples (*table 1*), most of the crystalline phases formed around 750–800 °C as indicated by the pyroxenes. The smelting point of these slags is about 1100–1150 °C. The amount of amorphous material is directly related to their high SiO_2, silicate or quartz content, and with their low Fe and Mg content points to highly viscous and quickly cooled slags. The higher the amorphous content, the faster was the cooling (i.e., within a few minutes). Sample Z89-662 in Table 1 represents the characteristic tapped-slag material: silica rich thus highly viscous. This kind of slag forms relatively quickly, outflows and cools rapidly. Even if Z58b-227 has similar physical characteristics to the previous one, the strongly dissimilar mineralogy would suggest a different classification. The high amounts of fayalite and wüstite indicate a moderately slow cooling in the 1200–900 °C range, under oxidizing conditions. The textures of the examined tapped-slags often contain glassy parts in great proportion, which is confirmed by the relative high amount of amorphous phase (sometimes 55–60 %) calculated based on the XRD results.

Some SEM micrographs of the tapped-slag samples show an almost pure glassy structure with the characteristic conchoidal fracture with sharp edges. Tapped-slag forms during the early period of the smelting process. However its flowing outside the furnace depends

Phase type	**Phase Name**	**Z89-662 T**	**Z58b-227 T**	**Z89-645 F**	**Z89-466 F**	**Z58a-156 F**	**Z89-468 P**	**Z58b-48 P, S(?)**	**Z56-160 S**	**Z58b-46**	**Z58a-74**
main silicate	**Fayalite (Ca,Mn) (Ca,Mn,Fe^{2+})SiO^{4}**		**36,0**		**69,0**		**52,0**		**2,9**		
	Fayalite (Mg) (Mg,Fe^{2+})SiO^{4}			**55,5**		**67,4**					
	Forsterite (Fe) (Mg,Fe^{2+})SiO$_4$			**8,6**							
K-solids	**Leucite KAlSi$_2$O$_6$**		**3,8**	**8,5**	**8,0**	**2,9**					**0,7**
	Sanidine (Na,K)AlSi$_3$O$_8$			11,0							
	Kalsilite KAlSiO$_4$		1,0			0,6		1,5	2,8		
	Wuestite FeO		**18,9**				**21,1**	**21,8**	**21,5**		**0,1**
Spinels	Titanomagnetite Fe^{2+}(Fe^{+3},Ti)$_2$O$_4$					1,7					
	Magnetite Fe^{2+}F$^{3+}{}_2$O$_4$		2,0	4,4	1,5		1,6		6,1	1,1	0,5
	Spinel (Fe) (Mg,Fe)Al$_2$O$_4$				7,5						
High T slag	Monticellite (CaMg)SiO$_4$		9,9			4,5			29,0		
	Kirschsteinite (CaFe^{2+})SiO$_4$							44,5			
	Srebrodolskite Ca$_2$Fe$^{3+}{}_2$O$_5$									2,9	
High T klinker	Cristobalite low SiO$_2$	2,1						0,6			1,4
	Mullite Al$_6$Si$_2$O$_{13}$	0,4									1,7
	Cordierite Mg$_2$Al$_4$Si$_5$O$_{18}$										0,3
	Anorthite CaAl$_2$Si$_2$O$_8$	4,2									
	Diopside CaMgSi$_2$O$_6$	10,1									
	Quartz SiO$_2$	**27,1**	**2,3**	**1,1**		**1,8**	**0,7**	**6,5**	**4,7**	**15,5**	**32,8**
	Gehlenite Ca$_2$Al(AlSi)O$_7$	0,3									
	Zoisite Ca$_2$Al$_3$(SiO$_4$)3OH					2,1					
	Sillimanite Al$_2$SiO$_5$		4,1					2,5			
alteration	Calcite (Mg) (Ca,Mg)CO$_3$	0,8								5,4	
	Dolomite CaMg(CO$_3$)$_2$			0,9						6,4	
	Siderite FeCO$_3$									4,3	
oxida-tion	**Hematite Fe$_2$O$_3$**						**0,3**	**0,2**		**11,7**	**0,4**
	Goethite FeOOH						**9,3**	**4,4**	**10,0**	**8,2**	**0,9**
soil conta-mination	Muscovite KAl$_2$(Si$_3$Al)O$_{10}$(OH)$_2$									3,7	
	Kaolinite Al$_2$Si$_2$O$_5$(OH)$_4$									5,5	
	Albite NaAlSi$_3$O$_8$									4,3	0,2
	amorphous	**55,0**	**22,0**	**10,0**	**14,0**	**19,0**	**15,0**	**18,0**	**23,0**	**31,0**	**61,0**

Tab. 1. Results of the XRD examinations of some typical slag samples (T – tapped slag, F – furnace slag, P – purification slag, S – smithing slag).

Tab. 1. Výsledky XRD analýz některých typických vzorků strusky (T – struska z předpecních jam, F – pecní struska, P – struska z procesu kovářského zhutňování železné houby, S – kovářská struska).

on the slag's viscosity and temperature. Moreover, the shape of the furnace hearth, the breast-wall and the tap-hole are also influential. Although some papers reported that pure tapped-slag may contain up to 70 wt% FeO (*Tylecote 1986*, 176), numerous samples of the Zamárdi tapped-slags contain less (e.g. Z58b-227), in fact, sometimes insignificant FeO. In a case study on iron smelting slags from Merovingian workshops, the slag samples were distinguished according to their macroscopic aspect: compact material or porous slags, moreover, slags formed by a single flowing or by a succession of so-called corded flowing. The proportion of early wüstite facies was commonly high in compact slags, however, it was very low in the single corded slags which were denoted as a special category of the compact slags (*Le Carlier – Leroy – Merluzzo 2007*). The viscosity of the bloomery slag is inversely proportional to its FeO-content (*Buchwald 2005*, 96–97), however in general, given the thermal conditions of the early Medieval bloomery process in the hearth, a fayalite-rich slag may have been liquid enough to flow out of the furnace. Fast cooling of the silica-rich slag in the open air can cause an increased proportion of glassy parts in its texture. Because of the lack of tapped-slag, *Mehofer* (*2010*, 228) supposed that in the furnaces of the Avars at Zillingtal the temperature achieved was not high enough to form a sufficiently liquid slag. Based on the mineralogical analyses of the furnace slag samples from Zamárdi, it seems that the shape and the dimensions of the furnace were important to achieve this goal.

The furnace slags (*Pleiner 2000*, 262–263) belong to the other group of bloomery slags. These materials do not flow out of the furnace, but remain inside it until the end of the process. They are generally large, strongly indented, sponge-like slag-blocks with a lot of gas holes, having a lower density and usually a very heterogeneous structure. Embedded pieces of charcoal and furnace wall-fragment can be observed often. Most of the slags (~ 80 %) found at the sites of Zamárdi belong to this type. Some slag pieces coalesced with a fragment of furnace lining also were unearthed at these sites. A significant difference between the average chemical compositions of tapped-slags and furnace slags was not observed, however, furnace slags usually have a lower iron(II)/iron(III) oxide ratio. Numerous samples of furnace slags have 20–35 wt% FeO with 20–30 wt% calculated Fe_2O_3 (*Török – Kovács – Gallina 2015*, 232). While XRD (and SEM-EDS) does not provide information regarding Fe valence in amorphous components, we can identify crystalline phases of Fe^{2+} and Fe^{3+}. The source of Fe^{3+} denotes oxidation, which may be related to the smelting process (e.g. unreduced ore grains or contact of incandescent slag with air), but it may also be a late oxidation effect that occurred in the soil over the course of centuries.

The overwhelming majority of the examined slag (and ore) samples from Zamárdi, in particular the furnace slags, have a relatively high MnO-content (6–9 wt%). This may be considered as a regional feature as compared to the MnO-content of other examined early medieval slags found in other parts of the Carpathian Basin (*Török 1999*, 218; *Gömöri – Török 2002*). In the SEM-images of the examined furnace slags, a great degree of variations in the three-phase microstructure, mentioned above, can be observed. If the fayalite crystallized in blocks, it implies relatively slow cooling, while fayalite laths denote a faster cooling (*Török – Kovács 2010*, 457).

In some cases the composition of furnace slags has a significant phosphorous content (0.3–0.6 wt% by EDS point analysis) in the moderate amount of amorphous content (by XRD). Phosphorous associated with K and Na gives the slag a high liquidity even at 850–900 °C. According to *Selskiené* (*2007*, 23) P_2O_5 content is associated to tapped-slag

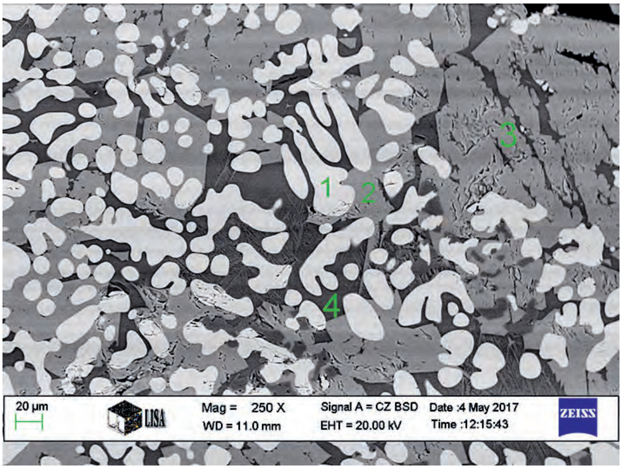

Fig. 6. SEM-micrograph of sample Z89-468. Photo in figs. 6–7 by Á. Kovács.
Obr. 6. Mikrosnímek vzorku Z89-468 pořízený pomocí SEM. 1 – O:12.68, Mg:0.32, Al:0.76, Si:0.15, P:0.06, K:0.15, Mn:4.70, Fe:81.06; 2 – O:19.57, Na:0.26, Mg:3.04, Al:0.23, Si:18.67, P:0.22, Ca:1.79, Mn:10.72, Fe:45.41; 3 – O:19.62, Na:0.10, Mg:2.71, Al:0.18, Si:18.40, P:0.16, K:0.11, Ca:2.16, Mn:10.79, Fe:45.78; 4 – O:23,41, Na:0.53, Mg:0,35, Al:9,56, Si:21,34, P:0.88, K:3,27, Ca:11,71, Mn:4,67, Fe:24,30.

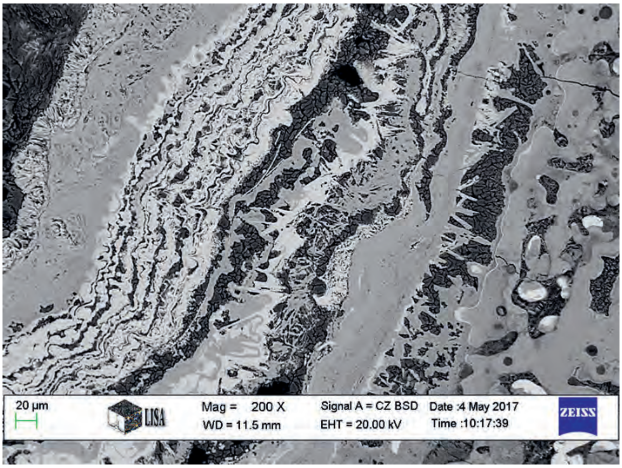

Fig. 7. Layered structure of the sample Z58b-48.
Obr. 7. Vrstevnatá struktura vzorku Z58b-48.

and furnace (bottom) slag, and smithy slags always contained much lower concentration of phosphorous as compared to the smelting slags. According to our results, furnace slags and smithy slags can be distinguished by their wüstite content, since wüstite will not appear in furnace slags. The occurrence of fayalite with Mg, Mn and/or Ca substitution indicates a temperature of ca. 1200 °C (*Deer – Howie – Zussman 1997*, 132); high enough to separate the silicate slag from the bloom.

During the hammering of the hot and raw bloom, relatively small pieces of purification slag are squeezed out of the bloom, which commonly have a plano-convex shape and a heterogeneous, frequently layered structure (*Buchwald 2005*, 97–99). This kind of slag may occur in shallow bowls that are very similar to the burning pits, about a hundred of which were unearthed at the Zamárdi sites. It is feasible that both the purification of the bloom and ore pre-roasting were carried out in the same feature. A common chemical composition was not observed in the identified purification slag samples, however, a typical SEM-micrograph of a purification slag sample can be seen in *fig. 6*.

Since only one clearly identifiable forge was unearthed at Zamárdi, the occurrence of smithy slag was not really expected in large numbers. Smithy slags are characterized by the presence of significant wüstite, a low amount of quartz and glassy phase as well as the absence or very small amount of fayalite. Instead of fayalite, monticellite and kirschsteinite can be found, these phases crystallize <900 °C. *Fig. 7* shows a layered structure which can often be observed by the examinations of smithing or purification slags.

4. Summary

The workshops at Zamárdi and Kaposvár are among the largest Central European archaeometallurgical sites and the largest early medieval so far discovered in the Carpathian Basin. The Avarian type workshop commonly shows several specific features, such as associated work-stage features close to the bloomeries including: roasting pits, storage pits, wells, very low number of smithies, and traditional settlement features. This overall picture, however, is coloured by variations in work management practices (*Gömöri 2000a*, 223; *2000b*, 163–164, 184, 190–193; *Gallina 2002*, 77–80).

Based on the so called barbarian servant population model (*Györffy 1972*, 269; *Gömöri 2000a*, 221), the large area of smelters workshops suggests that they were craftsmen settlements founded in close proximity to the central localities of important leaders and bog iron ore deposits. It also implies that iron production and iron smelting were controlled by a centralized authority. After the distribution of blooms from the centres, iron forging were conducted in the smaller settlements where the final products were utilized, lacking further centralized coordination.

Chemical and mineralogical analyses carried out on slag samples provide us useful information for determining the nature of the metallurgical workshops and of the technologies used. Our investigations can reveal the main characteristics which connect a slag to a particular phase of the iron working process.

Fayalite, wüstite and leucite could be additional reference phases for slag classification:

1. High SiO_2 mineral and glassy phase content, without most of the minerals of 2 and 3 types: **tapped-slag** characterized by high viscosity, solidified with fast cooling of high crystallization rate in the 800–500 °C range.
2. Fayalite with leucite, without a high amount of wüstite and low amorphous content: **furnace slag** slowly cooled in the 1200–1000 °C range. Leucite is the solidus phase of K-content introduced by hard wood ash. It should be noted that according to *Selskiené* (*2007*, 24) many smithing slags, examined by them, had a larger quantity of leucite and wüstite than smelting slags had.
3. Wüstite in significant amount with fayalite, low amorphous content: **purification slag**, oxidizing cooling of an incandescent bloom in the 1100–900 °C range.
4. Wüstite with high (900–1000 °C) Ca-Mg-Fe silicates and moderate amorphous content: **smithy slag**.

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BÉLA TÖRÖK, Faculty of Materials Science and Engineering, University of Miskolc, H-3515 Miskolc-Egyetemváros; bela.torok@uni-miskolc.hu
ZSOLT GALLINA, Ásatárs Kft., Futár u. 12, H-6000 Kecskemét; gallinazsolt@gmail.com
ÁRPÁD KOVÁCS, Faculty of Materials Science and Engineering, University of Miskolc, H-3515 Miskolc-Egyetemváros; femkov@uni-miskolc.hu
FERENC KRISTÁLY, Faculty of Earth Science and Engineering, University of Miskolc, H-3515 Miskolc-Egyetemváros; kristalyf@gmail.com

The *haizeola* and the origins of the 'Catalan method'
The medieval iron metallurgy culture in the Pyrenees

Haizeola a počátky „katalánské metody“
Středověká metalurgie železa v Pyrenejích

Mercedes Urteaga – Xabier Alberdi – Iosu Etxezarraga –
Fernando Martín Suquía – Mertxe Urkiola – Jose Luis Ugarte

Recent research shows that furnaces characteristically used in the 'Catalan method', a direct system of obtaining iron, are much older than they were thought to be. Archaeological evidence obtained in recent years indicates that the same model of furnace, although with smaller dimensions, was part of the iron-making culture of the pre-water-powered phase, when work was done by manpower. This phase has been dated to between the 9th and 14th centuries and relates to installations known as haizeolas. They have been recognized in the Basque territories of Biscay, Gipuzkoa and Alava, in a geographical area on the western edge of the Pyrenees.

Catalan process – Middle Ages – Basque country – early ironworking

Nový výzkum ukazuje, že pece používané při „katalánské metodě“, přímém způsobu získávání železa, jsou mnohem starší, než se předpokládalo. Archeologické důkazy získané v posledních letech naznačují, že stejný model pece, byť menších rozměrů, byl součástí železářské výrobní tradice předcházející fázi zavádění vodní síly, kdy práce byla vykonávána silou lidskou. Tuto fázi lze datovat od 9. do 14. století, a souvisí se zařízeními známými jako haizeola. Ty byly rozpoznány na baskických územích Biscay, Gipuzkoa a Alava nacházejících se na západním okraji Pyrenejí.

katalánský proces – středověk – Baskicko – rané železářství

1. Introduction

Until the beginning of the 20th century, the Pyrenean region had its own ironmaking tradition based on the direct reduction process. It is known in literature as the 'Catalan method', 'Catalan Forge' and 'Catalan hearth' (*Tomás 1999*). This process took place in a low bloomery with a square bottom and inverted tapered-pyramid shape in which iron was obtained by the direct reduction system using hydraulic energy. In the final phase (17th–20th centuries), installations were divided into two groups: firstly, there was the Catalan forge group in the eastern zone, which was characterized by having a water-powered *trompe* to inject air into the furnace and, secondly, the Basque forge group (*ferrerías*) in the western zone, which used bellows as a forced ventilation system until their disappearance. Both types produced good quality iron ingots intended for both the European and American international market, competing with the iron produced in blast furnaces.

The same type of furnace, but in a smaller version, has been discovered in non-hydraulic establishments, mostly located in the mountains near mining areas. These are the

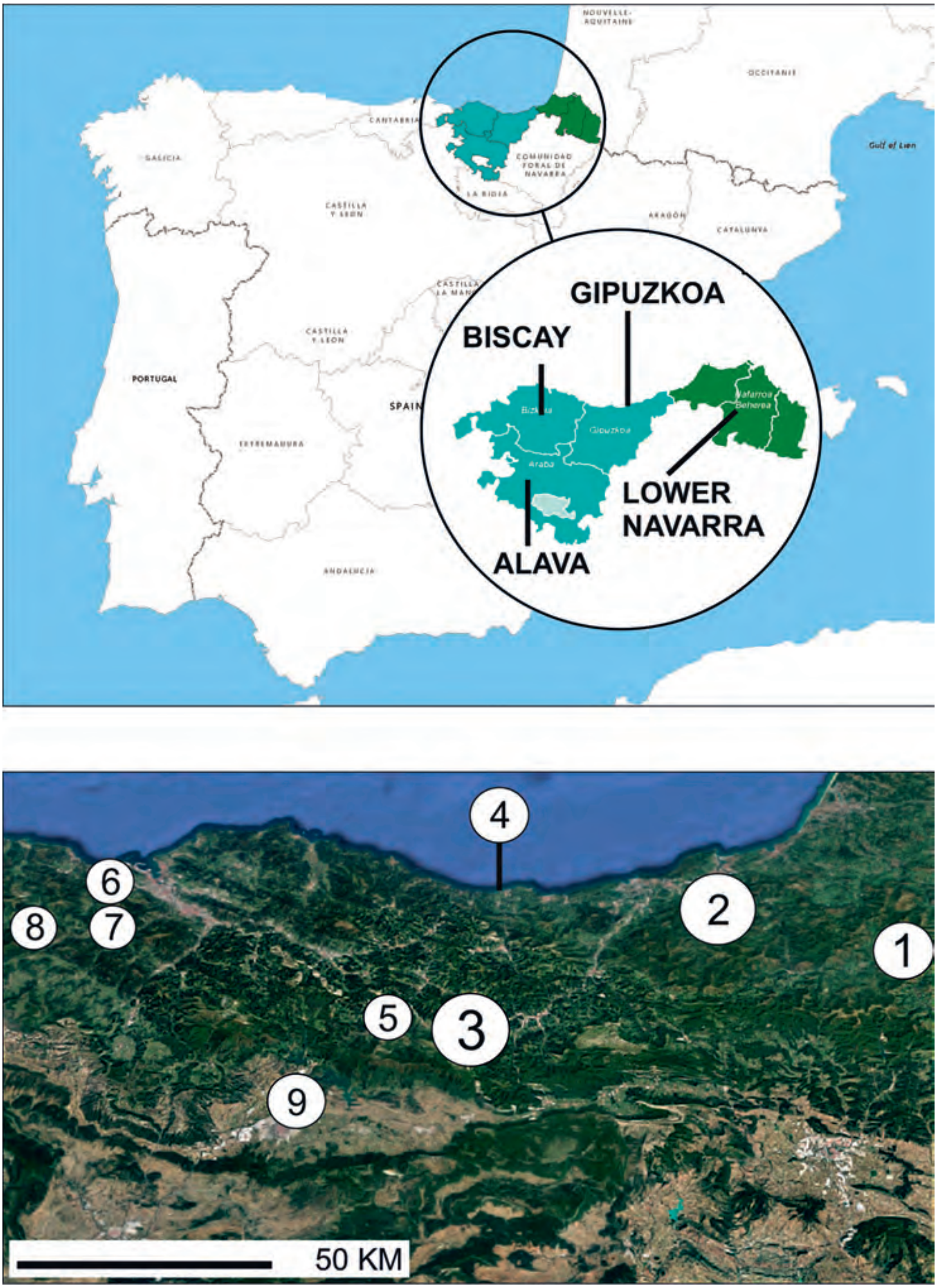


Fig. 1. Location of the area with indication of the places mentioned in the text: Drawing by M. Urteaga.
Obr. 1. Poloha oblasti s vyznačením míst uvedených v textu.
1 – Larla, 2 – Peña de Aya-Oiartzun, 3 – Legazpi-Segura, 4 – Mutriku, 5 – Arrasate/Mondragón, 6 – Muskiz-Trapagaran, 7 – Galdames, 8 – Artzentales-Sopuerta, 9 – Arrazua-Ubarrundia.

so-called *haizeolas*, the archaeological records of which date back to at least the 9th century.

The incorporation of water wheels and waterfalls must have begun in around the 11th century, although it seems to have spread and become more common place later, in the 13th century. The application of hydraulic drive power made it possible to increase the injection capacity in furnaces and the furnaces to increase in size. In this new technological context, installations came down from the mountains and were located next to rivers.

2. The name *haizeola* and pre-water-powered ironworking

In the 1950s, the engineer Manuel Laborde interviewed an elderly man in the Zerain area of Gipuzkoa who reported the use of the two Basque words *haizeola* and *gentilola*. Both terms had been used by his ancestors to refer to the old iron smelting furnaces from which abundant accumulations of slag were still extant.

Laborde (*1956*; *1979*) incorporated the term *haizeola* into the technical language of early Basque ironworking, using it to refer to the iron slag heaps found in mountain areas. From the location of the slag heaps and the characteristics of the slag itself, he also established a relationship with forges not powered by water.

These slag heaps have long been identified with manually-powered iron works. In the sixteenth century, the chronicler Esteban de Garibay (*Garibay y Zamalloa 1556*, 96) wrote that the first installations for making iron were located in the ‘high areas of these same mountains’ and that they were powered by hand rather than by water. He based his deduction on the fact that the slag heaps stood at a considerable distance from the river courses. Soon afterwards, Lope Martínez de Isasti (*Martínez de Isasi 1625*, 236) repeated Garibay’s suggestion that the water-powered iron works were preceded by ones in which the iron was worked ‘by hand’ in the mountains. Villarreal de Bérriz (*Villarreal de Berriz 1736*, 43) and *Larramendi* (*1756*, 64–65) gave similar reports, as did other twentieth-century historians such as *Caro Baroja* (*1949*, 259–260) and Laborde who, as mentioned, introduced the term *haizeola*.

3. Archaeological identification of the *haizeola*: The catalogue of mountain slag heaps

Calle Iturrino (*1963*) published the first list of iron slag heaps in the Basque Country in the middle of the last century; in this chapter of precedents, mention can also be made of the group of 10 slag heaps recorded in Legazpi (*Arbide et al. 1980*). But in these cases, there was no identification of the site by means of geographical coordinates, and there was no description accompanying the location. These requirements were fulfilled for the first time in the work of *Gorrochategui* and *Yarritu* (*1984*), in which 34 slag heaps were catalogued in 6 geographical areas of Biscay.

A new episode in the evolution of the archaeological knowledge of *haizeolas* took place in 1988, with the archaeological work carried out at the Ilso Betaio slag heap in Artzentales/Sopuerta, Biscay. The program lasted until 1990 and included anthracological analyses of carbon samples, palynological analyses and radiocarbon dating. Among the discoveries are two calcination furnaces, dust ore residue and structures with unknown functions. The slag heap dated to between 940 and 1100 AD (*Gorrochategui et al. 1995*).

After this first initiative, excavations followed at the Oiola slag heap in Trapagaran (Biscay) between 1990 and 1993 (*Aldama – Lorenzo 1991*), resulting in a corpus of reference information for learning about the metallurgical process that took place in these facilities between the 11th and 13th centuries (*Pereda García 1997*; *Larrazabal 1997*). After those dates, archaeological work became commonplace in slag heaps, also moving to other regions. In Gipuzkoa, work started in 1993 (*Urteaga 1996*; *Alberdi – Etxezarraga 2014*), in Lower Navarra in 1998 (*Beyrie 2002*) and in Alava a few years later (*Alberdi – Etxezarraga – Artetxe 2013*).

As a result of this activity, there is a catalogue of 500 slag heaps, 250 of which have been registered in Gipuzkoa, 170 in Biscay, 55 in Larla (Saint-Étienne-de-Baïgorry, Lower Navarra) and 25 in Alava. Archaeological operations have also been carried out in 52 of them, 21 in Biscay, 17 in Gipuzkoa, 13 in Lower Navarra and 1 in Alava.

It should be noted that the figure of 500 slag heaps recorded to date was certainly much more extensive. As happened in Montagne Noire (France) and in many other European regions where there was a major modern iron-steel industry, the iron slag heaps in the Basque Country were exploited industrially in the foundries of the 20th century. Moreover, it can be said that only those heaps that are difficult to access or of little importance have been preserved.

Having made this assessment, the available records show concentrations in specific areas, such as the 124 slag heaps around Legazpi (*Ugarte – Urteaga 2014*), the 55 in Larla in Saint-Étienne-de-Baïgorry (*Beyrie 2008*), the 54 in Galdames (*Franco Pérez 2008*) and the 45 in Peñas de Aya (*Alberdi – Etxezarraga – Artetxe 2013*). This distribution is related to the existence of significant iron ore deposits.

4. Archaeological work and the chronology of *haizeolas*

Table 1 shows dated slag heap data and their chronology. Of the 45 registered sites, 44 of them are slag heaps, but one (Bagoeta) is a rural settlement. The dated sites are 8.5 % of the total. A significant portion of them have chronologies from the Second Iron Age, the Roman Era and the Late Antiquity; they represent 3.2 % of the total and the 35 % of the dated slag heaps; there are also very complete records of the furnaces from that period in the case of Larla (*Beyrie 2014*).

In the other 26 dated slag heaps, chronologies fall between the 9th and 14th centuries, with a higher concentration in the 11th and 13th centuries (16 examples).

The Larla furnaces belong to a type that has been well-known for centuries that frame the change of era; semi-excavated in the natural terrain, with a narrow and elongated plant divided into two distinct parts: the entrance and the reduction chamber, which is closed with a chimney. According to the archaeological experimentation campaigns, they worked with a natural draught (*Beyrie 2014*).

Although the term *haizeola* is used to identify the furnaces that have produced the accumulations of iron slag that are located in mountain areas, following the historiographic

Name	A=Alava; B= Biskai; G=Gipuzkoa; L.N.=Lower Navarra	Reference	III	II	I	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Zepamendi	A	*Alberdi – Etxezarraga – Artetxe 2015*				■	▨	▨											
Bagoeta	A	*Azkarate – Solaun 2014*															▨	▨	
Oiola 2 (Loiola)	B	*Cepeda – Unzueta 2015*				■	▨	▨	▨										
Akalarra	B	*Franco Pérez 2014*							▨	▨									
Arteta	B	*Franco Pérez 2011*								▨	▨	▨							
Artobilla 2	B	*Franco Pérez 2011*									▨	▨	▨						
Lekubarri	B	*Franco Pérez 2014*										▨	▨						
Biriguera	B	*Franco Pérez 2008*										▨	▨						
Crucero	B	*Franco Pérez 2008*									▨	▨	▨						
Gongeda 1	B	*Franco Pérez 2008*											▨	▨	▨				
Los Campillos	B	*Franco Pérez 2007*												▨	▨	▨			
Salbartondo 2	B	*Franco Pérez 2007*													▨	▨			
Ilso Betaio	B	*Gorrochategui et al. 1995*												▨	▨	▨	▨		
Arrastaleku	B	*Franco Pérez 2014*														▨	▨		
Peña Helada 1	B	*Franco Pérez – Etxezarraga – Alberdi 2015*												▨	▨	▨	▨		
Saukutza 3	B	*Franco Pérez 2011*														▨	▨		
Peñas Negras	B	*Franco Pérez et al. 2014*														▨	▨		
Callejaverde II	B	*Franco Pérez et al. 2014*														▨	▨	▨	
Callejaverde I	B	*Franco Pérez et al. 2014*														▨	▨	▨	
Oiola 4	B	*Pereda García 1997*														▨	▨	▨	
Peña Helada 2	B	*Franco Pérez – Etxezarraga – Alberdi 2015*															▨	▨	
Erdokazabaleta 3	G	*Ugarte – Urteaga 2014*												▨	▨				
Basaundi 2	G	*Ugarte – Urteaga 2014*													▨	▨			
Teniola 1	G	*Franco Pérez – Etxezarraga – Alberdi 2015*												▨	▨	▨	▨		
Erdokazabaleta 5	G	*Ugarte – Urteaga 2014*															▨	▨	
Otaño 3	G	*Ugarte – Urteaga 2014*														▨	▨	▨	
Aizaleku 5	G	*Ugarte – Urteaga 2014*															▨	▨	
Galarraga	G	*Franco Pérez – Etxezarraga – Alberdi 2015*															▨	▨	
Zabarain 7	G	*Ugarte – Urteaga 2014*															▨	▨	▨
Aizpee 5	G	*Ugarte – Urteaga 2014*															▨	▨	▨
Teniola 4	G	*Ugarte – Urteaga 2014*																▨	▨
Larrosain	G	*Ugarte – Urteaga 2014*															▨	▨	▨
Erlaitz 1	G	*Ugarte – Urteaga 2014*															▨	▨	▨
Harotzainekoborda	L. N.	*Beyrie 2014*				■													
Oheta	L. N.	*Beyrie 2014*				■													
Larla 1	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 2	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 3	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 4	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 5	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 6	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 7	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 8	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 9	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 10	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										
Larla 11	L. N.	*Beyrie 2014*	■	■	■	■	▨	▨	▨										

Tab. 1. The chronology of the slag heaps.
Tab. 1. Chronologie struskových hald.

tradition and the results that are analyzed, our work has reduced the field of application of that name to square, low and open furnaces which chronology extends between the 9th and 14th centuries in our era.

One contemporary text explicitly refers to installations in which iron was made without the use of water power – in other words, *haizeola*. The document dates from 1335 and forms part of a bylaw whereby the local council of Segura required ironworkers in their jurisdiction to sell their iron and purchase their supplies through the town. The preamble makes particular mention of the different types of iron works in the area and differentiates between *masuqueras,* those which used water-driven hammers, *mazo de agua,* and those which used 'omes'. The first two refer to water-powered installations, whereas those powered by 'omes' (a Spanish medieval term meaning *men*), as their name suggests, were the hand-operated installations (*Urteaga 1996*). It also shows that they co-existed with water-powered works and that the latter were sufficiently developed. In the fifteenth century, the increased production capacity of the newly expanded water-powered works forced the more primitive ones out of business.

5. Introduction to the archaeological identity of the *haizeola*

The sites

With the exception of Torre in Astigarribia, all the other slag heaps are located in mountain areas close to iron ore deposits. Although they were situated near mining areas, they did not form part of them; they were built in the immediate vicinity. In addition, they all share two other features: an adjoining river or stream, and clay soil. The reason they were not located next to the iron mines may have been because of the need for a supply of water or also for other reasons. Indeed, a water source is a feature of practically 100 % of the slag heaps catalogued. These tend to consist of springs or streams with a weak flow, but they would have been enough to meet the requirements of a small group of people and basic industrial activity. Another constant is the clay soil on which the installations are built. Such sites may have been preferred because they made it easier to dig the base of the furnaces and build the foundations of the wooden structures or because they provided the clay required for building the walls of the furnaces and other auxiliary items.

It is also worth bearing in mind that larger quantities of charcoal than iron ore were required for the process. The exact ratio of iron ore to charcoal used in the *haizeola* is not known, but in the water-powered works the volume is estimated at around 3 to 5 (*Urteaga 2000*, 258). As we shall see, water-powered works and *haizeola* appear to share the same ironworking tradition and the loads of charcoal required would have been much greater than those of ore. This would have made it more important to build them near woodland than close to deposits of iron ore (albeit they could not be too far from the mines).

The installations identified in Astigarribia constitute an exception, in that according to analyses, the ore used there did not come from the immediate environs (*Pérez Centeno 2009*). This difference may have something to do with the monastery to which it appears to have been attached and the existence of a sea and river port at the site.

Finally, we should also note that the sandstone used in the construction of the furnaces and auxiliary structures was also available in the sites chosen.

Characteristics of the installations

Based on the information we have gleaned to date, the works appear to have consisted of small sheds situated on small plots of levelled ground, dug out of gently-sloping land (*Fernández Carvajal 2009*). The furnaces occupied a central and important position and were accompanied by small roasting structures in the immediate area; the ore and charcoal were stored beside the furnace. The most complete information comes from Basaundi 2 (Legazpi). In this case it has been seen that there is a basic building next to the furnace where the charcoal was stored and auxiliary operations were carried out. The furnace is located outside this building, but protected by a roof supported by wooden poles.

The ore

The samples analysed (*Simon 2014*, 87) coincide in indicating that the ore was quite pure, comprising hematite iron ore (Fe_2O_3) with remains of siliceous gangue (SiO_2). This is quite a pure iron oxide which is easy to reduce. The samples recovered are of ore that has been treated previously to remove impurities. The resulting concentrate was roasted on site and broken up to be put in the furnace.

The charcoal

A lot of research work still needs to be conducted in this area, since each slag heap contains a large quantity of charcoal which needs to be identified and quantified. To date, 4 different sites analysis has been performed (*tab. 2*): Torre (Astigarribia, Mutriku), Oiola IV (Trapagaran), Ilso Betaio (Arcentales) and Bagoeta (Arrazua-Ubarrundia). This last site does not correspond to the mountain location of the iron slag heap or *haizeola*; it was found during an archaeological excavation in a medieval rural settlement, but has the same type of furnace and the same chronology (*Azkarate – Solaun 2014*).

From these data an extreme variety in the origin of charcoal is deduced; in the case of Torre can be established three groups: oak charcoal accounts for 35 % of the whole, followed by apple, 29 %. Of the remainder, the most abundant species is beech, which comprises 15 % of the total. Bagoeta is in the opposite side; in this case a single species has been used for charcoal: oak. Ilso Betaio provides the beech domain with almost 90 % of the total, and in the last case, Oiola IV, the oak is the most important species, exceeding 50 % of the sample.

The arragoas or roasting structures

The ore was roasted in elongated oval structures, with two low parallel walls about 1 m apart, as can be seen at the slag heap of Basaundi 2 (*Ugarte – Urteaga 2014*, 60). This type of “*arragoa*” has also been identified in the slag heap of Oiola IV in Trapagaran, Bizkaia (*Pereda García 1997*) and at Peñas Negras (*Franco et al. 2014*, 201). The shape of those constructions may vary from site to site though, since a circular plant roasting structure has recently been found at Peña Helada (Galdames, Biscay) (*Franco Pérez – Etxezarraga – Alberdi 2015*). However, at the moment, oval arrangement seems to be the average feature.

Species	Common name	Percentage
Torre 1 (Astigarribia, Gipuzkoa). ***Pérez Centeno*** **(*****2007*****).**		
Quercus subg. *Quercus*	Oak	35%
Rosaceae Pomoideae	Apple	29%
Fagus sylvatica	Beech	15%
Rhamnus alaternus / Phillyrea	Thorn	6%
Taxus baccata	Yew	11%
Corylus avellana	Common hazel	4%
Oiola IV (Trapagaran, Biscay). ***Zapata*** **(*****1997*****)**		
Quercus subg. *Quercus*	Oak	55.8%
Fagus sylvatica	Beech	12.5%
Corylus avellana	Common hazel	7%
Rosaceae Pomoideae	Apple	3.2%
Frangula alnus	Alder buckthorn	5.5%
Others		15%
Ilso Betaio (Arcentales. Biskay). ***Zapata*** **(*****1993*****)**		
Fagus sylvatica	Beech	89.6%
Quercus subg. *Quercus*	Oak	6.18%
Ilex aquifolium	Holly	2%
Bagoeta (Arrazua-Ubarrundia, Álava). ***Azkarate – Solaun*** **(*****2014*****)**		
Quercus subg. *Quercus*	Oak	100%

Tab. 2. Documented wood species used for charcoal.
Tab. 2. Dokumentované druhy dřeva používané pro výrobu dřevěného uhlí.

The furnaces

The furnaces are of square sloped type (*figs. 2* and *3*). They are low and open, with air forced in by handed bellows. The best information comes from the 11th–13th century *haizeola* of Callejaverde 1, Callejaverde 2 (Muskiz, Biskay), Peñas Negras (Ortuella, Biscay), Peña Helada (Galdames, Biskay), Anporreta (Arrasate-Mondragón, Gipuzkoa), Olazar 3 (Oiartzun, Gipuzkoa) and Basaundi 2 (Legazpi, Gipuzkoa). In the three last examples only the lower part of furnaces remains, but they are similar in their characteristics to those seen in the well-preserved furnaces of the other sites. In all cases the area on which the furnace was constructed can be seen to have been carefully prepared to repel damp.

The walls are around one metre thick and were built out of medium-sized sandstone blocks, held together with clay. The base of the furnace was dug into the ground. Viewed from above, it is rectangular with rounded angles. Its size is around 35 cm long by 30 cm wide and beneath this level a tank with the shape of a bowl was dug deeper. The tank was separated from the base with a levelled slag layer.

The base is smaller than the frame at the top, where reaches 70 × 60 cm, and slopes slightly backwards. The nozzle (*tuyère*) was placed halfway up the back wall through which the air from the wall bellows entered the furnace. The upper section overhangs the *tuyère*, narrowing the upper opening of the furnace. The *tuyère* leaded through the wall on a horizontal slab. The opposite wall stands at an angle of 45º and finishes in a prepared stone

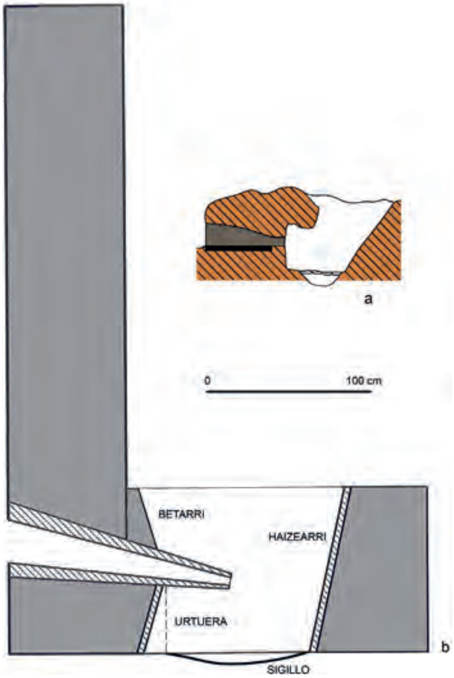


Fig. 2. a – the haizeola furnace; b – the water-powered ironworks furnace. Drawing by M. Urteaga & J. Maroto.
Obr. 2. a – pec *haizeola*; b – pec železárny s vodním pohonem.

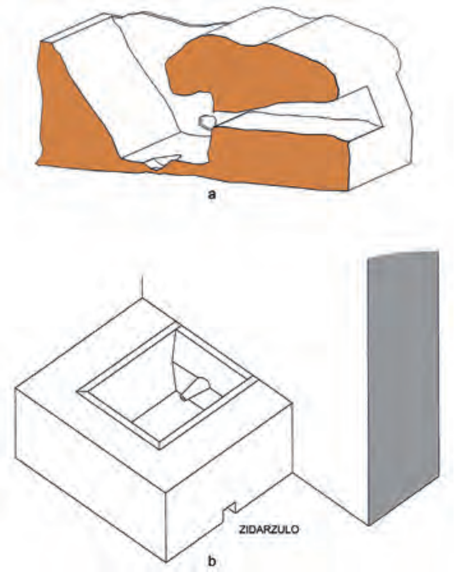


Fig. 3. a – the haizeola furnace; b – the water-powered ironworks furnace. Drawing by M. Urteaga & J. Maroto.
Obr. 3. a – pec *haizeola*; b – pec železárny s vodním pohonem.

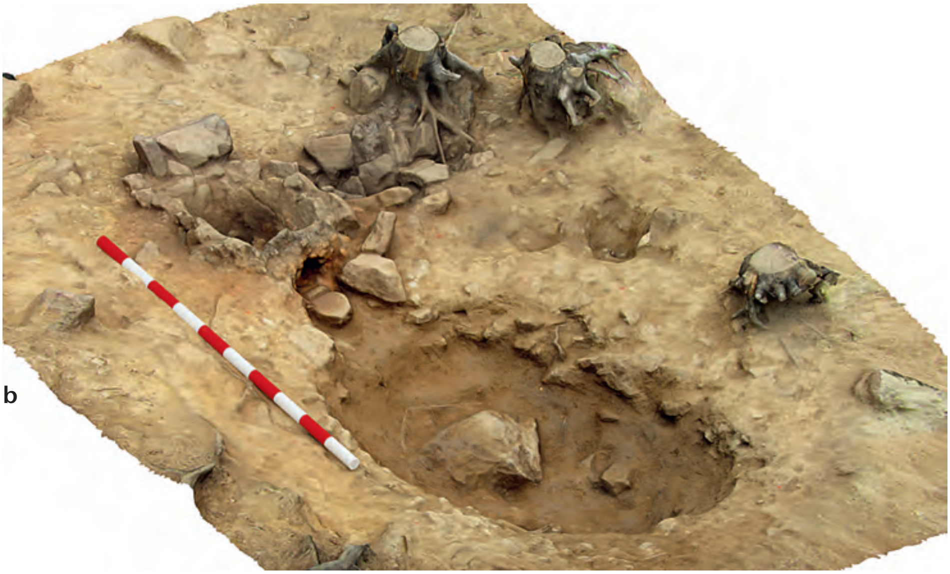
with the same angle. One of the other two walls has a gap at the base level of the furnace for removing slag.

The furnace of the *haizeola* was about two-thirds of the size of that used in the water-powered works. Whereas the furnace of the water-powered forge was a metre in height, that of the *haizeola* was 60 cm and the other parts were more or less to the same scale (*fig. 2* and *3*).

However, some geographical differences are observed in this described model. The four furnaces found at Biscay were built excavated in the ground (see *fig. 3*). Two of its walls are the terrain slopes, while the wall of the *tuyère* and the remaining wall were built with stones and clay in a massive way (*Franco Pérez – Gener Moret 2017*). In the furnaces from Gipuzkoa only the base was excavated in the ground. The rest were built out of medium-sized sandstone blocks, held together with clay. The walls are around one meter thick. In Basaundi 2, for example, the perimeter ring on which the walls are erected has been excavated to a depth of around 30 cm; this would have facilitated drainage and ensured that the base of the furnace was protected from seepage (*fig. 4*).

There is extensive documentation for the terms used for the different parts of the furnace in water-powered works. In the 18th century Metallurgy Manual from the Royal Society of Friends of the Basque Country (*Urteaga 2000*, 260), the wall with the *tuyère* was called in

a



b

Fig. 4. a – Callejaverde 1 Site; b – Callejaverde 2 Site. Photo by Ondare Babesa S. L.
Obr. 4. a – lokalita Callejaverde 1; b – lokalita Callejaverde 2.

Basque language the *betarri* (unknown meaning) in the upper part and *urtuera* (unknown meaning) in the lower one. The opposite wall was the *haizearri* (translated: the wind stone). Out of the two other walls, the one with the hole for slag tapping was the *zidarzulo* (translated: the slag hole). The hole was in the lower part of the furnace at the same height as the plate of the *sigillo* (from Latin *sigillum*? – to seal?).

Archaeological experiments at the 18th century rebuilt Agorregi hydraulic ironworks (Aia, Gipuzkoa) conducted by Peter Crew (*Crew – Crew 2002*) shows that this arrangement creates a circular draught inside the furnace, allowing temperatures of 1300 °C close to the mouth of the *tuyère* (*Fluzin – Herbach – Dillmann 2002*). It is in that area that the bloom or *agoa*, created by reduction of the iron ore in contact with the charcoal, is formed.

Analysis of the slag from the *haizeola* furnaces also shows evidence of these temperatures. Solidified fayalite has been found, indicating a temperature of 1205 °C, as well as leucite, suggesting that the temperature in the furnace was 50–100 °C higher (*Simon 2014*, 96).

Iron production in the haizeola

To judge from the type of furnace and associated structures identified and the remains of ore and slag analysed, the *haizeola* obtained iron in much the same way as the water-powered iron works, although output was smaller and they were hand-operated. Good quality and easily reducible ore was used, iron oxides (hematites), that were roasted and broken up on site before being placed in the furnace. As in the water-powered works, the charge would have been carefully studied, since the result of the reducing operation depended to a great extent on how this was done. Because the furnace was open, the process could be controlled quite easily and any necessary changes made. The furnaces used forced injection, in other words, the air was injected from the rear using hand-operated bellows. This allowed temperatures of up to 1300 °C, enough to obtain sponge iron through direct reduction and to tap the liquid slag, helped by reduction of the wüstite. Work in the *haizeola* concluded when the *agoa* (bloom) was produced. The refined blooms must have been prepared in separate premises, since none of the characteristic waste material of forging operations has been found on the slag heaps.

If we focus on water-powered iron production, we find that in Pyrenean regions, particularly Catalonia, Ariège and the Basque Country, iron continued to be produced in low and open square furnaces until the twentieth century, despite the fact that elsewhere in Europe, indirect smelting in blast furnaces had been commonplace since the end of the Middle Ages. These installations were gradually abandoned as a result of the introduction of the blast furnaces, accompanied by mechanisation of the processes and industrial levels of output. With the closure of the last such installations in the Pyrenees in the twentieth century, direct reduction finally came to an end. Technological change also led to the disappearance of the bloomeries which, with variations, used the same open, square sloped model described above throughout the Pyrenees.

Thanks to the evidence obtained from the *haizeola* it is possible to trace the basic design of that type of furnace back to the pre-hydraulic period, establishing its origins at least as early as the tenth century or even earlier in the Basque provinces of Bizkaia, Gipuzkoa and Alava. In short, this type of furnace appears to correspond to a different tradition to those used in the pre-Roman and Roman periods. We do not know with any certainty when it was introduced and how much further back it dates than the earliest available records. What we do know is that once adopted, it was retained long after the *haizeola* themselves had disappeared. The design continued to be used in the furnaces of water-powered ironworks until, with the coming of the Industrial Revolution, they closed due to competition from blast furnaces.

There is an increasing body of information on the transition from the *haizeola* to water-powered ironworks. As we have seen, it shows that the *haizeola* and the water-powered ones share a common culture, reflected in the model of furnace. This model formed part of the medieval ironworking culture of the Pyrenean area, between the Atlantic and the Mediterranean, from the High Middle Ages.

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MERCEDES URTEAGA, Provincial Council of Gipuzkoa, Archives and Heritage Services, Culture Department.
Urdaneta street 9, E-20006 Donostia-San Sebastián, Basque Country; murteaga@gipuzkoa.eus
XABIER ALBERDI, Mining Museum in the Basque Country, Bº Campodiego, S/N, E-48500 Gallarta
(Abanto-Zierbena) Bizkaia; x.a.lonbide@gmail.com
JOSU ETXEZARRAGA, Mining Museum in the Basque Country, Bº Campodiego, S/N,. E-48500 Gallarta
(Abanto-Zierbena) Bizkaia; iosu.eo@gmail.com
FERNANDO MARTÍN SUQUÍA, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa)
fernando.sukia@sidenor.com
MERTXE URKIOLA, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa)
murkiola@gmail.com
JOSE LUIS UGARTE, Burdinola Society, Bº Telleriarte Auz, S/N, E-20230 Legazpi (Gipuzkoa)
jl-ugarte@euskadi.eus

Slag-pit bloomery furnace of the Tarchalice type
Reconstruction and experimental research

Pece se zahloubenou nístějí typu Tarchalice
Rekonstrukce a experimentální výzkum

Paweł Madera – Dariusz Kik – Ireneusz Suliga

The paper presents the results of the first stage of experimental research on reconstruction of the bloomery process in the slag-pit furnace of the Tarchalice type. The phenomenon of bloomery furnaces from the Przeworsk culture settlement in Tarchalice (*Tarxdorf*), *Lower Silesia, Poland, has been known to the scientific community since 1903. With regard to ancient slag-pit furnaces discovered in the second half of the twentieth century in the Świętokrzyskie Mountains and Mazovia region, these features had two-times larger diameter of slag-pits and almost four-times greater weight of slag blocks. The large sizes of the slag-pits suggested dissimilarity of conditions of running the process, formation of iron bloom and block of slag in relation to quite well known from scientific experiments the bloomery process from the Świętokrzyskie Mountains.*

experimental archaeology – iron smelting – Przeworsk culture – Silesia – slag-pit bloomery furnace – bloomery process

V příspěvku jsou prezentovány výsledky první fáze experimentálního výzkumu rekonstrukce procesu přímé výroby železa v pecích se zahloubenou nístějí typu Tarchalice. Fenomén železářských pecí převorské kultury v Tarchalicích v Dolním Slezsku je odborné veřejnosti znám již od roku 1903. Pokud jde o starověké pece se zahloubenou nístějí, objevené ve druhé polovině 20. století ve Svatokřížských horách a na Mazovsku, tyto objekty měly dvojnásobně větší průměr nístějí a téměř čtyřnásobně větší hmotnost struskových bloků. Velké rozměry zahloubených nístějí naznačovaly rozdílné podmínky procesu tavby, tvorby železné houby a bloku strusky oproti, z vědeckých pokusů poměrně dobře známému, procesu přímé výroby železa ve Svatokřížských horách.

experimentální archeologie – hutnictví železa – převorská kultura – Slezsko – pec se zahloubenou nístějí – přímá výroba železa

1. Introduction

Experimental research, in addition to intensive excavations at ironmaking sites, played a decisive role in explaining the essence of the bloomery process. Despite the passage of over 60 years, attempts to reconstructing furnace constructions typical for a given area and the specificity of the bloomery process, carried out in various scientific centers[1], still encounter difficulties resulting mainly from general lack in the archaeological remains

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[1] In Western Europe, experimental iron smelting was initiated in the second half of the 1950s by archaeologists and metallurgists from Belgium, Germany, England and Denmark. At the same time, similar works began in Poland, and a few years later in other countries of Central and Eastern Europe: in Czechoslovakia, in the Soviet Union and Yugoslavia (see *Orzechowski – Przychodni 2014*, 249–250).

of above-ground parts of furnaces, smelting residues in the form of iron blooms and even batch materials. Although it is usually far from fulfilling the expectations of experimenters, the knowledge and experience accumulated over the years allow to approach new challenges with optimism, which is proved by this work.

The experimental research on the reconstruction of the furnace and the bloomery process undertaken in Poland was one of the first in this field. They were initiated in 1957 by the discoverers and researchers of the ancient metallurgical center in the Świętokrzyskie Mountains: the metallurgist and historian of technology, Prof. Mieczysław Radwan and the archaeologist, Prof. Kazimierz Bielenin (*Radwan 1958*). Initially, experiments were conducted in laboratory conditions at the Academy of Mining and Metallurgy in Kraków (AGH), and later at the Truck Factory *Star* in Starachowice. The Museum of Ancient Metallurgy in the Świętokrzyskie Mountains in Nowa Słupia became a permanent place of experiments of field character since 1962, and then the annual archaeological festival *Dymarki Świętokrzyskie* organized nearby. Since 2000 experimental tests have also been carried out at the Blast Furnace Complex in Starachowice as part of the *Iron Roots* educational event. Previous research has concerned almost exclusively slag-pit single use furnace, which was actually the only kind of bloomery furnace used in prehistory in Polish lands. Experimental furnaces were constructed on the basis of dimensions of slag-pits from the Świętokrzyskie Mountains, the diameter of which varied in the range of 30–50 cm, assuming the height of a shaft made of clay blocks from 80 (initially even from 25 cm) to 120 cm (see *Suliga 2006a*; *Bielenin – Suliga 2008,* 59–62; *Orzechowski – Przychodni 2014,* 250–260).

Results of the experiments referred to archaeological evidence have consolidated opinions on the general furnace construction, an air supply system, a type of batch material and its dosing into the furnace. The state of the slag-pit during the smelting was still in question (empty or filled, with charcoal or wood), and above all the form of smelting products remained unsatisfactory. Slag-iron conglomerate structures forming accretions around the blow holes was commonly obtained (*Suliga 2006a*, 173). Grainy separations, as well as iron plates and grids immersed in mass of slag could not have technical significance. Of course, the intensification of the blast led to the increase of the temperature in the furnace, liquefaction of the slag and its runoff to the pit, but reduced iron was then carburized, and even melted down, becoming pig-iron which was useless for ancient smelters.

Prof. Bielenin tried to overcome an impasse in the reconstruction of the bloomery process (*Bielenin 1978,* 60; *1985*, 187–193; *1998–1999*, 523 ff.). He drew attention to the common features of slag blocks from archaeological excavations that are typical for casting liquid material into a cold form. Since the slag was so fluid that it flowed into a pit at a certain time in the process, the iron bloom was sufficiently drained from the slag and was suitable for direct processing. The concept of Prof. Bielenin, called the ‘free solidification surface’ of slag blocks concept (FSS), formulated the principles of leading the process differently. At a certain point in the smelting it was necessary to devote liquefaction of the slag and its inflow into the pit, counting on draining the bloom from slag and final separation of both phases (*Bielenin 2002,* 15; *2005*; *2011*). The metallurgical verification of the correctness of the FSS concept pointed to an unknown aspect of the phenomena occurring within the slag that filled the pit – the effect of the secondary fayalite reduction leading to the formation of iron grids in slag (*Suliga 2006b*; *Suliga – Kargul 2007*; *Bielenin – Suliga*

2008). The secondary reduction effect confirmed along with other features of the crystallization of the slag block (crystal structure, segregation of phases) the FSS concept, but also indicated the possibility of such process in the slag phase earlier, during the smelting in the furnace shaft (*Suliga – Karwan 2014*, 170). It was necessary to introduce this to experiments, that was strongly encouraged by Prof. Bielenin.

At the end of the last decade, thanks to the efforts of the members of the Świętokrzyskie Association of Industrial Heritage (ŚSDP) in Kielce, significant progress has been made in experimental research. Attempts conducted by Andrzej Przychodni and Adrian Wrona contributed to this, as well as establishing cooperation with Jens Jørgen Olesen, the experienced experimenter from the museum in Thisted, Denmark. Undoubtedly, the use of definitely richer hematite ore was also important for improving the results of the experiments. Smelts carried out in 2013–2014 in accordance with the principles of the FSS concept gave the expected results. In two stages of the process, reduction of iron from ore and from slag in the furnace shaft as well as liquefaction and draining of slag into the pit, the iron bloom of 3.65 kg weight, technically pure, with ferritic structure and slag in the form of a block was obtained (*Przychodni – Suliga 2016*).

2. The phenomenon of the Tarchalice furnaces

The Silesian metallurgical region was one of three, next to the production centers in the Świętokrzyskie Mountains (*Bielenin 1992*; *Orzechowski 2007*) and in western Mazovia (*Woyda 1978*; *2002*), the main areas of the ancient iron industry in Poland. It was situated in the upper and middle Oder basin. The smelting sites were concentrated mainly in the wide zones of the Odra valley, from Racibórz to Nowa Sól, and the valleys of its larger tributaries, including Mała Panew, Nysa Kłodzka, Oława, Ślęza, Bystrzyca, Widawa and Barycz (*Madera 2002*). Metallurgical production, dated from the younger pre-Roman period to the early Migration period (1st c. BC – 5th c. AD), was associated with the Przeworsk culture. The raw material for smelting was local bog ores. The production was conducted in unorganized ironworks including usually a small number of slag-pit furnaces. It was implemented for local needs, within settlements or in their direct vicinity (*Orzechowski 2013*, 224–243).

Iron smelting site in Tarchalice (before 1945 *Tarxdorf*), district Wołów, Lower Silesian Voivodeship, site 1, is located about 50 km on the NW from the capital of the region – Wroclaw, on the right bank of the Odra valley (*fig. 1*). It was the first excavated metallurgical site in Polish lands. The archaeological research was made in 1903 and 1908 in connection with repeated finds of iron slag and fragments of pottery on the surface (*Seger 1894*; *Olshausen 1909*, 60–66; *Weiershausen 1939*, 97–104). In an area of approx. 10 × 10 m the remains of 37 bloomery furnaces in the form of pits filled with blocks of slag were then uncovered. Due to their large size and good state of preservation they aroused extraordinary interest not only among archaeologists, but also engineers-metallurgists. These studies and the accompanying discussion in *Zeitschrift für Ethnologie* (*von Luschan 1909*; *Olshausen 1909*; *Krause 1909*; *Giebeler 1909*) should be regarded as the beginning of archeometallurgy in Central Europe. The significant concentration of discovered furnaces in small trench in the presence of slag on the surface of 6 ha and finding in their context

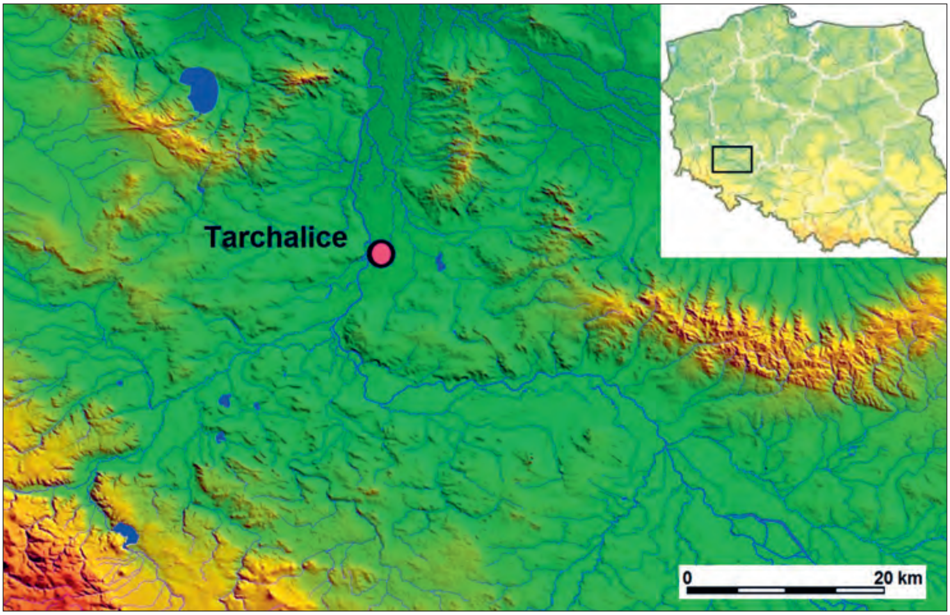

Fig. 1. Tarchalice (before 1945 *Tarxdorf*), district Wołów, Lower Silesian Voivodeship, site 1. Block of slag with widening at the top in form so-called 'cap' (there are remains of the slag-pit walls clay lining and the negatives of the wooden rods on the lateral surface of the block). Photo Kazimierz Bielenin.
Obr. 1. Tarchalice (před r. 1945 Tarxdorf), okres Wołów, Dolnoslezské vojvodství, lokalita 1. Blok strusky s rozšířením v horní části (nesoucí zbytky výmazu zahloubených nístějí a negativy dřevěných prutů na boční ploše bloku).

pottery from the Hallstatt period caused, that the site for some time was considered as the largest and one of the oldest centers of iron production north of the Alps.

After WW2 research was continued by Polish archaeologists (*Hołubowicz 1956*; *Domański 1972*; *2000*). In total, in the area of about 12 ares, relics of at least 75 furnaces located mainly in 2 clusters along the shore of the one Odra oxbow lake were discovered. While in the test-trenches established in the eastern part of the site there were remnants of the Przeworsk culture settlement in the form of residential buildings, hearths and farm pits. Thus the excavations did not confirm the previously predicted huge number of furnaces (30,000 – 40,000 units.). Due to the lack of ^{14}C analysis, the production activity is dated in a wide chronological framework of the settlement's functioning, determined on the basis of ceramic material from 1st c. BC to 3rd c. AD (*Domański 2000*).

It is significant, that until the 1970s there was no consensus on the construction of furnaces discovered over there. Initially, they were considered as sunken hearts features with a blowing canal from the surface to the bottom of the furnace (*Giebeler 1909*) or partially sunken with a conical shaft, but also with a blast to the bottom of the furnace (*Krause 1909*). After the resumption of research after the War, under the influence of *Weiershausen* (*1939*, 102), they were treated as shaft devices (*Hołubowicz 1956*, 212; *Domański 1972*, 422–433; *1975*), although this was in conflict with their stratigraphic position. A design of the slag-pit furnace was first proposed by Prof. Radomír Pleiner, but the location of the blast in the upper part of the pit still was not a satisfactory solution (*Pleiner 1965*, 32, 38). Eventually, the main interpretation problems in favor of the slag-pit furnace were settled by Prof. *Bielenin* (*1975*).

Certain features of the discussed devices allow them to be treated as a special type of slag-pit furnace named Tarchalice type (*Bielenin 1983*). It belonged to the category of furnaces with a large slag-pit (internal diameter above 50 cm). Most of the slag blocks preserved in their entirety presented an exceptional regularity of a cylindrical or conical shape crowned with a characteristic 'cap'.[2] The slag-pits were usually equipped with pit canals. Most importantly, however, they all had a unique wall construction in the form of a clay lining about 10 cm thick, reinforced with vertical wooden rods (*fig. 1*).[3]

Some of the slag-pits were distinguished by huge dimensions (maximum diameter over 80 cm, preserved depth of nearly 90 cm) and the weight of the slag blocks reaching 342 kg. This means that they had two-times larger diameter and blocks of slag had almost four-times greater weight than in typical furnaces from the *Świętokrzyski* and Mazovian metallurgical centers. This allows the inclusion of the finds from Tarchalice in the recently defined group of furnaces with 'very large' slag-pit (*Madera 2008*). Features with similar parameters are found in a large area of the European *Barbaricum*, that forms a wide arch running through the territories of Norway, Sweden, Denmark, East Germany and Poland. However, in the Silesian region their highest density (they occurred on 26 excavated sites) and dimensions (internal diameter of the pits up to approx. 1.5 m, slag weight up to 850 kg) are observed. Apart from the phenomenon of a close connection between iron production and settlement and consequently its widespread especially in the late Roman period, these furnaces undoubtedly represent the technical and technological specificity of the ancient iron industry in Silesia, not only in the area occupied by the Przeworsk culture (*Madera 2008,* 195–196).

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[2] The authors have in mind here a kind of the widening occurring at the top of the slag block, usually interpreted as a result of widening of the upper part of the slag-pit. Such form is commonly found on slag blocks, but in Tarchalice on some blocks it was of extraordinary size and shape reminiscent of a 'cap' or 'hat' (*Pleiner 2000*, 260, fig. 68: 6–7, 9–12).

[3] A number of furnaces discovered in Silesia originally considered as Tarchalice type have been negatively verified and for some time the features from Tarchalice have been a unique among slag-pit devices. In 2005 traces of big size furnaces with analogous construction of slag-pit walls were located in Dębno, site 14, at a distance of about 2.5 km from the settlement in Tarchalice.

3. Reconstruction assumptions

The reconstruction of the ‘legendary’ furnaces and the smelting process carried out in them for several years remained in the sphere of unfulfilled plans for a group of enthusiasts who earlier led to the creation of the *Dymarki* Ecomuseum in Tarchalice. The obstacle in the implementation of experiments with a device of unprecedented size was too high for local conditions financial outlays. Therefore, the proposal to build and run the furnace of Tarchalice type on *Dymarki Świętokrzyskie* in Nowa Słupia was very much welcomed.[4]

In this first stage of the research it was decided to make significant simplifications in relation to archaeological data. The cylindrical form of the slag-pit was used, omitting the matter of the presence of the ‘cap’. The lining of slag-pit walls was also abandoned because of the dry and concise loess ground. However, there was no question of using the pit canal type 1 according to Prof. *Bielenin* (*1983*, 55, fig. 8: 1) classification. Considering the limited material and time possibilities, an average size of the inner diameter of the Tarchalice slag-pits was assumed for the model.

The large dimensions of the furnace suggested using in the smelting process natural draft, which caused great problems in the case of running much smaller furnaces. When choosing the shape and height of the shaft, the experimenters were guided by the construction of furnaces, which have been functioning until recently in West Africa. Already in the context of the first discoveries in Tarchalice, the attention was drawn to the Banyeri / Bandjeli type shaft furnaces from Togo area, having a regular conical shaft structure and working without bellows (*v. Luschan 1909*, 39–43). The detailed description of this and other categories of African furnaces based on autopsy and interviews with their users was recently presented by *Łapott* (*2008*). The devices with inside diameter of the shaft of 70 cm and the height of 2.5–3 m were considered as a good starting point for experiments (*Łapott 2008*, 105, fig. 12).

Ultimately, the basic dimensions of the experimental furnace were as follows: the depth of the pit – 70 cm; its internal diameter (and the lower part of the shaft) – 65 cm; height of the shaft – 2.5 m; diameter of the shaft outlet – 45 cm. The outlet of the horizontal section of the pit canal with a diameter of 12 cm was placed at a height of 15 cm above the slag-pit bottom; the pit canal inlet at ground level had a diameter of 25 cm. 8 blow holes, initially horizontal, placed on the average height of 10 cm from the ground level were used. During the first smelt their diameter was determined experimentally[5] at 8 cm and this dimension was used in all experiments (*fig. 2a* and *3a*).

The shaft was built of hand-formed ‘bricks’ from loess with straw chaff admixture. The thickness of the walls erected in this way was approx. 15 cm at the bottom of the shaft and approx. 12 cm at its outlet. The considerable height of the shaft forced the use of a construction platform, which was then used for charging the furnace. In favorable weather

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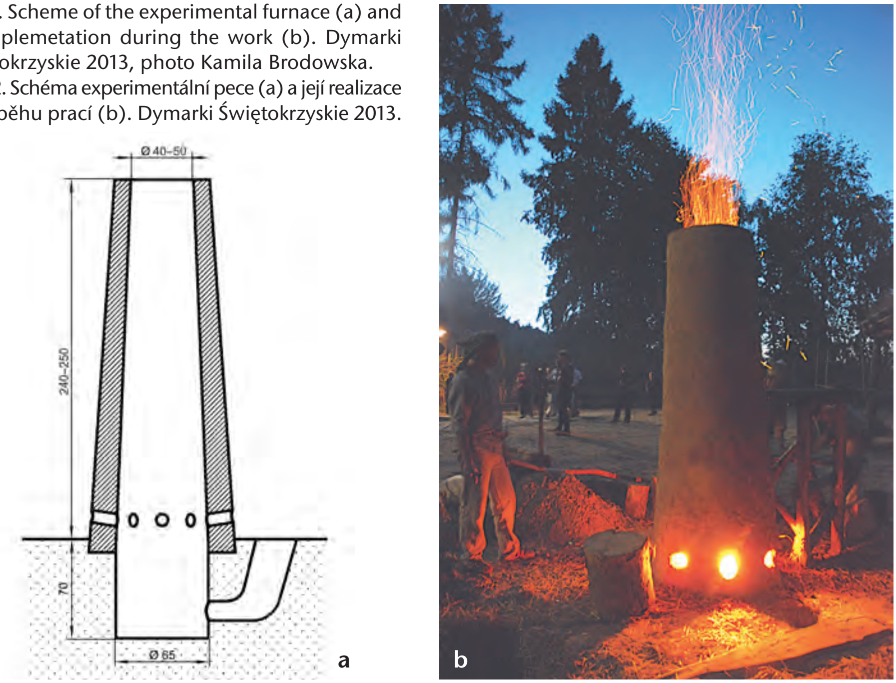
[4] The core of the team conducting experiments were: Paweł Madera, Dariusz Kik and Artur Kosmalski (District Office in Wołów, TTR *Cross*), and in the last seasons also Maciej Tomaszczyk (*Officina Ferraria*) and Maciej Fortuna (the freelance reenactor).

[5] The trial and error method was used, examining the furnace behavior (temperature) after each change of the blow holes. As a starting point a diameter of 10 cm was adopted used in Banyeri type furnaces with similar shaft parameters (*von Luschan 1909*, 40, fig. 18).

Fig. 2. Scheme of the experimental furnace (a) and its implemetation during the work (b). Dymarki Świętokrzyskie 2013, photo Kamila Brodowska.
Obr. 2. Schéma experimentální pece (a) a její realizace v průběhu prací (b). Dymarki Świętokrzyskie 2013.



conditions the construction time of the shaft with the involvement of 4–5 people, including successive drying, was 3 days. The furnace was used for single smelt and then the shaft was dismantled.

4. Characteristics of experimental smelt

The proposed experimental model was similar to the current scheme of the furnace *Świętokrzyski* type, verified by successive discoveries and experiments. However a completely different size scale and basing the furnace operation on natural draft forced the use different conditions of running the smelting process, including amount of batch materials, service principles, duration of smelting or the way of evacuation of iron. A wide knowledge concerning experimental smelts was used, as well as the experience that was gathered by experimenters working on *Dymarki Świętokrzyskie* in identical location conditions and using the same building and batch material.

The batch material was roasted hematite ore with a Fe content of approx. 59 % and a granulation of 1–4 cm and 'brown ore' with a Fe content of approx. 37 %. As fuel commercial charcoal from deciduous trees in pieces of 5–15 cm was used. The ores used differed from the potential raw material present in the area of Tarchalice, but allowed to refer the results of smelts to experiments carried out in the Świętokrzyskie Mountains (*tab. 1*).

All the experimental smelts started in evenings (*fig. 2b*). After igniting the furnace at the level of the slag-pit bottom, it was gradually loaded with charcoal to about half the

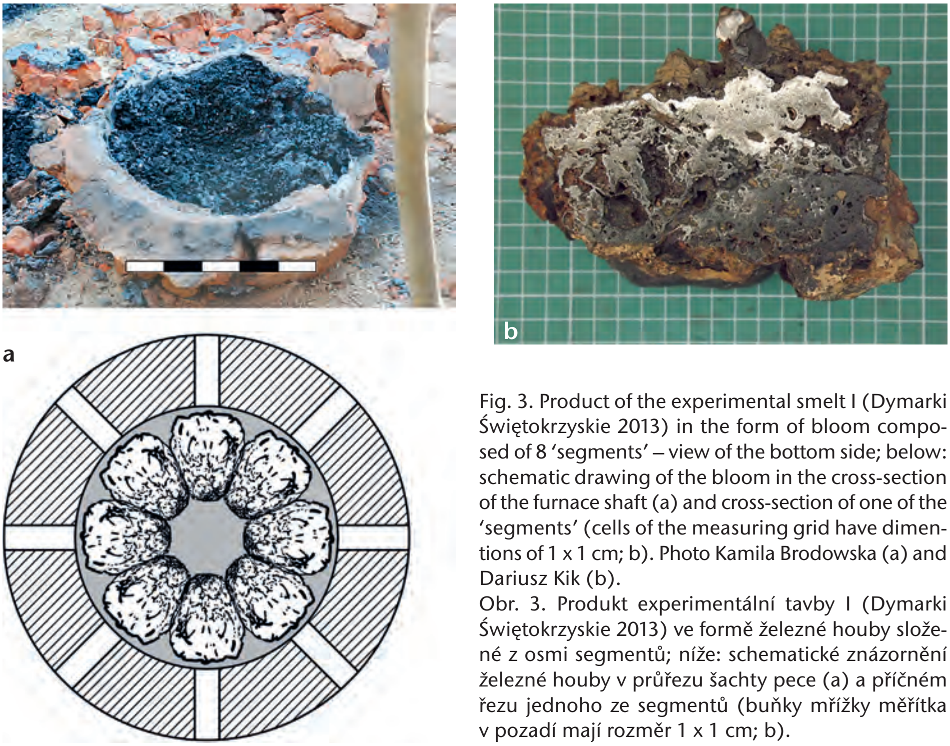


Fig. 3. Product of the experimental smelt I (Dymarki Świętokrzyskie 2013) in the form of bloom composed of 8 'segments' – view of the bottom side; below: schematic drawing of the bloom in the cross-section of the furnace shaft (a) and cross-section of one of the 'segments' (cells of the measuring grid have dimentions of 1 x 1 cm; b). Photo Kamila Brodowska (a) and Dariusz Kik (b).

Obr. 3. Produkt experimentální tavby I (Dymarki Świętokrzyskie 2013) ve formě železné houby složené z osmi segmentů; níže: schematické znázornění železné houby v průřezu šachty pece (a) a příčném řezu jednoho ze segmentů (buňky mřížky měřítka v pozadí mají rozměr 1 x 1 cm; b).

shaft height and heated up to obtain at the level of the blow holes the temperature about 1200 °C. Then the shaft was charged with equal portions of charcoal and ore in the amount of 15–20 kg. Charges were repeated at intervals of 30–130 minutes, assuming the charging level 105–110 cm above the blow holes.

Within 16–18,5 hours of smelting duration 11–14 charges were made using 200–220 kg of ore and charcoal. The furnace was opened only after 3–5 hours from the last charge. Its high temperature prevented quick demolition and removal of iron immediately after the process. Altogether, during *Dymarki Świętokrzyskie* (years 2013–2016) four experiments were carried out (smelts I–IV). The last experiment (smelt V) was made in September 2016 as part of the *ARTifacts* Archaeological Festival in Pruszków organized by the Museum of Ancient Mazovian Metallurgy (*tab. 2*).

During the first and subsequent experiments adverse phenomena appeared in the form of weakening of the chimney draft as a result of the forming bloom blocking the blow holes, 'overgrowing' the shaft with slag or changing atmospheric conditions, as well as difficulties in spontaneously draining slag into the pit. In order to improve the work of the furnace a number of modifications of its structure and way of running the smelt were made, consisting in: tilting the blow holes (up to 15°); selection of charcoal fraction also in the preheating stage; mechanical clearing of the zone of the slag flow to the pit; use additional draft from the side of pit canal; increasing the portion of the batch to 20 kg; use in the process of so-called 'cold' slag-pit; increasing the height of the shaft to more than 3 m.

Ore	Fe	SiO_2	Al_2O_3	CaO	MgO	Mn	S	P	Roasting losses
Hematite	58.72	5.87	0.39	0.3	0.32	0.54	0.11	0.017	
Hematite (roasted)	59.82	4.23	0.4	0.34	0.63	0.98	0.045	0.009	10.89
‘Brown’	32.36	20.19	13.91	1.91	2.04	1.02	0.14	0.052	
‘Brown’ (roasted)	37.46	23.39	15.97	1.91	2.36	1.02	0.13	0.048	24.78

Tab. 1. Chemical composition of ores used in the experiments based on EDXRF analysis (Twin-X analyzer Oxford Instruments) in wt%.
Tab. 1. Chemické složení rud použitých v experimentech, ED-XRF anlaýza (analyzátor Twin-X Oxford Instruments) v hm%.

In addition, the entire arsenal of current means affecting the continuity of the process was used, such as: cleaning of blow holes; scaffolding of the shaft; periodically lowering the level of charge; use of admixture of wood in portions of fuel; blowing support with 3–4 hand bellows (smelt IV) or electric blower (smelt V).

The result of the experiments were slag-iron structures with a ring-shaped or circular form bonded to the shaft walls below the blow holes. They consisted of 8 ‘segments’ associated with particular openings (*fig. 3a*). The ‘segments’ differed quite significantly with the amount of reduced iron and associated slag and other impurities (*fig. 3b*). The presence of compact metallic phases in the structures obtained in smelts I, II and V allows to define them as ‘blooms’. Their weight (including impurities) ranged from about 50 to 75 kg. Assuming reduced iron content of about 50 %, 25–37.5 kg of raw material was obtained, which gives yield of iron of its available quantity on the level 20–30 %. This value is similar to that received in small experimental furnaces using artficial draft, working in recent years on *Dymarki Świętokrzyskie*.

Generally, the amount of slag produced in the proces because of use quite rich ore was relatively small, and only a part of it flowed into the pit. Even after use an admixture of poorer ore (smelts III, IV) it was not sufficient to fill the slag-pit and create such an expected regular in the shape and heavy block. Also the presence of solid structure slag, so characteristic of upper parts of prehistoric blocks, was insignificant and local. The center of the pit was dominated by porous slag with charcoal imprints. In the lower part droplets and lumps of slag in layer of charcoal were observed. In one of the experiments an exceptionally strong inflow of solid slag occurred in the sector where the outlet of the pit canal

Smelt	Shaft height	Preheating		Charging			Time of smelt (h)
		Charcoal	Time	Ore	Charcoal	Intervals	
I (2013)	2.4 m	1/2 of shaft	4 h	H/B = 5:1; 14x15 kg	14x15 kg	30–85 min	18
II (2014)	2.5 m	1/2 of shaft	5.5 h	H/B =10:1; 4x15 kg, 7x20 kg	4x15 kg, 7x20 kg	50–100 min	16
III (2015)	2.45 m	1/2 of shaft	3.5 h	H/B = 1:1; 4x15 kg, 8x20 kg	4x15 kg, 8x20 kg	35–90 min	18
IV (2016)	2.5 m	1/2 of shaft	2.5 h	H/B = 1:1; 4x15 kg, 7x20 kg	4x15 kg, 7x20 kg	40–120 min	18.5
V (2016)	3.05 m	1/2 of shaft	3 h	H only; 11x20 kg	11x20 kg	60–130 min	18

Tab. 2. Parameters of the experimental smelts I–V carried out in 2013–2016 (the abbreviation ‘H/B’ means the Hematite/Bog ore mixing ratio).
Tab. 2. Parametry experimentálních taveb I–V realizovaných v letech 2013–2016 (zkratka H/B znamená směsný poměr hematitu a bahenní rudy).

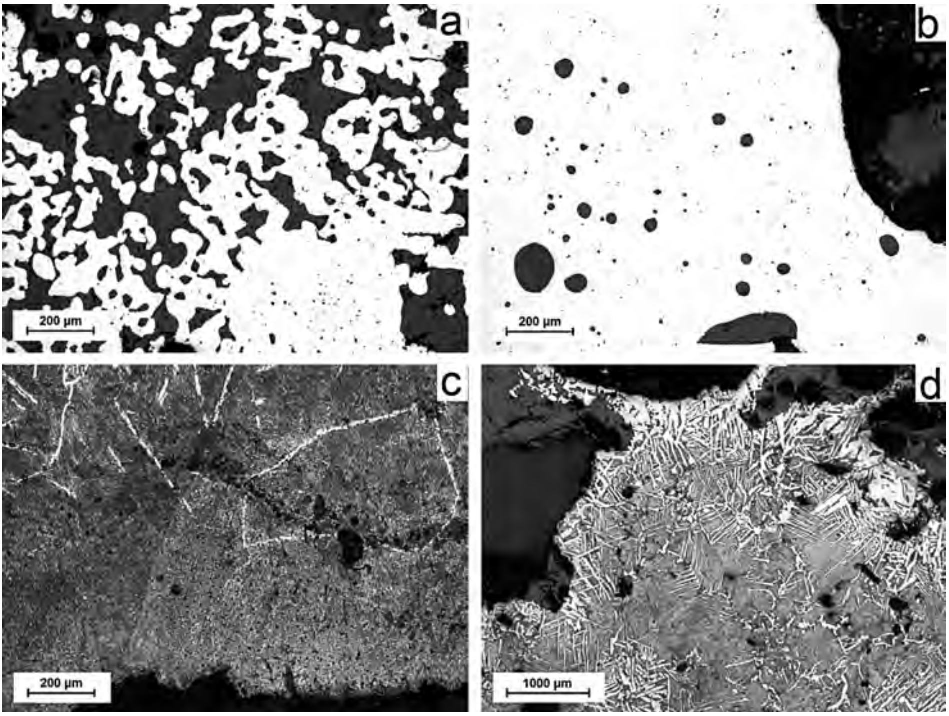


Fig. 4. Microstructure of the bloom from experimental smelt I (Dymarki Świętokrzyskie 2013). Sample before (a, b) and after (c, d) etching with 3% Nital.
Obr. 4. Mikrostruktura železné houby z experimentální tavby I (Dymarki Świętokrzyskie 2013). Vzorek před naleptáním 3% nitalem (a, b) a po něm (c, d).

was located. It may confirm its important role in the mechanism of draining this material, as long as the conditions of appropriate 'ventilation' of the slag-pit are met.

5. Bloom and slag characteristics

The microstructure of the bloom obtained in smelt I indicates the formation of iron in the form of filigree and solid zones (*fig. 4*). Solid iron was created within filigree zones probably according to the mechanisms known from the smelts carried out in furnaces *świętokrzyski* type (*Suliga – Karwan 2014*; *Przychodni – Suliga 2016*). The pieces of charcoal, on which the grids of reduced metal were emerged, also played a role in the formation of iron. The extensive solid iron zones were characterized by high purity. Only minor oxide inclusions and few slaggings were observed. However, the metallic phase appearing in the upper part of the bloom was heavily carburized to the eutectoid composition (0.77 % C) on the surface (*fig. 4c*). The observed gradient of carbon concentration indicated the diffusive nature of this carburization (*fig. 4c–d*). This was caused by too long leaving the produced bloom in the heated furnace. In the microscopically examined slag-iron structure

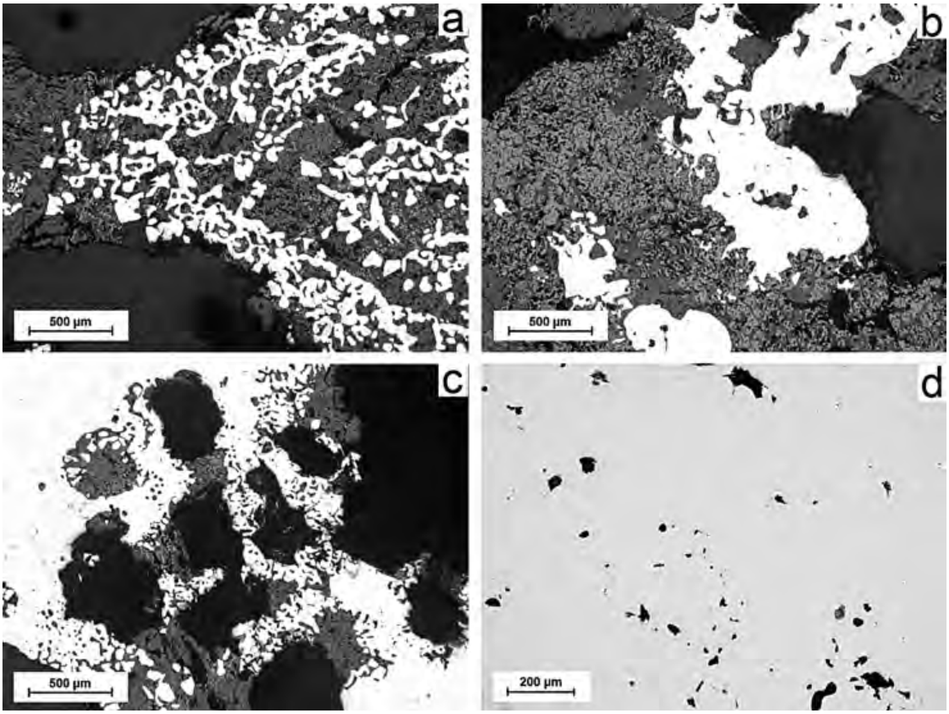


Fig. 5. Microstructure of the pseudo-bloom from the experimental smelt III (Dymarki Świętokrzyskie 2015).
Obr. 5. Mikrostruktura pseudo-železné houby z experimentální tavby III (Dymarki Świętokrzyskie 2015).

(pseudo-bloom) obtained in smelt III, iron was also formed in the form of filigree and solid zones, but these were already relatively small (*fig. 5*). Surrounded with slag and oxide phases, they were not exposed to the carburizing atmosphere in the furnace and retained ferritic structure.

The microstructures of slag samples from smelt III are typical for acid slags from iron production processes (*fig. 6*). Gangue of ores, iron oxides and ash components formed alloys from the FeO-SiO_2-Al_2O_3-K_2O system. On the background of gray fayalite Fe_2SiO_4 bright dendrites or grains of wüstite FeO can be seen. In intergranular spaces of fayalite, hercynite is probably located.[6] The presence of its may result from the reaction between slag and the material of the shaft, which was heavy melted in the area of the blow holes. This material contained clay, which could be a source of Al_2O_3. At the same time, the component in question does not show the features of the intergranular glass phase, typical for nearly all bloomery slags, because it did not shine in the 'dark field of view'.

The fine-crystalline structure of clots of slag indicates their rapid crystallisation in the potentially small volume of the slag phase, and the structural composition testifies to the higher FeO content than in solid slag. The bright bands in the structure of both clots of

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[6] It was identified using the diffraction method on the EDS microanalyzer and confirmed by computer simulation in the FactSage program.

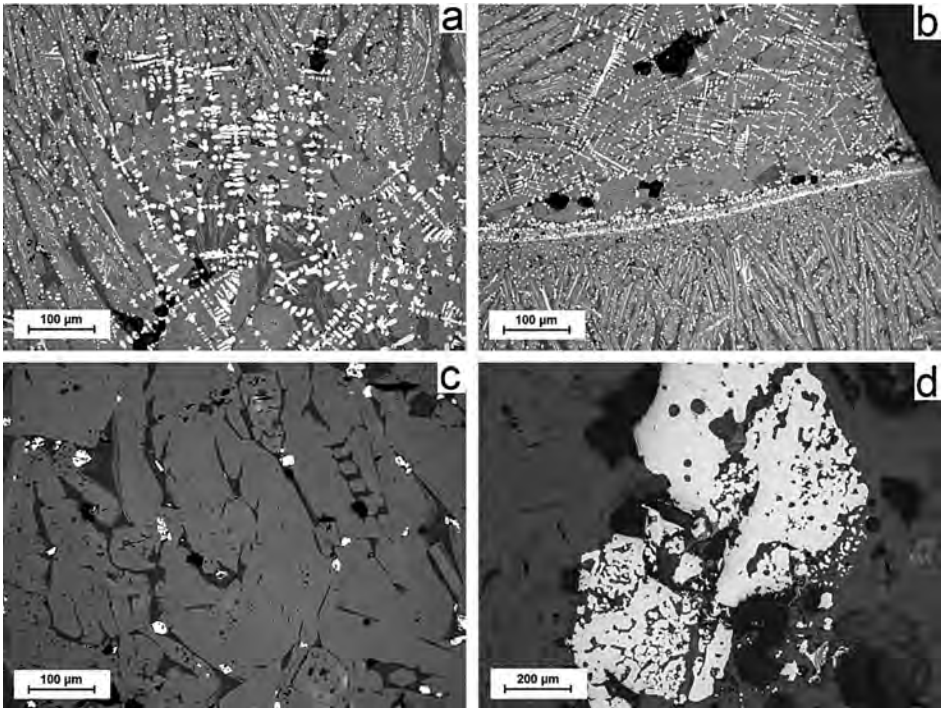

Fig. 6. Microstructure of clots of slag (a, b) and solid slag (c, d) from experimental smelt III (Dymarki Świętokrzyskie 2015).
Obr. 6. Mikrostruktura strusky s vysráženinami (a, b) a strusky monolitické (c, d) z experimentální tavby III (Dymarki Świętokrzyskie 2015).

slag and solid slag are boundaries of consecutive portions of slag inflowing over each other (*fig. 6b*). In the absence of the possibility of melting together (low temperature, low thermal capacity), these layers are separated by wüstite zones, resulting from the surface oxidation of fayalite. Particular layers of clots of slag have a different volume, they crystallize at different speeds and consequently differ in the size of crystallites. Solid slag has a coarse-grained structure indicating the slow crystallization of its large portions. The microstructure also marks the bright boundaries of the inflow layers. Generally, it is characterized by a lower FeO content than in clots of slag, it comes from a different phase of iron smelting, and also contains phases associated with K_2O (leucite $K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$; $K_2O{\cdot}4SiO_4$; *fig. 6c*). Locally, separations of metallic iron with identical morphology as in the bloom were observed (*fig. 6d*).

6. Conclusion

The first stage of the presented experimental research, aiming to better understand metallurgical aspects of the Tarchalice type furnace operation, allow the following conclusions to be made.

Since the only evidence for the functioning of this kind devices were slag-pits filled with slag blocks, archaeological and ethnographic data, as well as scientific interpretations and reconstruction results from other metallurgical centers, mainly from the Świętokrzyskie Mountains, appeared to be useful for the presented research.

Conducted experimental smelts yielded metallic iron separated from slag to a greater or lesser extent. In the process natural draft was used, aided by bellows or a blower in extreme cases of 'freezing' of the furnace. Regarding the genuine slag blocks, the experimental smelts did not meet expectations. No regular and heavy block of slag with 'cap' and 'free solidification surface' was obtained. The phase and structural composition of slags obtained was identical to archaeological and experimental slags from the Świętokrzyskie Mountains (there is the lack of metallographic analysis of slags from the Tarchalice site). In the $FeO\text{-}SiO_2$ system the resulting slags were alloys on the SiO_2 side and had traces of a large share in their formation of ash components from charcoal ($K_2O\text{-}Al_2O_3\text{-}SiO_2$ alloys).

The iron was obtained in the form of slag-iron structures composed of 'segments' associated with blow holes. In the case of using hematite with possibly a small admixture of poorer 'brown ore' they had features of iron bloom. This kind of smelting product can not be referred to non-existent archaeological evidence, but their internal structures are analogous to the above quoted experimental blooms from the Świętokrzyskie Mountains. One can see there stages of forming of solid metal from filigree and grid forms to dense metallic areas contaminated with slaggings and non-metallic inclusions. Iron originally had probably a ferritic structure, but remaining necessarily for a long time in the cooling furnace was carburized into the pearlitic composition on the surface.

An unquestionable success of the experiments was the demonstration that in the determined construction parameters of the furnace and in favorable weather conditions (especially in the presence of constant blow of wind) it was possible to conduct the bloomery process only thanks to natural draft (smelts I–III), which according to the available source material was the basic air supply system to bloomeries in Polish lands in antiquity (*Orzechowski 2013*, 130). This problem regarding the Tarchalice type furnaces is, of course, still open, but even if we assume that artificial draft was in use at that time, it should be taken into consideration, that the lack of the necessity of blowing e.g. 4 bellows for over a dozen hours could compensate for the effort put into construction of a higher shaft.

In turn, the main drawback of the discussed research was the composition of the batch material. Rich hematite ore favored the yield of iron and enabled smelting results to be compared to other experiments, but it differed from the potential raw material for production site in Tarchalice. The sign of this was among others a small degree of use of the slag-pit capacity in comparison with the original furnaces. In correct experiments one should work on good quality local bog ore, which unfortunately has not been found yet.

Further research should concern optimization of a fraction of batch material and a method of its loading into the furnace, determination of a role of a filling the slag-pit and verification of views on the importance of the pit canal. However, these tests can not be carried out on such large furnace units due to the high costs and inertia of the devices. The building material of the furnace shafts also requires experimental testing. The lack of evidence of a relatively large amount of demolition material in the form of highly burnt or vitrified fragments of shafts on ironmaking sites with 'big' furnaces should be explained experimentally by specialists in ceramics. Similar research should relate to a reaction between liquid slag and the shaft casing or material forming the slag-pit walls, which could solve the problem of creating of the slag ‘caps’and other widenings at the top of slag blocks.

Admittedly the results of experiments should be considered correct in terms of the quality description of the furnace and the process itself (such is the character of observations, associations and general thoughts that emerged during tests), however further work must be directed towards the quantitative description, creation of a thermal and thermodynamic model as well as material balance, what requires the instrumentation of experimental furnace and taking measurements of temperature, air consumption and exhaust gas composition.

We are grateful to all who supported our actions in terms of organization, especially to authorities of the ŚSDP: Andrzej Przychodni, Szymon Orzechowski and Adrian Wrona, as well as with their hard physical work and … in mental way. Special note of thanks to Jens Jørgen Olesen for his precious tips and active help, without which we would not have achieved the above results.

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PAWEŁ MADERA, Museum of Archaeology Wrocław, ul. Cieszyńskiego 9, PL-50-136 Wrocław
pmadera@mmw.pl
DARIUSZ KIK, Silesia Castings, ul. Wolności 318, PL-41-800 Zabrze; dariusz.kik@silesiacastings.pl
IRENEUSZ SULIGA, AGH University of Science and Technology, Al. Mickiewicza 30, PL-30-059 Kraków
ireneusz.suliga@gmail.com

Modelling of bloomery processes in a medieval Russian furnace

Modelování procesu přímé výroby železa v ruské středověké peci

Vladimir I. Zavyalov

A fully preserved 14th-century AD bloomery furnace was excavated in 2014 on the settlement of Kolesovka-4 (Russia, Tula district). This extraordinary find has been taken as a model for experimental work. The iron ore used came from the Loknya River, a metallurgical conglomerate used came from the archaeological site of Staraya Ryazan. The most successful result was achieved by using the conglomerate from Staraya Ryazan – three pieces of blooms were made, weighing about 1 kg, and consisting of soft iron and a large number of very coarse slag inclusions. These show a similar trace-element composition as the medieval bloom coming from the same site. Experiments conducted have shown that the bloomery furnace uncovered at the Kolesovka-4 settlement is a rational pyrotechnological construction, allowing for a large number of smelting cycles.

bloomery process – modelling – furnace – metallography

V roce 2014 byla na sídlišti Kolesovka-4 (Rusko, okres Tula) odkryta plně zachovaná železářská pec ze 14. stol. n. l. Tento mimořádný nález posloužil jako model pro experimentální práce. Použitá železná ruda pochází z řeky Loknja, použitý metalurgický konglomerát pak z archeologické lokality Stará Rjazaň. Nejlepšího výsledku bylo dosaženo použitím konglomerátu ze Staré Rjazani – získány byly tři kusy železné houby vážící asi 1 kg a sestávající z měkkého železa a velkého množství velmi hrubých struskových vměstků. Ty vykazují podobné složení stopových prvků jako železná houba pocházející z té samé lokality. Provedené pokusy ukázaly, že redukční pec odkrytá na sídlišti Kolesovka-4 je racionální pyrotechnologické zařízení umožňující řadu výrobních cyklů.

přímá výroba železa – modelování – pec – metalografie

One of the most challenging issues when modelling a bloomery process is defining the type and size of a bloomery furnace. Archaeological remains of pyrotechnological structures, in the vast majority of cases, survive only fragmentarily, and information on numerous important features, such as construction of a furnace shaft and its height, position and number of tuyeres etc., are lacking. From this perspective an outstanding discovery was made by archaeologists of the museum ‘Kulikovo Pole’, who uncovered a fully preserved bloomery furnace at the 12th–14th century AD settlement of Kolesovka-4 (Tula region, Russia).

The furnace is a self-supporting, rounded construction with a vertical 75 cm high shaft (*fig. 1*).[1] Thickness of wall: 12 cm; diameter below: 46 cm; diameter at the top: 16 cm. A hole situated in its lower part was closed during smelting by a panel with an opening for the tuyere (through which air was blown into the furnace); when the smelting was finished, the hole was opened again to pull out the bloom. In front of the tuyere panel there was a small clay platform edged with short boards on the sides. The furnace was built on the

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[1] I thank dr. Andrey Naumov for permition to use unpublished materials.

Fig. 1. The medieval furnace from Kolesovka-4 archaeological site (Tula region). Photo by A. Naumov.
Obr. 1. Středověká pec z archeologické lokality Kolesovka-4 (oblast Tula).

clay base, which was a little bit wider than the lower part of the furnace. The base of the furnace on the perimeter had a layer of limestone rock particles. The outer surface of the furnace was covered with clay.

The replica of this furnace was built in Ryazan[2] to conduct experiments on modelling of medieval metallurgic processes (*fig. 2*). The construction of the bloomery (excluding preparation work) took about one hour. After drying, which took a week, the furnace was fired with dry pine firewood.

In total, eight smelting experiments were performed using the furnace constructed in 2015–2016. It should be mentioned that the construction withstood well the wintertime. After a long (about ten months) pause only an additional daub of the outer and inner surfaces was needed.

Tuyeres made of local clay (with addition of sand or charcoal) were used for all the experiments conducted. Length of the tuyeres was 20–25 cm; inner diameter was 2–2.5 cm. The tuyeres were put into the furnace at an angle of about 30 degrees. A single bellow, provided continuous air supply, (*fig. 3*) was used for air blasting (speed of air flow was 260 l/min).

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[2] The furnace was built and experiments were carried out with the help of Mikhail Ratkin (Ltd Arta, Ryazan).

Fig. 2. The experimental model of the medieval Russian furnace. Photos in *figs. 2–4* by V. Zavyalov.
Obr. 2. Experimentální model ruské středověké pece.

The process started with 1 to 1.5 hour pre-heating of the furnace using dry pine firewood. The temperature on the throat of the shaft reached up to 550–600 °C. Afterwards, the furnace was charged up with charcoal and a powerful draft was provided.

Metallurgical raw materials used for the experiments were collected on the archaeological sites. The most successful result was obtained using a slag-iron conglomerate from Staraya Ryazan (Старая Рязань, archaeological site, town destroyed by Mongols in 1237). However, the success is connected mainly with the fact that the correct temperature regime (achieved by powerful draft before charging first iron ore, moderate draft in the consequent process of ore charging and the continuation of the powerful draft before the end of the process) was successfully maintained during the experiment.

Before the smelting, ore was roasted on a bonfire. An ore layer, which was cross-covered by poles, was lain on the row of wooden poles. The next ore layer was spread and then from four to five more layers. The ore roasting lasted 1–1.5 hours (until the complete burning out of a wood). Finally the ore lost 7–10 % of its initial weight.

The proportion of ore to charcoal in a charge was from 1 : 1 to 1.5 : 1 (not counting the charcoal charged into the furnace before the smelting process). The proportion of the iron conglomerate to charcoal was the same. The charge was added into the furnace in portions of 2–3 kg (first – the ore, then the charcoal) after the subsidence of the previous portion. Time intervals between charging were from 5 to 15 minutes. It is worthy to note that in successful experiments these intervals were minimal. Therefore it took 1.5 hours to charge 10 kg of ore and the process itself (from charging the first portion) took 2–2.5 hours.

As mentioned above, the most successful result was achieved by charging the iron conglomerate from Staraya Ryazan. The conglomerate is a mechanical mixture of a not completely slagging gangue, iron oxide (FeO), magnetite (Fe_3O_4) and some small fragments

Fig. 3. The experimental furnace in operation.
Obr. 3. Experimentální pec za provozu.

of reduced iron. During the experiment 7 kg of the conglomerate was used and three pieces of bloomery iron weighing 1 kg (altogether) were made. Metallographic examination of one of these pieces revealed a structure of ferrite with disproportionate grain size (2–5 GOST[3]) and with a number of large slag inclusions. Microhardness of the ferrite is 170–181 HV0.1.

A concentration of the conglomerate was found in the surface layer on the plain between Northern Promontory and Northern settlement in Staraya Ryazan. While studying the conglomerate, a bloom, which had a shape of irregular hemisphere, stretched a bit in a plan was noticed. The size of the bloom is 13 × 10 × 4 cm and its weight is 0.83 kg. The bloom is covered with a slaggy layer, and the iron is concentrated in its lower part. There are a lot of pores and slag on the surface of the metal, the structure of which contains tempered martensite as determined by metallographic examination. Microhardness of the metal is 383–420 HV0.1. In order to determine the carbon content, the fragment was annealed by heating at 800 °C and by consequent slow cooling (the fragment was placed next to a hearth) to ambient temperature. Metallography of the annealed sample revealed ferritic and ferritic-pearlitic structure. Carbon content reaches up to 0.7 % in places. Microhardness of the ferrite is 110–128 HV0.1, and of the ferrite-pearlite 193–221 HV0.1.

A bloom discovered in Staraya Ryazan offered an opportunity to compare the element composition of the experimental samples with the archaeological material. Eighteen analyses have been carried out in total: one – ore from Istye, three – experimental bloomery iron, six – bloom from Staraya Ryazan, six – experimental conglomerate and two – archaeological conglomerate from Staraya Ryazan.

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[3] GOST 5639–82 (Russian state standard for grain size determination in steels and alloys).

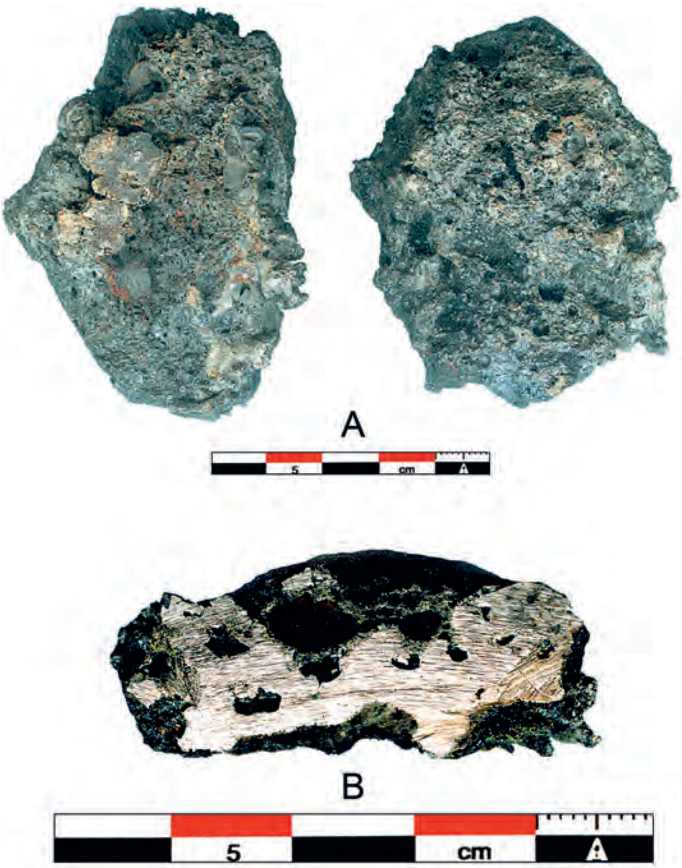

Fig. 4. A – bloomery iron made during the experiment; B – cross section of a sample from the bloom.
Obr. 4. A – železo vyrobené v rámci daného experimentu; B – průřez vzorku železné houby.

The archaeological slag-iron conglomerate from Staraya Ryazan differed in quite high concentration of iron oxide (53.5–60.8 %) with silica (8.1–12.1 %) and alumina (0.1–1.1 %) concentration. The conglomerate yielded within the experiment has 63.7–65.6 % of iron oxide, 34.1–38.2 % of silica and 11.2–15.5 % of alumina. Hence, in the experimental smelting more iron was needed for slagging the gangue in comparison with the medieval process. However, more gangue occurred in the experimental conglomerate.

An important factor of a successful bloomery process is the viscosity index of slag which shows the complete burrow removal from the charge (first of all, silica and alumina). According to Bachman's data, the viscosity index varies from 0.5 to 1.0 (*Bachman 1982*). The computation of the viscosity index for the mentioned samples showed that only one sample (13080) received in the experiment has this index close to the range given. In the metallographic analysis an even dark grey structure (fayalite) was discovered in the sample 13080 with a large amount of pores and separate round particles of white colour. So to say exactly this sample is actually a piece of slag. Still the rest of the fragments (experimental as well as archaeological) which showed the viscosity index significantly higher than 1 and did not have flow characteristics – in other words, they were conglomerates.

Sample	Ag	As	Mo	Cu	Ni	Fe	Mn	Al	S	P	Si	Mg
Ore from Istya				–		**46.4**	0.9	0.8	0.1	0.2	3.4	
Conglomerate	0.4	–	–	–	–	**38.5**	0.2	–	–	–	–	–
Conglomerate	–	–	–	–	–	**55.0**	0.2	7.4	0.2	0.1	18.1	–
Slag	–	–	–	–	–	**49.5**	0.2	5.9	0.2	–	15.9	–
Slag	–	–	–	–	–	**51.0**	0.2	8.2	0.2	–	17.8	2.2
Slag	–	–	–	–	–	**3.9**	0.1	17.8	–	–	39.8	–
Slag	–	–	–	–	–	**3.4**	–	15.6	–	–	48.7	0.7
Bloom exp.	–	–	0.1	–	–	**99.8**	–	–	–	–	–	–
Bloom exp.	–	0.1	0.1	0.1	0.3	**99.3**	–	–	–	–	–	–
Bloom exp.	–	–	–	0.2	0.9	**97.4**	0.7	–	–	–	–	–
Bloom St.Ryazan	–	–	–	–	–	**99.9**	0.1	–	–	–	–	–
Bloom St.Ryazan	–	–	–	0.1	0.1	**99.7**	–	–	0.1	–	–	–
Bloom St.Ryazan	–	–	–	0.1	0.3	**98.2**	0.5	–	–	–	–	–
Bloom St.Ryazan	–	–	–	0.1	0.3	**98.2**	0.4	–	–	–	–	–
Bloom St.Ryazan2	–	–	–	–	–	**100.0**	–	–	–	–	–	–
Bloom St.Ryazan2	–	–	–	0.1	0.2	**97.6**	0.1	1.0	0.4	0.2	–	–
Slag-aug2016	–	–	–	–	–	**55.7**	0.1	3.3	0.1	0.3	17.4	–
Slag-aug2016	–	–	–	–	–	**48.9**	0.1	1.6	0.2	0.2	16.8	–

Table 1. The element composition of materials analysed (in wt%; XRF spectroscopy).
Tabulka 1. Prvkové složení analyzovaných materiálů (v hm%, XRF spektroskopie).

It is known that the result of the bloomery process was chemically ‘pure’ iron and the elements discovered during the experiment (excluding carbon, phosphorus and arsenic which form a solid solution with iron) enter the slag (the amount of which can reach 2–3 %) saturating bloomery iron (*Kolchin 1953*; *Zavyalov – Estrova 1987*). Considering the element composition of the metal from Staraya Ryazan and that of the experimental blooms, it should be mentioned that all elements detected were trace impurities which did not influence the metal characteristics. At the same time, similar concentration ratios of elements were observed in the experimental and archaeological blooms: in both cases the peaks are accounted for nickel and manganese, while contents of copper, arsenic, lead and titanium were close to zero (see *tab. 1*). The element composition of iron products from Staraya Ryazan and from the settlement of Istye-2 is similar.[4] In comparison, the element composition of iron products from Sarmatian sites was considered. As it can be seen from the chart in Sarmatian items the trace impurities of copper are significantly prevailing while the content of other elements is close to zero.

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[4] The site of Istye-2 was a specialized metallurgical settlement providing Staraya Ryazan with iron (*Bulankin – Zavyalov – Ivanov 2012*).

The results of the experimental and analytical researches allow the following conclusions to be made:

1. The bloomery furnace uncovered at the settlement of Kolesovka-4 is a rational pyrotechnological construction allowing for a large number of smelting cycles.

2. Experimental works on extracting iron from slag-iron conglomerate showed that the conglomerate could be used by medieval bloomery smelters instead of iron ore. This conclusion proves the suggestion of A. Espelund on processing of production residuals (*Espelund 2005*).

3. The bloom received from the medieval slag-iron conglomerate had the content of trace impurities similar to the archaeological bloomery iron found at the same site.

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VLADIMIR I. ZAVYALOV, Institute of Archaeology RAS, ul. Dm. Ulyanova 19, 117036 Moscow, Russia
v_zavyalov@list.ru

The manufacturing technology of a pattern-welded knife from Kobilić (Republic of Croatia)

Technologie výroby damaskovaného nože z Kobilić (Chorvatsko)

Ádám Thiele

A pattern-welded knife dated to the 13th century was found during an archaeological excavation conducted on the site of Kobilić 1 in 2010. Nowadays, pattern-welded knives are very popular due to their decorative appearance and supposedly excellent mechanical properties. This paper introduces some new experimental results gained during the manufacturing of a copy of the medieval pattern-welded knife using historical techniques. During this experimental work some new practical observations were taken in general about smelting and processing bloomery iron and concerning the decorative effect of phosphoric-iron used in pattern-welding.

experimental archaeology – pattern-welding – phosphoric-iron – knife – Middle Ages

Damaskovaný nůž ze 13. století byl nalezen při archeologickém výzkumu lokality Kobilić 1 roku 2010. V současné době jsou damaskované nože velmi oblíbené pro svůj dekorativní vzhled a údajně vynikající mechanické vlastnosti. Tento článek představuje některé nové experimentální výsledky získané při výrobě kopie daného středověkého nože s použitím autentických technologií. Během experimentálních prací byly vypozorovány nové praktické poznatky ohledně výroby a zpracovávání svářkového železa i ohledně zdobného účinku fosforového železa používaného v damaskových kompozitech.

experimentální archeologie – svářkový damask – fosforové železo – nůž – středověk

1. Introduction

Nowadays pattern-welded (referred to hereafter as PW) knives and also other PW objects (axes, swords, etc.) are very popular due to their decorative appearance and supposedly excellent mechanical properties; several companies are making and trading PW items to serve the needs of customers (although PW is a rather misunderstood term among enthusiasts, cf. the terminological mix-up of ‘pattern-welded’, ‘Damascus steel’ or ‘Wootz’). Although scientists are investigating PW artefacts and several well-trained craftsmen are forging reconstructions of medieval PW artefacts (usually even using bloomery iron as well), some details about the historical manufacturing technology and the archaeometallurgical background of PW objects remained unrevealed. This paper introduces some new experimental results gained during the manufacturing of a copy of a medieval PW knife applying historical techniques.

In PW a composite material was produced by the forge-welding of alternating layers of bloomery iron alloys. PW blades show decorative surface patterns after being correctly treated, i.e. fine ground and etched. The visibility and contrast of PW is significantly higher in an etched state, therefore it is generally accepted that PW iron objects were etched in the plast (*Pleiner 1993*; *Tylecote – Gilmour 1986*; *Buchwald 2005*; *Hošek – Bárta – Šmerda 2017*).

As for iron, three basic bloomery iron alloys were known and used by the medieval blacksmiths; 1) iron (sometimes also referred as ‘plain iron’), non-quench-hardenable iron-carbon alloy containing less than 0.3 wt% of carbon, 2) steel, quench hardenable iron-carbon alloy containing more than 0.3 wt% of carbon and 3) phosphoric-iron (referred to hereafter as P-iron), non-quench-hardenable iron-phosphorous alloy containing more than 0.1 wt% of phosphorus (*Vega et al. 2003*). In the historical technique of PW, iron and P-iron or steel and P-iron were forge-welded together in 5–15 alternating layers and after forge-welding this layered bar was twisted in most cases. Thereafter, these bars were as rule forge-welded between the cutting edge and the back of the knife blades, and two or more bars as the core of sword blades or, in the form of surface panels, onto their core, etc. Ostentatious knife blades of simpler construction did not contain twisted composites, i.e. PW bars, but only strips of P-iron, which could be straight or serrated/wavy-shaped at the lower edge (*Boháčová – Hošek 2009*, 375).

The first objects displaying evidently deliberate PW are Roman swords dated to the second half of the 2nd century AD (e.g. *Gilmour 2007*; *Hošek – Beran – Komoróczy 2011*). PW swords reached the peak of their popularity around the 7th century (*Kucypera in press*), and then in the 8th–9th century, PW turned into the form of iron inlays forged into the surface of the blades (*Moilanen 2009*; *Williams 2012*, 62; *Hošek – Košta – Bárta 2012*). Finally PW disappeared from sword-making around the turn of the 11th century (*Kucypera in press*). As for knives, PW, striped and serrated or wavy-welded knife blades were manufactured between the 10th–14th centuries (*Boháčová – Hošek 2009*, 375; *Ottaway – Rogers 2002*; *Hošek – Zavyalov 2014*; *Pleiner 1982*, 275). PW and serrate-welded saxes were the predecessors of these knives (*Westphal 1984*), while in the 14th century PW knives were definitely substituted by blades decorated with non-ferrous inlays, as their fabrication was easier and faster. Besides swords and knives, a number of PW scramasaxes and spear-heads are known (*Hošek – Šilhová 2006*; *Pleiner 1993*, 214–222; *Anteins 1973*).

All PW blades achieve their pleasing appearance due to the use of P-iron containing as a rule 0.4 to 1.4 wt% of phosphorus (*Thiele – Hošek 2015a*). The crucial role of P-iron in PW blades was evidenced (*Tylecote – Gilmour 1986*; 251–252; *Buchwald 2005*, 283; *Hoyland – Gilmour 2006*, 77–79) but its reducing effect on their mechanical properties was also shown (*Thiele et al. 2015*). Although iron with increased amount of phosphorus has higher strength (phosphorus has the strongest solid solution hardening effect on ferrite among substitutional solid-solution strengtheners), phosphorus is an avoided element in modern steel industry for its detrimental effects (*Stead 1915*), which include various forms of embrittlement, decreasing ductility, dynamic and static toughness. It is for this reason that its content in modern steels is controlled to <0.04 wt% (*Boyer – Gall 1990*, 144). Characteristic values of toughness and ductility for typical P-iron used in historical PW are very low (e.g. impact energy, percentage elongation after fracture etc., cf. more details in *Thiele – Hošek 2015b*). Therefore, in historical blades, neither PW nor individual P-iron strips improved their mechanical properties, although the limited amount of P-iron in the blades did not cause the significant decline of mechanical properties. So P-iron and PW were used solely for aesthetic purposes. An advantageous property of P-iron is highlighted during etching applied for revealing the pattern of PW blades; P-iron is more resistant to solutions and vapours of various acids than non-P-iron and steel (*Thiele et al. 2014*), so it preserves its silver-like lustre and provides a contrastive pattern.

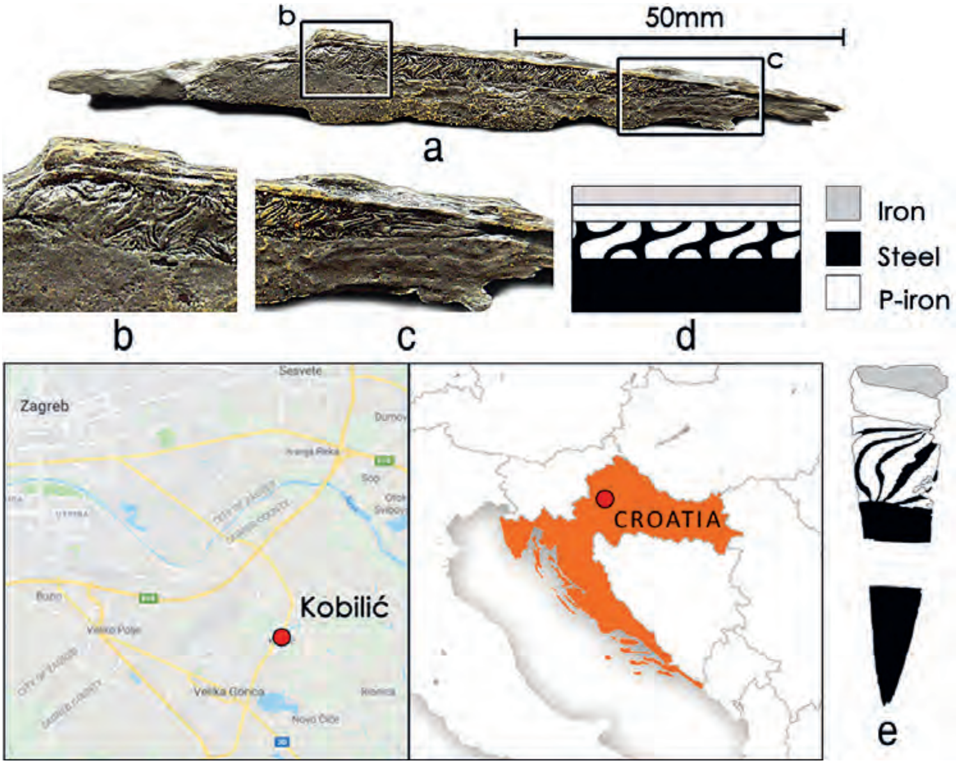

Fig. 1. The PN_52 PW knife and its construction: a) photo of the knife; b) and c) macro photos of the pattern-welded core; d) schematic drawing of the lateral construction of the knife showing the ferrous alloys used; e) schematic drawing of the cross section of the knife on the basis of the metallographic examination [23]. Photos and drawings in figs. 1–4 by Á. Thiele.
Obr. 1. Damaskovaný nůž PN_52 a jeho konstrukce: a) foto nože; b) a c) makrosnímky damaskového jádra; d) schematické znázornění boční konstrukce nože s vyznačením použitých slitin železa; e) schematický nákres průřezu nože na základě metalografické analýzy [23].

2. Materials and methods – the manufacturing of a copy of the PN_52 knife

2.1. Archaeological background and the construction of the PN_52 knife

The PN_52 whittle tang knife (*fig. 1: a*), which is the first PW knife known from Croatia, was found during an archaeological excavation conducted on the site of Kobilić 1 in 2010. This site is situated on the western edge of the present-day village of Kobilić. The knife is dated to the 13th century and was found in a presumable waste pit located farther from the majority of the settlement features (*Antonić – Rácz in press*). Taking into consideration that this knife is the only PW one known from the territory of Croatia to date, it is more likely that it was imported than locally produced (cf. details in *Thiele et al. 2017*).

The total length of the knife was 126 mm from which the blade was 85 mm with a max. width of 13 mm and max. thickness of 4 mm tapering to 2 mm. The overall construction

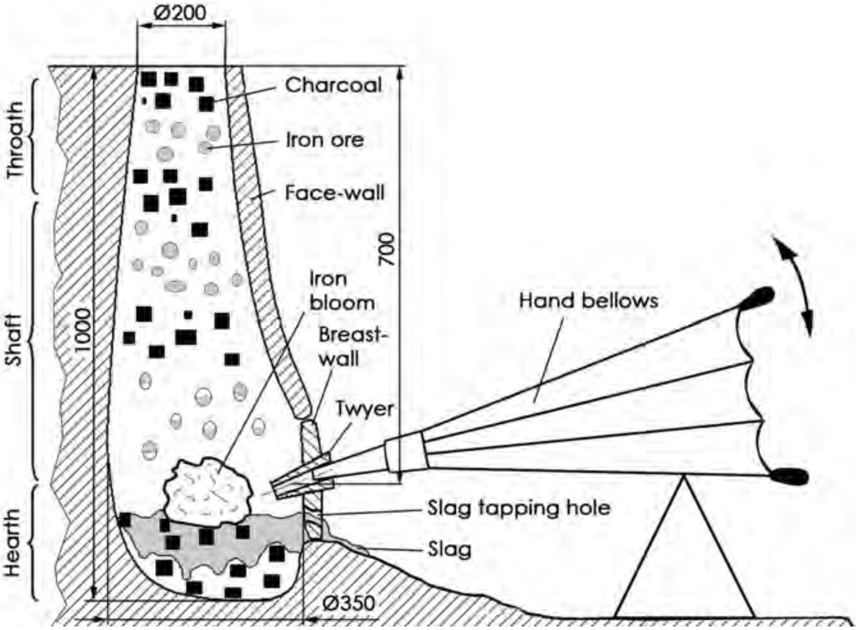

Fig. 2. The construction and the dimensions of the experimental furnace used for iron smelting.
Obr. 2. Konstrukce a rozměry experimentální pece použité pro tavby železa.

of the knife is fairly typical of such 13th century PW ones. Only the cutting edge was hardened which had a tempered martensitic microstructure whose carbon content was estimated at 0.5–0.6 wt%. The hardness of the tip of the cutting edge was ca. 580 HV0.2. The PW core with an 'X' pattern appeared between the cutting edge and the back of the blade. The back was mostly corroded, but the lateral surface examination of the blade suggested that a simple decorative P-iron strip was forge-welded onto the patterned core (*fig. 1: b*), which ended before reaching the pointed part of the blade as well as the PW core (*fig. 1: c*). 12 alternating layers of steel and P-iron could be distinguished in the PW core in which the steel had a C-content of ca. 0.3 wt%, while the coarse-grained P-iron had a P-content of ca. 0.5 wt%. The pattern-welded core was bordered with a decorative strip of P-iron at the back of the knife to increase the overall decorative effect. The upper part of the back was iron with a pure ferritic microstructure. Detailed metallographic and SEM-EDS examination was published in *Thiele et al.* (*2017*).

2.2. Smelting iron

The reconstruction work was started from collecting suitable iron ores for smelting iron, steel and P-iron. P-iron could usually be extracted of phosphorus-rich bog iron ores.

Several bog iron ore deposits are known in Somogy County (South-West Hungary), where microbial bog iron ore lenses were formed in back marshes due to the precipitation of Fe(III) minerals (goethite) during the microbial and chemical oxidation of fluids containing solved Fe(II), streaming under the surface. Microbial bog iron ore lenses were redeposited by creeks in areas which uplifted from the Early Holocene on (*Kercsmár – Thiele 2015*). Bog iron ores from the microbial bog iron ore lenses and from the redeposited bog iron ore layers were smelted intensively during the Avar and conquering ages due to the abundance and high Fe-content of the ores.

But the smelting of these P-rich bog ores may result in non-forgeable P-iron as above a certain temperature and P-content (1048 °C and P=2.8 wt%, cf. the Fe-P dual phase diagram, *Okamoto 1990*) molten Fe-Fe_3P eutectic phase appears on the grain boundaries. P-content of the iron blooms could be decreased during the smelting by charging fluxes of high CaO content (such as limestone, bog iron ores with high CaO content or ash). The higher the CaO/SiO_2 ratio of the slag, the lower the activity factor of P_2O_5 due to the formation of a complex compound of $3CaO{\cdot}P_2O_5$ (tricalcium-phosphate), hence the lower amount of phosphorus dissolved in the iron (cf. the metallurgical and physico-chemical background more detailed in *Török – Thiele 2013* and *Thiele 2014*).

P-iron was smelted of bog iron ore collected from a redeposited bog iron ore layer that covers the bed of a fishpond near to the village of Lábod where furnaces from the Avar-Age (*Költő 1999*) and an iron bloom (*Török et al. 2017*) were also found. The chemical composition of this ore was measured by the means of ICP-OES method in the Mining and Geological Survey of Hungary (*tab. 1*).

#	Ore deposit site	Main oxides (wt%)							
		Al_2O_3	SiO_2	P_2O_5	CaO	MnO	Fe_2O_3	H_2O	Σ
1	Lábod	0,46	3,82	6,6	3,44	1,61	78,02	5,01	98,96
2	Barót	1	11,2	0,71	0,63	1,12	70,6	12,67	97,93

Tab. 1. ICP-OES analysis results for the main oxides of the iron ores used for iron smelting.
Tab. 1. Výsledky ICP-OES analýz hlavních oxidů železných rud použitých pro tavby železa.

For smelting iron and steel iron ore was collected in a sandstone mine near to the village of Barót (Transylvania, Central Romania). Iron ore appeared as ironstone concretions that grew in the spongy sandstone by precipitation from Fe(II)-rich post-volcanic thermal water and arranged themselves in near-concentric bands. This ore does not contain any phosphorus, its main mineral phase is also goethite but has an increased amount of SiO_2 originating from the surrounding sandstone (*tab. 1*).

Three smelts were carried out in the same furnace which was the copy of the so-called Fajszi-type Conquering age Hungarian embedded furnace found first in Somogyfajsz (*Gömöri 2000*, 34). The construction and the dimensions of the experimental furnace can be seen in *fig. 2*. In each smelt, after 1 hour preheating with wood and then charcoal, the iron ore which was roasted and crashed to a grain size of 2–15 mm was charged (altogether 12.5 kg) mixed with charcoal into the charcoal filled warm furnace and after about 4 hours the iron bloom was removed from the furnace.

During the smelting of P-iron from the bog ore from Lábod, in order to keep the phosphorus content of the bloom in a range of 0.5–1.0 wt%, roasted 2–5 mm fine grained burned limestone (CaO) was charged in a ratio of 1 : 5 CaO : ore. The ratio of charcoal:ore was 0.5 : 1 while the air supply was 50 l/min in this experiment and the resulting P-iron bloom weighed 2.7 kg after the first compressing and 2.1 kg after forging to a billet (the bloom was forged with a power hammer and heated in charcoal fire). Iron and steel was smelted from the ironstone from Barót in the same way but without charging CaO and with a ratio of charcoal:ore of 0.5 : 1 and an air supply of 50 l/min respectively 1 : 1 and 100 l/min. The iron bloom was 2.3 kg from which a billet weighing 1.8 kg was forged. The increased amount of charcoal and air resulted in a steel bloom of 2.6 kg which was forged to a billet weighing 2.0 kg. All the three billets had a similar shape with a length of ca. 450 mm and a cross section (referred CS hereafter) of ca. 40 × 15 mm.

For purifying and homogenising, each billet was cut into 6–8 pieces then packed again and the packets were forge-welded and folded 3 times. Thereafter ca. 80 cm long bars with a cross section of ca. 15 × 15 mm were forged. The final phosphorus content of the P-iron bar was between 0.6–0.9 wt% measured using p-XRF on a ground side of the bar. The C-content was 0.2 wt% in the iron bar and 0.6–0.7 wt% in the iron and steel bar. The carbon content was calculated from the results of HRc hardness measurement done in water quenched state on a ground side of the bars. The iron and steel bars could also be distinguished by spark test.

2.3. Forging the knife blade

For the PW core, 6–6 flat layers forged from steel and P-iron (each was ca. 60 × 15 × 2 mm) were piled alternatingly and the stock was forge-welded then forged into a bar of 6 × 6 mm CS. The bar was twisted and hammered flat to a CS of 7 × 4 mm and was cut to 80 mm long pieces used later as the PW layer. Each piece was hammered to wedge-shape at the point to a CS of 7 × 2 mm. The iron back of the knife had a CS of 7 × 3 mm and was 95 mm long while the P-iron bar for the decoration strip was 80 × 7 × 1.5 mm. To keep the original triangle shape of PN_52 knife the steel cutting edge had to be wedge-shape with a length of 95 mm and a CS of 7 × 8 mm at the beginning and 7 × 3 mm at the point. These four layers prepared were kept together with a tong and then forge-welded, first at the point and then, after a second heat, the whole body of the blade. Forge-welding had to be done quite quickly because the temperature of the small workpiece decreased fast. The blade was then shaped. The final thickness of the blade was 6 mm. The main forging steps can be seen in *fig. 3: a–e*.

During the forging of the knife blade some practical observations were made. Due to the presence of slag inclusions in the metallic matrix, bloomery iron bears much less plastic deformation at room temperature before delaminating and cracking than the almost slag-free modern steels, i.e. the ductility of bloomery iron is much lower because of the notching and stress concentration effect of the slag inclusions (cf. *Thiele – Hošek 2015b*). The low ductility of bloomery iron was observed on the forging temperature as well, thus less plastic deformation is allowed in one forging step compared to modern steels. Also, in general, uniaxial stress state is preferred during the plastic deformation (preferably compressive stress and shear stress should be avoided) to prevent delaminating or cracking. It is also important to start forging from the forge-welding temperature (1300–1350 °C depending on the C-content) for re-welding the delaminated layers, as well as to avoid forging under the Ac3 temperature (the lower temperature of the austenite field).

It was also observed that the yield strength of the bloomery iron is lower than that of modern steels at forging temperature. This is caused by the melting of the slag in the metal matrix, which led to less force-need for the same plastic deformation. The other reason

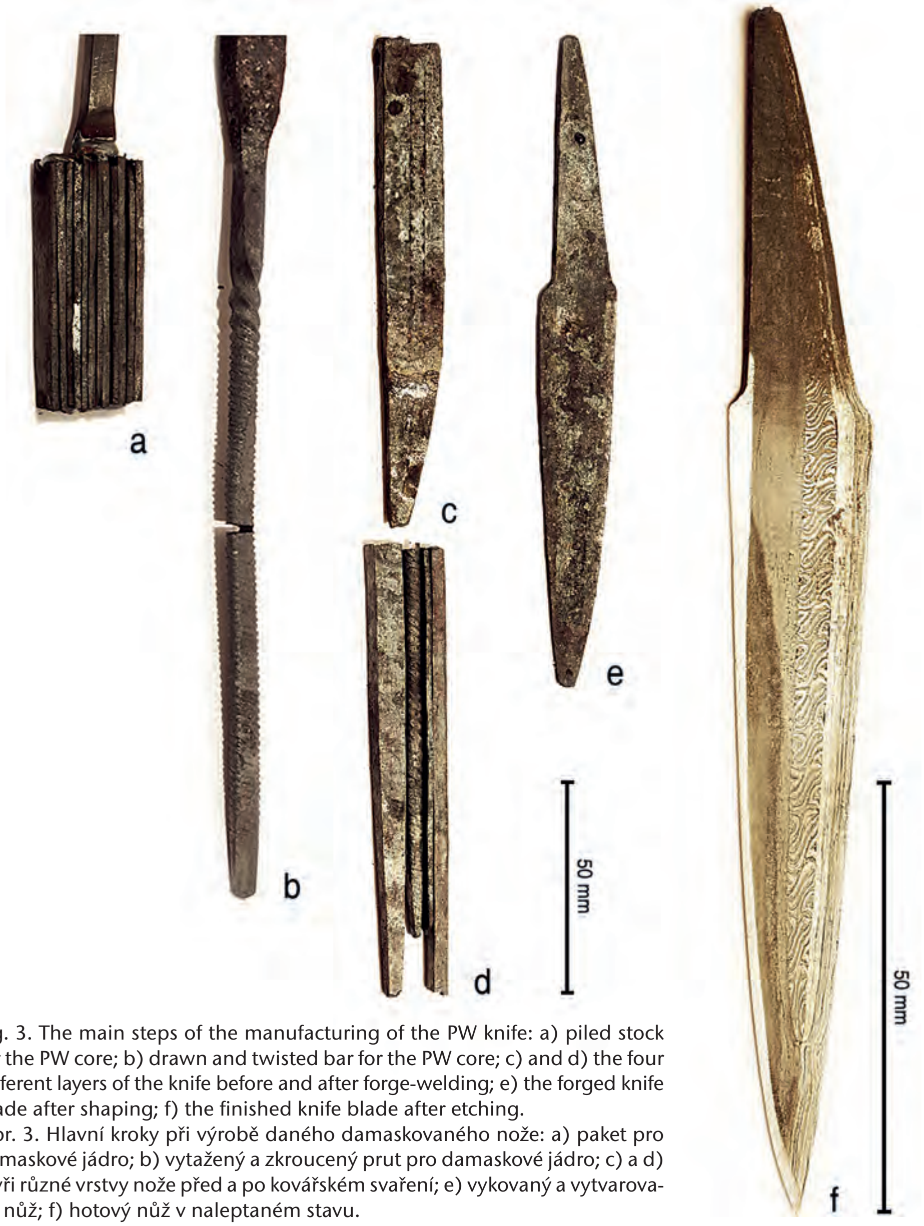

Fig. 3. The main steps of the manufacturing of the PW knife: a) piled stock for the PW core; b) drawn and twisted bar for the PW core; c) and d) the four different layers of the knife before and after forge-welding; e) the forged knife blade after shaping; f) the finished knife blade after etching.
Obr. 3. Hlavní kroky při výrobě daného damaskovaného nože: a) paket pro damaskové jádro; b) vytažený a zkroucený prut pro damaskové jádro; c) a d) čtyři různé vrstvy nože před a po kovářském svaření; e) vykovaný a vytvarovaný nůž; f) hotový nůž v naleptaném stavu.

could be the lack of alloying elements (such as Si and Mn), which are alloyed to almost all industrial steels for deoxidization and which provides a solid solution hardening effect in austenite.

At the beginning of forging the spongy structured bloom there was no need to use any flux as it contained enough slag for forge-welding. Later, when the billet was dense and its slag-content decreased, borax was used as flux. However, bloomery iron is easier to forge-weld than modern steels probably also due to its slag inclusions and the lack of alloying elements which decelerate the recrystallization, which is important during forge-welding.

Finally an interesting observation was that P-iron had a special smell (probably caused by the vapour of phosphorus) at forging temperature, which may also help to distinguish P-iron from non-P-iron.

2.4. Finishing the PW knife blade

The forged knife blade was roughly ground and sharpened on a manual sandstone water-cooled grinding wheel. As the blade was narrow, the ground surface remained almost flat and the blade had a simple 'V'-shape CS with a 2–3 mm wide sharpened cutting edge. The roughly ground blade had a thickness of 4 mm, so ca. 1 mm of material was removed from each sides. The cutting edge of the blade was subsequently quenched in oil in a width of ca. 10 mm from a temperature of ca. 900 °C (water quenching was also tried but the edge was cracked). There was no annealing applied. After heat treating, the blade was ground again using fine grained flat grind whetstones with grit sizes of 80, 120 and 240. The cutting edge was sharpened again.

The next step is the finishing of the surface with a kind of etching. It is yet unknown how the historical PW objects were exactly etched, but without a special treatment the fine ground or polished surface does not show any clear pattern (there is no contrast between the layers of different chemical composition), although the slag inclusions that follow the forge-welding lines might be seen with the naked eye. There are three possible methods for making the pattern visible, the etching method (in which the surface of the blade is exposed to liquid organic or inorganic acids, *Thiele et al. 2014*), the method of abrasive grinding (*Mäder 2001*), and finally the so-called controlled corrosion process. Following this latter technique (described in details in *Hošek – Bárta – Šmerda 2017*) the knife blade was positioned on a holder on its flat back (*fig. 4: a*) approximately 10 mm above the level of 10% vinegar in room temperature and exposed to its vapours in a closed container for 24 hours. The forming corrosion products (*fig. 4: a*) were mechanically removed from the treated surface by a wet rag every 8 hours. Then the blade was washed and the final surface treatment consisted of slight hand polishing using a hand polishing pad of 1200 grit size. The nice, contrastive pattern of the finished PW knife can be seen in *fig. 3: f* and in *fig. 4*. As the PN_52 knife was originally probably also slightly bigger, the total length of the reconstructed knife was 135 mm from which the blade was 90 mm with a max. width of 15 mm and max. thickness of 4 mm tapering to 2 mm.

Some practical observations regarding the etched surface could also be made. The P-iron layers were not only shiny compared to the grey coloured iron or steel layers but individual crystals of the P-iron could also be recognized. This phenomenon was observed only after the controlled corrosion process using the vapour of vinegar and not in case of etching in liquid etchants (*Thiele et al. 2014*). This secondary decoration effect of P-iron is caused by its highly coarse-grained microstructure in which the ferrite grains have a size of 0.1–1 mm (*fig. 4: b*).

Areas with a different shade are also visible in the layers of iron and steel because of the difference in their carbon content and microstructure, i.e. the different cooling speed of the edge and the back of the blade. The historical use of P-iron for a decorative purpose

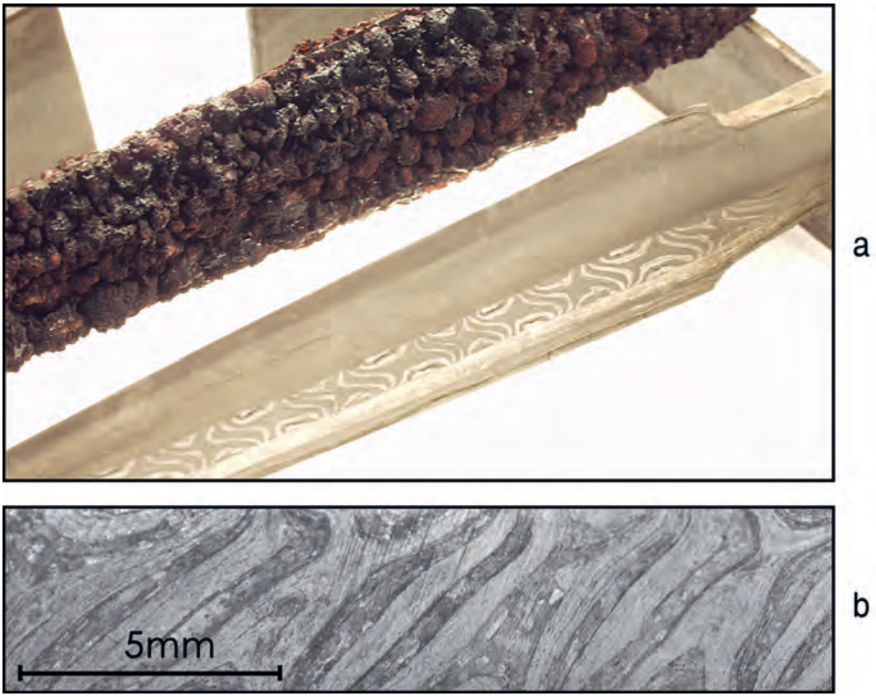

Fig. 4. Etching the PW knife with controlled corrosion in the vapour of 10% vinegar: a) above, corrosion products on the surface of the blade after 8 hours; below, the revealed pattern after washing and removing the corrosion products after the first 8 hours of etching; b) the secondary decorative effect of coarse grained structure of P-iron visible with the naked eye in the PW core under stereo-microscope after etching.
Obr. 4. Leptání damaskovaného nože pomocí řízené koroze ve výparech 10% octa: a) Nahoře, korozní produkty na povrchu čepele po osmi hodinové expozici; dole, vzorování viditelné po omytí a odstranění produktů koroze z čepele po prvních osmi hodinách leptání; b) sekundární dekorativní efekt hrubozrnné struktury leptaného fosforového železa, viditelný v damaskovém jádru čepele i pouhým okem, zdokumentovaný pomocí stereomikroskopu.

is also supported by the observation that the appearance of etched P-iron is rather homogeneous (apart from its visible grains) compared to iron or steel because carbon content remains low in P-iron according to the high P-content as phosphorus is a ferrite-stabilizing element in which phase the solubility of C is very low, i.e. over ca. 0.65 wt% of phosphorus the allotropic transformation of ferrite to austenite disappears (cf. Fe-P dual phase diagram: *Okamoto 1990*). And finally, slag inclusions in and between the layers also remained visible after etching (*fig. 4: b*).

3. Conclusions

During the experimental work of manufacturing a copy of the 13th century PN_52 PW knife from Kobilić, several new practical observations were made in general about smelting and processing bloomery iron and regarding the decorative effect of P-iron in PW.

1. P-iron was smelted of P-rich bog iron ore and it was possible to regulate the P-content of the iron bloom by charging burned limestone. Iron and steel was extracted by smelting P-free ironstone; increasing the air supply and the charcoal/ore ratio led to the carburizing of the iron bloom.
2. Compared to modern steels, bloomery iron:
   - has lower ductility at the forging temperature, so bears less plastic deformation in one forging step due to the presence of slag inclusions in the metallic matrix;
   - has lower yield strength at the forging temperature, caused by the melting of the slag inclusions and the lack of alloying elements;
   - easier to forge-weld;
   - P-iron has a special smell at the forging temperature.
3. After etching the fine ground PW knife blade in the vapour of vinegar, P-iron remained bright and shiny providing a contrastive surface pattern. A secondary decoration effect was also observed as the controlled corrosion process made the highly coarse-grained ferritic microstructure also visible.

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ÁDÁM THIELE, Budapest University of Technology and Economics, Department of Materials Science and Engineering, Bertalan Lajos str 7., bdg MT, H-1111 Budapest; thiele.adam@gmail.com

Metallographic examination of four 7th–8th century long-blade weapons from Želovce (Slovakia)

Metalografické rozbory čtyř dlouhých sečných zbraní ze 7.–8. století ze Želovců (Slovensko)

Jiří Hošek – Márk Haramza

The article presents the metallographic examination of three sabres and one double-edged sword coming from the 7th–8th century Slavic-Avar site of Želovce (*Slovakia*)*. All four weapons had been subjected to metallography as early as 1975, but the results were not published in sufficient detail. With this article, written in honour of Radomír Pleiner, the authors wish to repay this debt. The blades are compared with other* (*metallographically examined*) *weapons from Želovce, and the manufacturing methods of early medieval production of sabres are discussed.*

Želovce – Avars – sabres – sword – metallography – archaeometallurgy

Článek představuje metalografické rozbory tří šavlí a jednoho dvojbřitého meče, pocházejících ze slovansko-avarské lokality Želovce, datované do 7. až 8. století. Všechny čtyři zbraně byly metalograficky zkoumány již v roce 1975, výsledky rozborů však nebyly nikdy zveřejněny ve všech podrobnostech. Tímto článkem, napsaným k poctě Radomíra Pleinera, by autoři chtěli tento dluh splatit. Dané čepele jsou porovnány s dalšími (*metalograficky zkoumanými*) *zbraněmi ze Želovců a diskutovány jsou i metody výroby šavlí daného období.*

Želovce – Avaři – šavle – meč – metalografie – archeometalurgie

1. Introduction

In 1975, Radomír Pleiner metallographically examined one sword and three sabres from the 7th–8th century Slavic-Avar cemetery of Želovce (south Slovakia). The metallography of the sabres was published in a preliminary fashion in 1979, but no photographs or drawings were included (*Pleiner 1979*). Later, in 1989, R. Pleiner published simplified drawings of the metallographic samples, but no details of the metallography were provided (*Pleiner 1989*). In fact, R. Pleiner never published these weapons and the results of their investigation in full detail. In 1991, Ľ. Mihok published the results of the metallographic examination of several long-blade weapons from Želovce (*Mihok et al. 1991*), including the same 'Carolingian' sword that had been previously investigated by R. Pleiner. The opportunity was taken to check the metallographic samples stored in the Institute of Archaeology in Prague and to present details of the metallographic examinations.

2. Avar-Age long-blade edged weapons

Long-blade weapons coming from the Avaric environment form a specific group of weapons used in contemporary Europe. The most comprehensive study dealing with this topic

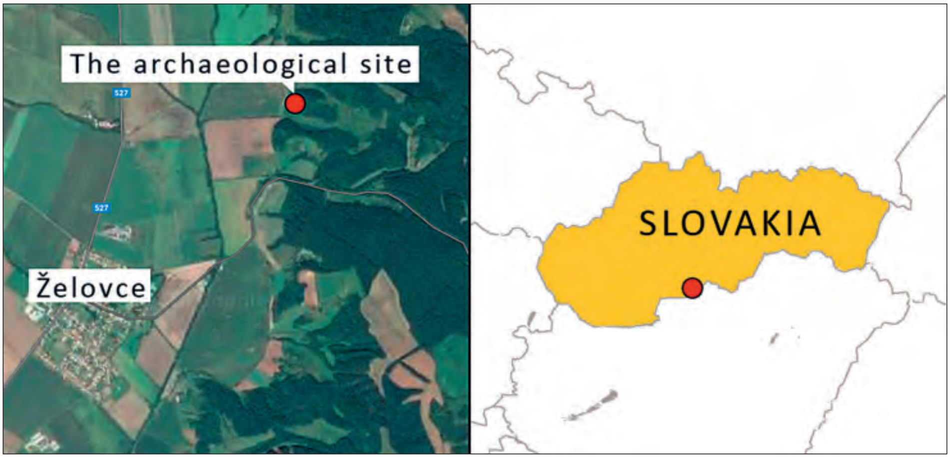

Fig. 1. Location of the site of Želovce.
Obr. 1. Poloha lokality Želovce.

was recently published by *G. Csiky* (*2015*), who also introduced a specific classification system for these objects. Following Csiky's classification, edged weapons (corresponding to category of artefacts 'E') coming from Avaric sites are categorized according to both the form and cross-section of blades: double-edged swords (E.I), single-edged swords (E.II), sabres (E.III) and seaxes (E.IV; *Csiky 2015*, 152). Observed through this grouping, the main trend in 7th–8th century Avar weaponry is the gradual decrease of sabre blade curvature, the relatively permanent presence of single-edged swords and the increasing appearance of crossguards. Weapons with a single-edged and curved blade, suitable for cutting, can be considered sabres. Sabre blades could also be provided with a false edge (or 'elman') running some distance (up to 260 mm) from the point upward (i.e. the lower third or quarter of the blade was double-edged). There are several theories on the function of the double-edged parts; they offered more options to cut and facilitate thrusting, 'since a lenticular cross-section has several advantages over a triangular cross-section' (*Csiky 2015*, 195). This particular feature is seen on Želovce sabres as well; the length of their false edges lies in a very wide range going from 0 to 205 mm.

Some sabres (such as those from the Želovce-cemetery graves nos. 167, 335, 442, 818) have a cross- or star-shaped crossguard, formed by two arms and two langets in the middle. The function of the langets was to fit the crossguard tightly to both the wooden grip and the scabbard's throat, thus protecting the blade from atmospheric factors and preventing accidental unsheathing when riding a horse.

Although the morphological features compose the main basis of classification, technological investigations play an increasingly important role in grouping the artefacts. Therefore, Csiky also drew attention to the metallographic results of Avar weapons (roughly 30 items in total).[1] He discussed the metallographic examinations of Avar sabres and single-edged

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[1] The examined weapons are: one sabre from Hoilare (grave No. 102), one sword from Hohenberg, two sabres (grave nos. B-23 and D-338) and one single-edged sword (grave No. D-3) from Zillingtal, one sword

swords published by *R. Pleiner* (*1967*, 90), *J. Piaskowski* (*1974*), Ľ. Mihok (*Mihok et al. 1991*; *Mihok – Pribulová – Mačala 1995*), and *M. Mehofer* (*2006*), who examined finds from Holiare (Slovakia), Környe[2] (Hungary), Želovce and Košice-Šebastovce (both in Slovakia), Zillingtal and Gnadendorf (both in Austria), respectively.

3. The archaeological background of the Želovce blades

The archaeological site of Želovce (excavated between 1963 and 1968 under the direction of *Z. Čilinská 1973*) was situated on the Slavic-Avar border, and today lies roughly 2.5 km northeast of the village of Želovce (Veľký Krtíš district, south Slovakia). It was a large burial ground (with 870 graves) and represents one of the most important Slovak sites of the 7th and 8th centuries. It consisted of two parts (as a structural analysis revealed) most likely belonging to two individual settlements (*Čilinská – Wolska 1979*, 154). A total of 628 graves were excavated in the first (earlier) part of the burial ground; burials were made there from the 630s. In the second (later) part of the burial ground, 242 graves were excavated, and it was in use from the second half of the 7th century. The latest burials at the Želovce site date to the second half of the 8th century (*Čilinská 1992*, 30–36). The Želovce burial ground features an unusually high number of weapons (17 sabres, one 'Carolingian' sword, one single-edged sword-palash, and one seax), which is unmatched by other contemporary burial grounds in the Carpathian Basin.

4. Weapons from Želovce examined metallographically

Radomír Pleiner examined the following long-blade weapons: sabres from grave nos. 27, 30 and 44, and a 'Carolingian' sword (undoubtedly from grave no. 124).

The metallography of the sabres was preliminarily published (*Pleiner 1979*; *1989*). Here, all the details gathered from Pleiners report (*Pleiner 1975*) are finally presented.

1) Sabre from grave 27 (specimen no. 301; *fig. 2*)

The presence of welding seams indicates that the blade was welded from three strips. One side was more carburised than the other. Before welding, the strips were somewhat homogenised by extensive forging at rather low temperatures. Even the most carburised places barely reach the quality of medium-hard steel, hence the material was not suitable for quenching, which was not applied. This weapon is of mediocre quality.

Metallographic description:

Two samples ('A' and 'B') were collected for metallography from the middle part of the blade. Part of sample 'B' was also used for chemical analysis.

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from Dabas/Gyón-Paphegy, one from Csolnok, three swords (grave nos. 78, 97, 149) 2 other swords (as stray finds) and 2 spearheads (grave no. 129 and stray find) from Környe, 3 spearheads (grave nos. 221, 238, 321) and one sabre from Košice-Šebastovce, eight edged weapons (grave Nos. 78, 124, 126, 235, 311, 335, 442, 818) from Želovce, and other spearheads and swords from Budakalász and Szegvár-Oromdűlő (*Csiky 2015*, 293–294: nos. 7–11).

[2] However, the Környe burial belongs to the Early Avar period and thus does not chronologically correspond to the Želovce cemetery.

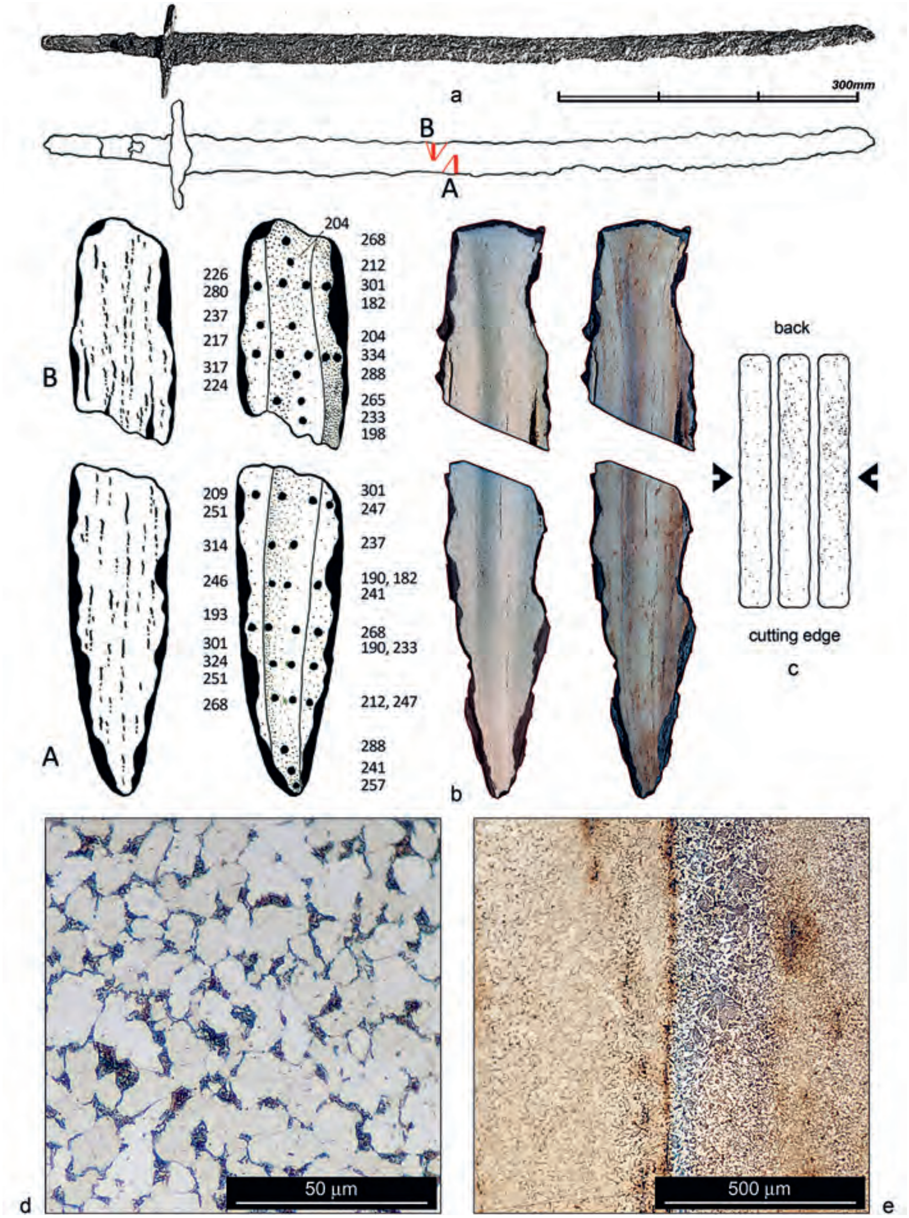

Fig. 2. Sabre, Želovce (Slovakia), grave 27: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of assembling individual rods to make the blade (edge to back layering); d – ferritic-pearlitic structure of the cutting edge (specimen A); e – one of the welding lines observed (specimen A). Etched with Nital (c) and Oberhoffer (d). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–e).
Obr. 2. Šavle, Želovce, hrob 27: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (vrstvení od břitu ke hřbetu); d – feriticko-perlitická struktura v břitu (vzorek A); e – jedna ze svarových linií (vzorek A); leptáno nitalem (d) a Oberhofferovým roztokem (e).

The surface layers of the metallographic samples are corroded. In sample ‘B’, the slag inclusions are chained in roughly three bands running lengthwise from the edge towards the back. Considering their number, corresponding to level 3–2 on the Jernkontoret scale, the metal is of mediocre purity. Sample ‘A’ also contains slag inclusions chained into several bands, but inclusions individually scattered throughout the sample prevail. The number of inclusions corresponds to levels 3 and 4 on the Jernkontoret scale.

Macroscopic etching with Oberhoffer’s and Heyn’s reagents revealed that the blade profile consists of several strips. In sample ‘B’ a strip (separated from one side by the weld) of fine-grained (ASTM 12) ferritic-pearlitic spheroidised structure runs through the centre of the sample. This structure slowly changes into ferrite (ASTM 11–12) with traces of pearlite and is separated by a weld from another strip of ferritic-pearlitic structure with a grain size of ASTM 12. Specimen ‘A’ shows a striped microstructure similar to that of specimen ‘B’, i.e. a continuity of the strips and two distinct welds. A strip of ferritic structure with traces of pearlite (grain size ASTM 11–12) is observed on the left side of the sample. This structure is beyond a weld changed into a fine-grained ferritic-pearlitic structure. Pearlite with a ferritic network and needles appears in places. This structure slowly changes into ferrite with traces of pearlite and tertiary cementite on the boundaries of grains of ASTM 8–9 size. This structure is separated by a weld from a strip of ferritic and ferritic-pearlitic structure. The blade has a very fine ferritic-pearlitic structure – globules of cementite can be seen within ferritic grains.

2) Sabre from grave 30 (specimen no. 302; *fig. 3*)

The blade was forge-welded from two, or (more likely) from three strips of material, of which each (mainly the central one) was unilaterally strongly carburised in advance. A significant diffusion of carbon to the adjacent ferritic areas occurred in the course of subsequent forging. The cutting edge was slightly hardened, perhaps by cooling it down in a stream of cold air or in warm oil, etc.

Metallographic description:

A specimen for both metallographic and chemical analysis was cut off crosswise from the middle part of the blade. The sample is covered by a thin corrosion layer. Non-metallic inclusions are chained in several bands running lengthwise from the edge towards the back. The number of inclusions corresponds on average to levels 2 and 3 on the Jernkontoret scale.

Etching revealed a highly heterogeneous structure. There is a narrow strip of ferrite with traces of pearlite at the back of the blade. The cutting edge shows a fine-grained sorbitic structure, which, towards the centre of the blade, changes in places to pearlite with a ferritic network, and further into a strip located in the lengthwise axis of the sample with a structure of ferrite with some pearlite (grain size corresponds to ASTM 9–10). At the right side of the sample there is a fine-grained ferritic-pearlitic structure that changes into ferrite (of ASTM–8 grain size) with traces of pearlite.

3) Sabre from grave 44 (specimen no. 396; *fig. 4*)

The blade was made of soft carbon steel. Considering the distribution of slag inclusions, it is likely that the billet was welded from at least two strips of such steel, of which one contained irregularly distributed zones richer in carbon. The cutting edge remained relatively soft and was not (and could not be) quench hardened; on the contrary, it seems that intensive final forging took place at rather low temperatures. The blade was a simple product.

Metallographic description:

Two samples (‘A’ and ‘B’) were collected for metallography from both the cutting edge and back of the blade. Part of sample B was also used for chemical analysis.

The surface layers of the metallographic samples are corroded, and the cracks filled with corrosion products are in places propagating into the metallic core. Slag inclusions are chained into several lines running lengthwise from the edge towards the back. In addition, numerous individually scattered inclusions occur in the whole sample. The total number of inclusions corresponds to levels 4 and 5 on the Jernkontoret scale, i.e. it is metal of very low purity.

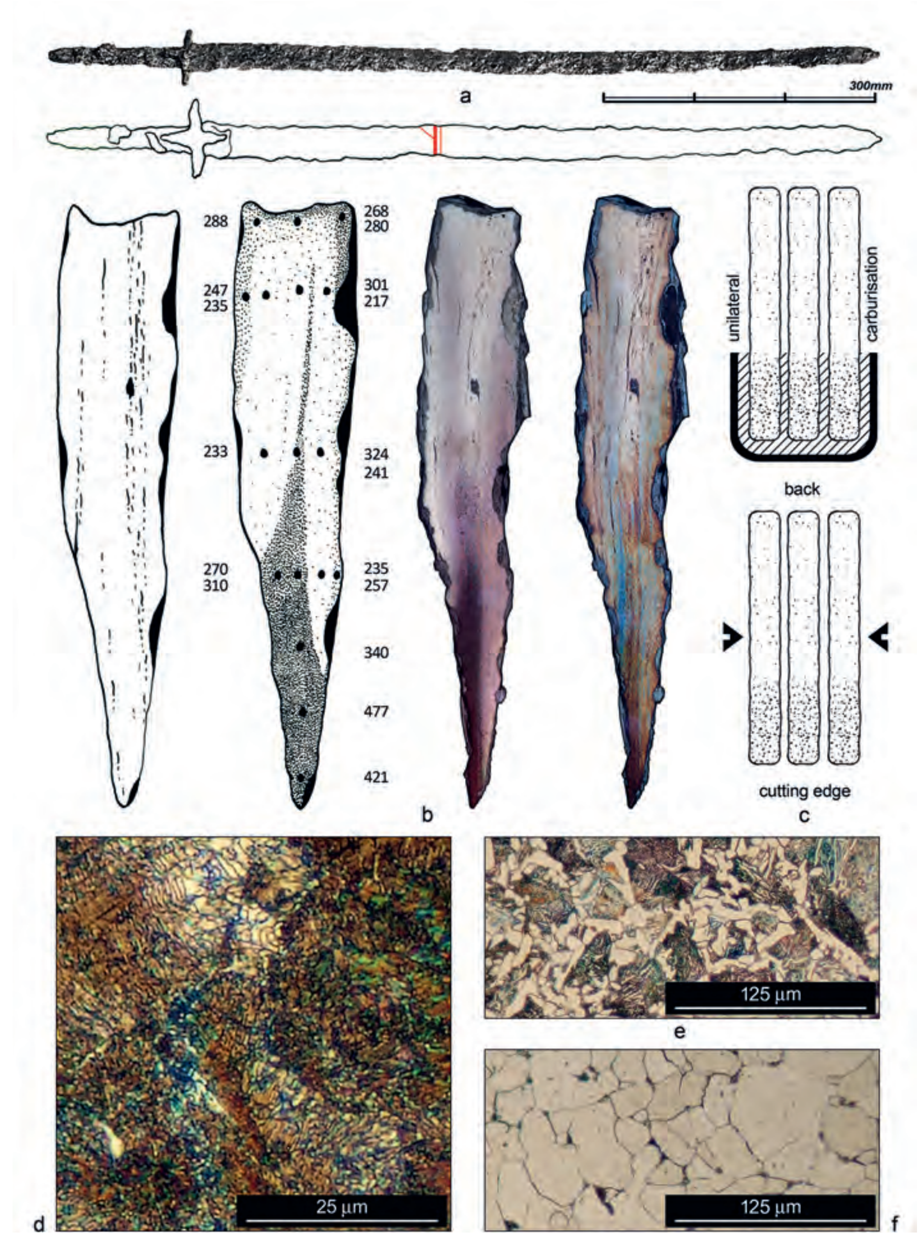

Fig. 3. Sabre, Želovce (Slovakia), grave 30: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of preparing and assembling individual rods to make the blade (unilateral carburisation followed by edge to back layering); d – pearlite in the cutting edge; e – pearlitic-ferritic structure in the middle portion of the sample; f – ferritic structure in the back of the blade. Etched with Nital (c–e). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–f).

Obr. 3. Šavle, Želovce, hrob 30: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (nerovnoměrné nauhličení polotovarů vrstvených od břitu ke hřbetu); d – perlitická struktura v břitu; e – perliticko-feritická struktura ve střední části vzorku; f – feritická struktura ve hřbetu čepele; leptáno nitalem (d–f).

Half of the sample 'B' has ferritic structure with traces of pearlite; the grain size corresponds to the ASTM 8–10. A narrow strip of ferritic-pearlitic structure is on the right side of the sample. The left side of the sample shows a very fine-grained (ASTM 10–11) ferritic-pearlitic structure that includes zones of pearlite with ferritic network and needles. A pearlitic structure appears on one side at the back of the sample. A predominant part of sample 'A' contains a ferritic structure (of ASTM 9–1 grain size) permeated entirely by spheroidised cementite. The middle portion of the blade shows an oblique strip of pearlite structure with ferritic network and needles, which gradually changes over to the structure of ferrite and pearlite (traces of pearlite in places). The cutting edge contains ferrite with a small amount of pearlite.

While the metallography of the sabres was published at least in a fragmentary manner, an examination of the 'Carolingian' sword (undoubtedly from grave no. 124) was never published. One of the possible explanations is that Pleiner lacked information he needed for the proper description and identification of the weapon.[3] His original interpretation of the sword production describes a blade made of a single piece of iron subjected to secondary carburisation (either the edges of the iron semi-product were carburised prior to the final forming to the shape of the blade, or the cutting-edge(s) of the nearly finished blade were carburised). However, this interpretation appeared slightly inaccurate when the sample was checked. Therefore, a re-assessment and re-examination recently conducted by the authors is presented here.

4) 'Carolingian' sword (grave 124; specimen no. 299; *fig. 5*)

The blade consists of steel cutting edges welded onto a middle portion consisting of surface panels and a core of iron. The overall character of the revealed part of the surface panel corresponds to a layered-and-twisted composite, which, however, cannot be considered a standard pattern-welded composite. The reason lies in the very low differences in the local contents of phosphorus. The blade was not quench hardened (at least not in the whole volume) in the place of sampling. The very low visibility of the welding lines, along with the extensive carbon diffusion beyond the welds, indicate that during the forging cycles the blade was exposed to high temperatures for a long time. The find seems to be a failed attempt to produce a more glamorous pattern-welded weapon.

Metallographic description:

Two samples were cut out roughly halfway down the blade, each from one side. While one sample had a well-preserved metallic core, the other was entirely corroded.

Metal purity varies considerably in both the central and cutting-edge portions of the blade (from level 2 to level 5 on the Jernkontoret scale).

When etched with Nital, the metallographic structure revealed three basic areas. Area I shows a pearlitic structure with a hardness of 220±27 HV0.2 (maximum hardness was 251 HV0.2 on the cutting edge, decreasing to HV0.2 towards the central portion). Area II is a mixture of pearlite and ferrite; the carbon content gradually decreases from circa 0.7 to 0.25 percent towards the central portion of the blade; the hardness reaches 133±8 HV0.2. Ferrite is present in the form of polyhedral grains network as well as lamellas penetrating the pearlitic grains. Area III is ferrite with some pearlite in places (max. c. 0.2% C). Hardness is 116±19 HV0.2, grain size c. ASTM 7–8.

Etching with Oberhoffer's reagent gradually revealed traces of welding lines separating the cutting edge (A), the core (B) and one surface panel (C). Sharply bounded areas appeared (C*) within this panel (C). Their hardness (133±6 HV0.2) is somewhat higher than the hardness (121±7 HV0.2) and apparently also the phosphorus content of the surrounding matrix.

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[3] The metallographic report lacks the number of the grave in which the sword was found, and there is no description, photograph or drawing of the weapon itself.

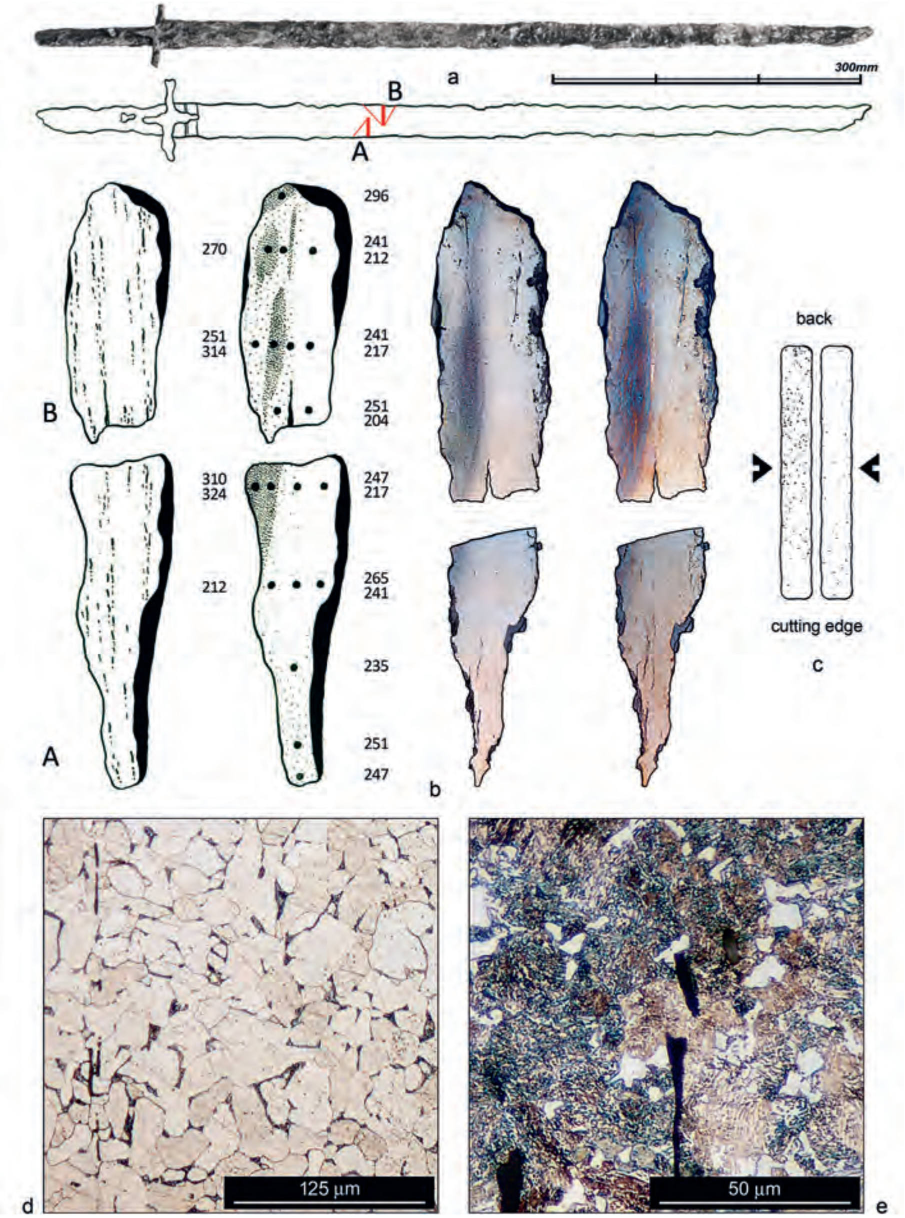

Fig. 4. Sabre, Želovce (Slovakia), grave 44: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of assembling individual rods together to make the blade (edge to back layering); d – ferritic structure with traces of pearlite in the cutting edge (sample A); e – pearlitic-ferritic structure in the back (sample B). Etched with Nital (c, d). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–e).
Obr. 4. Šavle, Želovce, hrob 44: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (vrstvení od břitu ke hřbetu); d – feritická struktura se stopami perlitu v břitu (vzorek A); e – perliticko-feritická struktura v hřbetu čepele (vzorek B); leptáno nitalem (d, e).

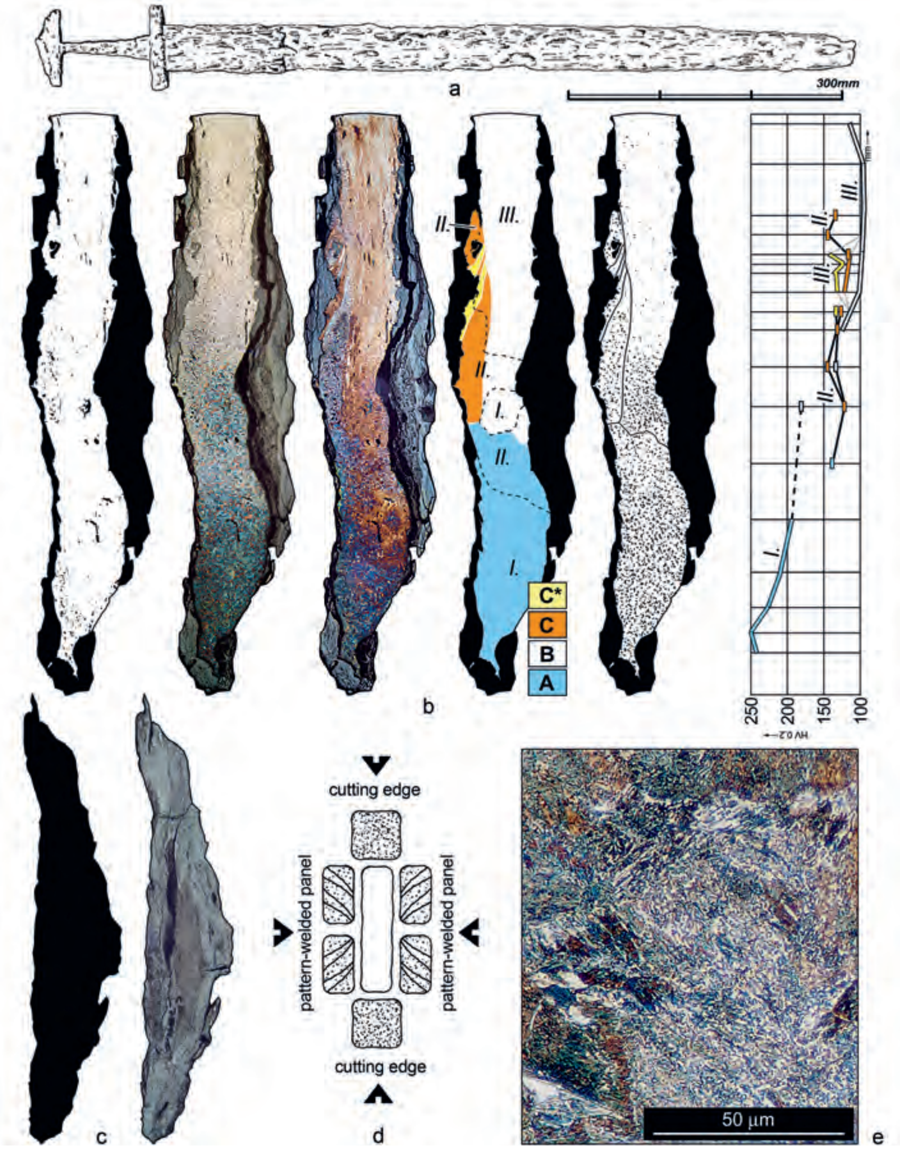

Fig. 5. Sword, Želovce (Slovakia), grave 124: a – the examined weapon; b – schematic drawings and photos of the blade samples (from the left: unetched state; after etching with Nital; after etching with Oberhoffer's reagent; layout of areas described; distribution of the microstructures and of the main welds across the sample; hardness distribution chart); c – the other sample, which was entirely corroded; d – the expected method of assembling individual rods to make the blade, if double-edged (cutting-edge welding onto a middle portion with pattern-welded surface panels); e – pearlitic structure in the Area I (etched with Nital). Photo and drawings after *Z. Čilinská* (*1973*, 199, Taf. XXII: 16) (a) and by J. Hošek (b–e).

Obr. 5. Meč, Želovce, hrob 124: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku čepele (zleva: neleptaný stav, po naleptání nitalem, po naleptání Oberhofferovým roztokem, rozložení popisovaných strukturních oblastí, vyznačení hlavních svarů a zachycených strukturních oblastí, graf průběhu tvrdosti); c – druhý odebraný vzorek, který byl zcela prokorodován; d – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele, je-li dvoubřitá (břity navařeny na střední část nesoucí povrchové damaskové panely); e – perlitická struktura v oblasti I (leptáno nitalem). Foto a kresby podle *Z. Čilinské* (*1973*, 199, Taf. XXII: 16) (a) a J. Hoška (b–e).

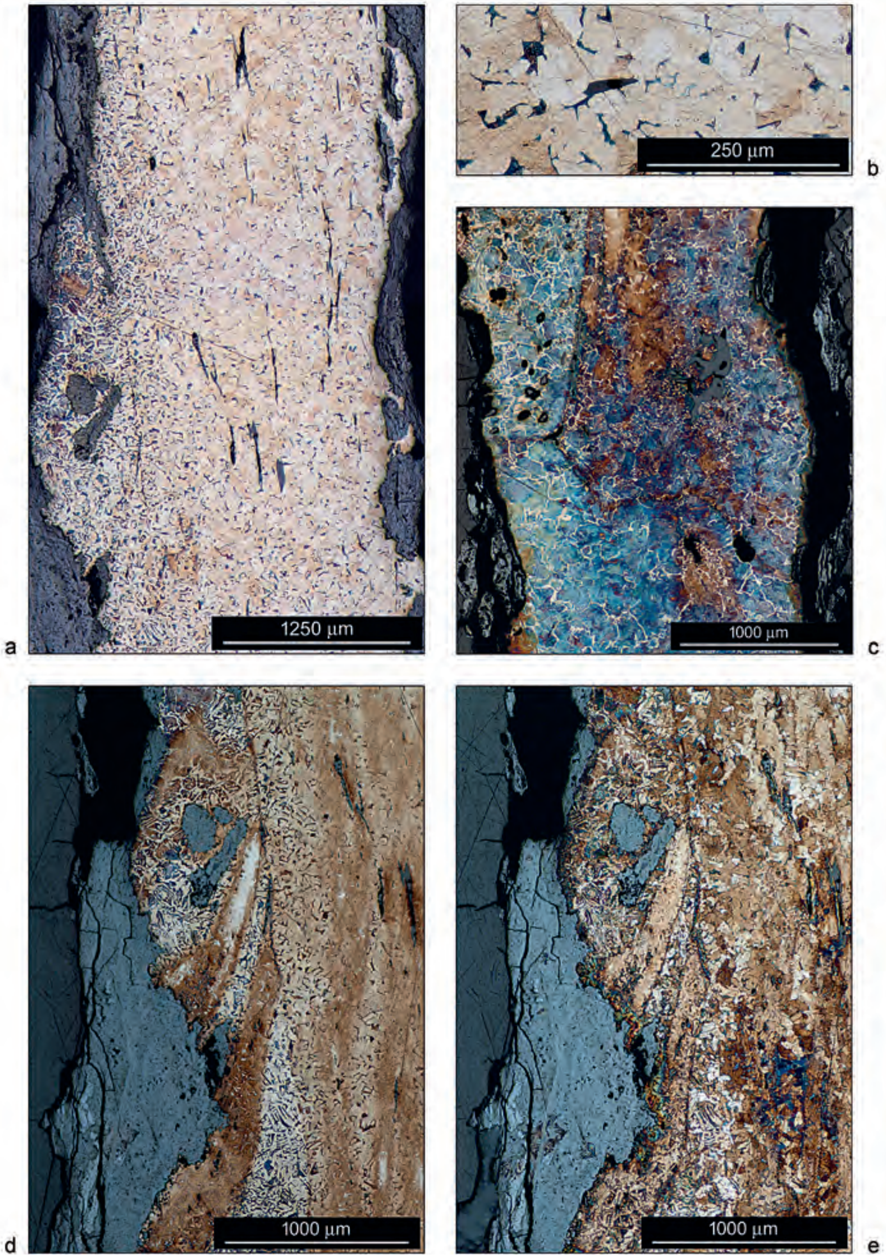

Fig. 6. Sword, Želovce (Slovakia), grave 124: a – macrophotograph of the changeover between the Areas II and III; b – ferrite with some pearlite in Area III; c – slightly visible welds in the place where the cutting edge, the core and the surface panel were attached to each other (when slightly etched); d – the surface panel (when slightly etched); e – well visible Areas (C*) within the surface panel (after strong etching). Etched with Nital (a, b) and Oberhoffer (c–e). Photo by J. Hošek.

Obr. 6. Meč, Želovce (Slovensko), hrob 124: a – celkový pohled na přechod oblasti II do oblasti III; b – ferit s trochou perlitu, oblast III; c – slabě viditelné svary v místě napojení břitu, jádra a povrchového panelu (při slabém naleptání); d – povrchový panel (při slabém naleptání); e – dobře viditelné oblasti (C*) v povrchovém panelu (po silném naleptání); leptáno nitalem (a, b) a Oberhofferovým roztokem (c–e).

The archive of metallographic specimens also contains sample nos. 684–687, which were detached from the Želovce weapons, but we do not know from which weapons in particular these samples were taken. Although R. Pleiner and his assistant Mrs. B. Novotná started with the metallographic examinations, they never completed them. The folders with semi-finished metallographic reports (each of which is labelled only as 'sword – Želovce') also contained a letter from Ľ. Mihok. The letter (now preserved in fragments)[4] explains that Ľ. Mihok sent photographs of metallographic specimens to R. Pleiner in 1990, which he himself examined and also published a year later (see *Mihok et al. 1991*). Therefore, we can only assume that the samples, which R. Pleiner had at his disposal, were provided by Ľ. Mihok. In that case, the samples should come from sabre nos. 78, 335, 442 and 818. Because these samples are of low importance for the research of the production techniques of Avar sabres, their description is not included.

Ľ. Mihok and his colleagues also examined several weapons from the Želovce cemetery (*Mihok et al. 1991*): four sabres (from grave nos. 78, 335, 442 and 818), one single-edged sword-palash (from grave no. 167), one seax (grave no. 311), one 'Carolingian' sword (grave no. 124), and one dagger (no. 235). The obtained results (except for the 'Carolingian' sword) are summarised in *fig. 7*. The blades of sabre nos. 78, 335, 442, 818 and the blade of dagger no. 235 were made by edge-to-back layering. Blade 818 is a steel-iron-steel sandwich, while blades 335 and 442 are a steel-and-iron sandwich. The blade of sabre no. 78 was welded from two plates of steel, and it seems that the cutting edge was also subjected to secondary carburisation. Sword-palash no. 167 was most likely made of a single piece of heterogeneous iron. Mihok himself believed that the palash has a side-to-side banded blade, but he did not provide any acceptable evidence for this hypothesis. The same situation concerns seax no. 311, the blade of which consists of heterogeneous iron and which is described as a side-to-side banded item. Sword no. 124 has, according to Ľ. Mihok, a single-edged blade made from an iron back and welded-on cutting edge of steel. No traces of quenching were detected in the examined weapons.

Another sabre examined metallographically by Ľ. Mihok and his colleagues (*Mihok – Pribulová – Mačala 1995*) came from the 7th–8th century Slavic-Avar cemetery of Košice-Šebastovce (Slovakia). The sabre is presumably the one from grave no. 161 dating to the first half of the 7th century (for more details see *Krivák 2017*, 69). According to Mihok, the blade of this weapon was made as a sandwich (a variant of the edge-to-back layering) consisting of a mildly carburised central plate to which a somewhat less carburised plate was laterally welded from each side. In addition, it seems that the cutting edge of the blade was secondarily carburised (but no more than 0.3% of carbon was observed). Two samples were taken from the blade crosswise, one near the hilt, the other near the point, but none shows traces of quenching.

R. Pleiner (*1967*, 90, 120) published a metallographic examination of the sabre coming from the 7th–8th century cemetery of Holiare (Slovakia). The weapon was found in grave no. 484, dated to the 7th century. The blade has a welded-in cutting edge of nearly eutectoid steel, and the back is iron. The blade was quenched and tempered (or slack-quenched).[5]

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[4] The archive, including the metallographic reports in question, was heavily damaged by flood in 2002.

[5] However, it is not clear from which part of the blade the sample for metallography was detached.

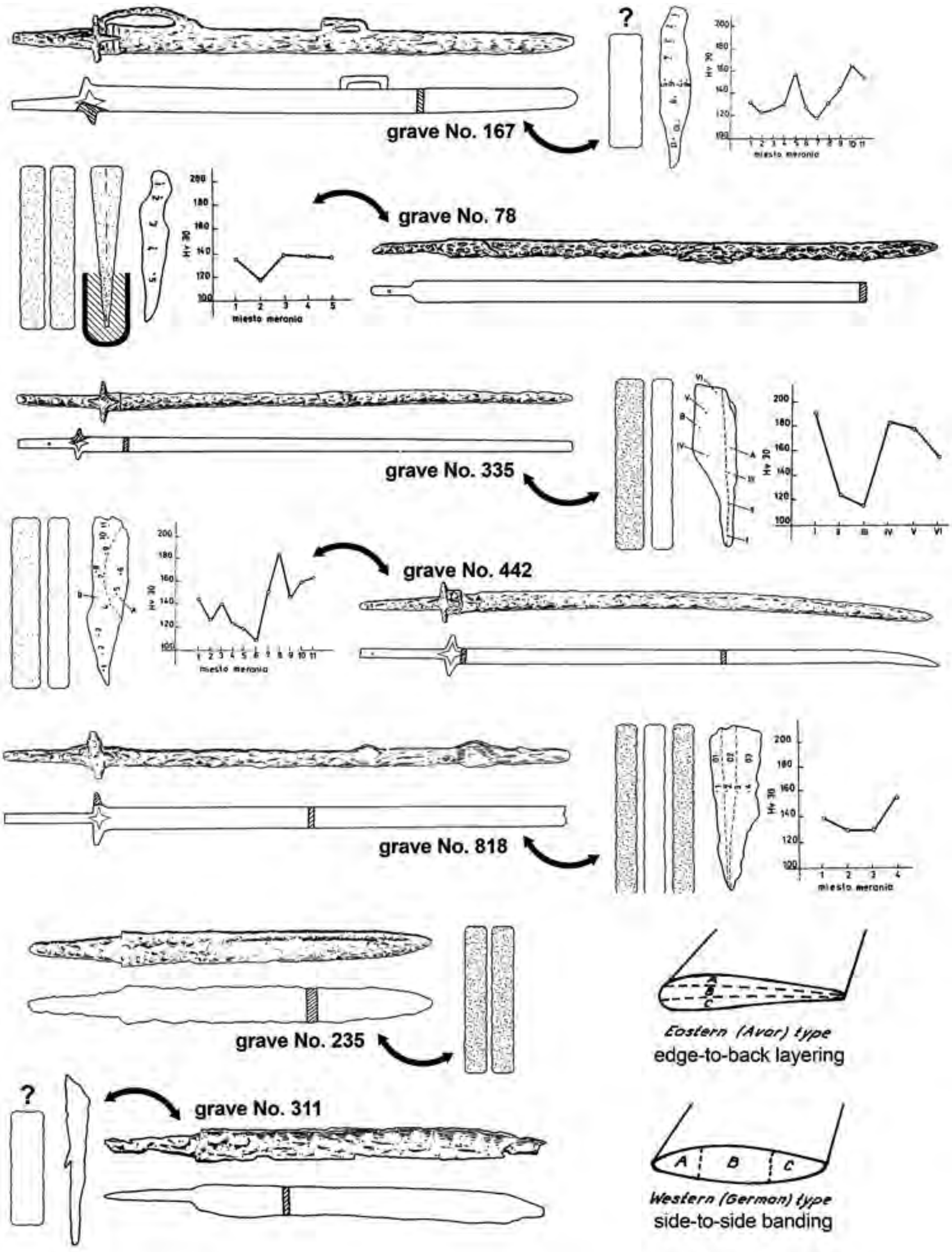

Fig. 7. Single-edged weapons from Želovce (Slovakia) examined metallographically by Ľ. Mihok: Sabres from grave nos. 167, 78, 335, 442 and 818, dagger from grave no. 335, and seax from grave no. 311. Drawings (not in scale) after *Ľ. Mihok et al.* (*1991*), adapted and amended by J. Hošek.
Obr. 7. Jednosečné zbraně z Želovců (Slovensko) prozkoumané metalograficky Ľ. Mihokem: Šavle z hrobů 167, 78, 335, 442 a 818, dýka z hrobu č. 335 a sax z hrobu č. 311. Nákresy (v různém měřítku) podle Ľ. Mihoka (*Mihok et al. 1991*), upravené a doplněné J. Hoškem.

Three single-edged long-blade weapons dating from the 7th to 8th century were also examined by *M. Mehofer* (*2006*); all three pieces (two sabres and one single-edge sword) come from the Avar burial ground of Zillingtal (Austria). Possible manufacturing techniques used to produce the weapons are described as follows (*Mehofer 2006*). The 8th century sabre from grave B 23 was made from a single piece of iron (with some steel in places), and no traces of hardening were observed (samples were taken half-way down the blade). The sabre from grave D 338, dating to the second half of the 7th century, was apparently made from a single piece of metal irregularly varying between iron and steel. While samples taken half-way down the blade show no traces of hardening, samples taken close to the point indicate rapid cooling or even quenching (although the carbon content was insufficient for the formation of typical quenched microstructures). The blade of the single-edged sword from grave D 3, dating to the second quarter of the 7th century, was made of at least two lamellas, as suggested by a corroded weld running from the back downwards. The carbon content of the blade is presumably low and its distribution uneven.

Certain comparisons can also be made with 7th to 9th-century sabres from Volga-Bulgarian cemeteries, which were examined and recently published by *Yu. Semykin* (*2015*). Two sabres come from the Novinkovskij kurgan burial ground /Новинковский курганный могильник/ (Russia) dating from the late 7th to the mid-8th century. The blade of the first one (no. 45) was made of heterogeneous material, mostly iron, but in places also steel. The other (no. 29) was presumably made of a similar material, but it seems that cutting edges were also secondarily carburized and subjected to quenching. While samples from sabre no. 29 were taken approximately half-way down the blade, the sample from sabre no. 45 was taken close to the hilt and just from the cutting edge. One sabre (no. 35) comes from Boľshe-Tiganskij I burial ground /Больше-Тиганский I грунтовый могильник/ (Russia) dating from the mid-8th to the mid-9th century. The blade of this weapon was forged from a piled billet (combining iron and steel). The sample was taken approximately half-way down the blade and just from the cutting edge. Five sabres come from the Boľshe-Tiganskij burial ground /Больше-Тиганский грунтовый могильник/ (Russia) dating from the mid-8th to the 9th century. The blade of sabre No. 21 was presumably made from a layer of steel welded to one side on a piece of iron (*Semykin 2015*, 139).[6] A sample for metallography was taken from a cutting edge in the upper part of the blade (closer to the hilt), and no traces of quenching were detected. The four other sabres (nos. 22 to 25) were made of steel with visible welding lines running from cutting-edge to back. Sabre nos. 22, 23 and 24 were sampled near the point, the hilt, and half-way down the blade, respectively. All three blades were subjected to quenching limited to the cutting edges. Three samples detached from blade no. 25 indicate that the blade was quenched along the entire length and in the whole volume. One sabre (no. 1), dating from the mid-8th to the mid-9th century, comes from the ‘burial ground at the 116th kilometre’ /могильник у 116 километра/ (Russia). The blade shows a layer of quench-hardened steel welded to one side of a piece of heterogeneous material varying between iron and steel. The sample for metallography was taken from a cutting edge in the upper part of the blade (closer to the hilt).

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[6] The same sabre is also described in the monograph as a piece made of a rather heterogeneous material, mostly iron with some steel in places (e.g. *Semykin 2015*, 56).

Considering the small number of the 7th–8th century sabres metallographically examined, it seems pointless to strive for a detailed comparison of the sabres from Želovce with those from other contemporary sites. We can just conclude that they did not differ significantly in any technological aspect. However, we can clarify the current knowledge of the techniques used in the manufacture of sabres. Their blades were in general forged from billets prepared by edge-to-back layering;[7] some of them consist entirely of steel, others entirely of iron or heterogeneous material varying between iron and steel. Various forms of sandwiching or cutting-edge welding-in seem to be a standard for making blades, deliberately combining iron and steel. Perhaps carburising cutting edges could also be practiced (as suggested by some of the examinations). No blades with cutting-edges of steel welded onto an iron back (corresponding to side-to-side banding) were encountered. No pattern-welding appears on sabres. In fact, the constructions of the sabre-blades correspond well to the constructions used in manufacturing knives in the given cultures (see e.g. *Semykin 2015*, 110; *Mihok – Pribulová – Mačala 1995*). The blades of 7th–8th century sabres were seldom quench-hardened in their whole volume (i.e. across the whole cross section and along their whole length).

Comparing the 'Carolingian' sword from Želovce (grave 124) with other contemporary swords is rather difficult. First, it is not clear whether the blade is single- or double-edged. *Čilinská* (*1973,* 57) described the sword as a single-edged sword, and Mihok was convinced that the results of his examination confirmed this (*Mihok – Pribulová – Mačala 1995*; *Mihok – Holý – Čilinská 1993*). However, in 1975 the weapon was already heavily corroded and 'preserved in poor condition'. Pleiner cut out two samples from the blade, one from each side, but only one sample contained a metallic core (see *fig. 6*). In addition, newly obtained metallographic results suggest instead that it was a double-edged pattern-welded blade (or rather an attempt to produce a pattern-welded blade). If so, the sword would be a common 7th–8th century 'spatha' in terms of the construction used, but an unusually poor piece in terms of the low quality of the pattern-welded composites.

5. Conclusion

The sabres from Želovce, examined in 1975 by Radomír Pleiner, show features similar to those of other contemporary sabres in terms of the manufacturing techniques employed. Deliberate combinations of iron and steel, encountered in 7th to 9th century sabre-blades, were typically based on edge-to-back layering, and most of the examined blades show no traces of quenching. The 'Carolingian' sword from Želovce (grave 124) has a welded and most likely double-edged blade deliberately combining iron and steel. The cutting edges were welded-on and the middle portion was provided with surface panels of layered and apparently twisted material resembling pattern-welded composites. If the sword is indeed a 'pattern-welded' specimen, like the majority of the 7th–8th century swords, the pattern-welding was virtually invisible.

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[7] Ľ. Mihok even considered edge-to-back layering of blades an eastern-type technique. In contrast, he believed that side-to-side banding was a western type technique (*Mihok – Holý – Čilinská 1993*).

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JIŘÍ HOŠEK, Institute of Archaeology CAS, Prague, v. v. i., Letenská 4, CZ-118 01 Prague; hosek@arup.cas.cz
MÁRK HARAMZA, Janus Pannonius Museum, Káptalan u. 5, H-7621 Pécs; haramza.mark@jpm.hu

Multi-phase microstructures in Anatolian Seljuks iron-steel objects: classification and production techniques

Vícefázové mikrostruktury anatolských železo-ocelových předmětů z období rúmského sultanátu: klasifikace a výrobní techniky

Ümit Güder – Cemal Cem Taşan – Alptekin Yavaş

In this paper a collection of iron objects from the Anatolian Seljuks Period, ca. 12th–13th century AD, are analysed and discussed from a metallurgical perspective. A total number of 21 iron-steel objects, small knives and flat bodied (*with thin cross-section*) *arrowheads was examined. These objects are coming from the Seljuks' cultural layers of Eğirdir* (*Isparta, Central Anatolian Caravanserai*), *Kubad Abad* (*Konya, Central Anatolian Sultan's Palace Complex*), *and Samsat* (*Adıyaman, Eastern Anatolian Fortress*). *In the samples which were taken from iron tools, composite-like structures formed by different ferrous phases were revealed by metallography, SEM-EDX and micro hardness examinations. These structures are classified according to the production materials and techniques. The first group revealed signs of continuous forging and, in some cases, bloomery iron folding, which can lead to such composite-like structures. The second group consisted of tools which were produced from different starting materials which were forge-welded before or during shaping process. The crucible steel knives can be classified as another group, in which the composite-like structure exhibits totally different constituents leading to more homogeneous mechanical character. In modern times, composite materials have gained importance and become key engineering materials due to their outstanding specific properties. This study reveals that skilled Seljuks' blacksmiths made similar materials design choices in the production of iron or steel objects, despite limited materials and metallurgical knowledge.*

Anatolian Seljuks – multiphase steel – crucible steel – arrowheads – archaeometallurgy

V příspěvku je diskutována kolekce železných předmětů z období rúmského sultanátu, ca 12.–13. stol. n. l., analyzovaná a hodnocená z metalurgického hlediska. Celkem 21 železných předmětů, menších nožů a plochých hrotů šípů (*s tenkým průřezem*). *Předměty pocházejí z kulturních vrstev rúmského sultanátu v Eğirdiru* (*Isparta, středoanatolský karavanseraj*), *Kubad Abad* (*Konya, středoanatolský sultanský palácový komplex*) *a Samsat* (*Adıyaman, východoanatolská pevnost*). *Vzorky odebrané z železných nástrojů vykazovaly struktury podobné kompozitním, sestávající z různých strukturních fází vymezených pomocí metalografie, SEM-EDX a měřením mikrotvrdosti. Dané struktury byly kategorizovány podle užitých materiálů a techniky výroby. První skupina vykazovala známky kontinuálního kování a místy paketování svářkového kovu, které může vést k takovýmto jakoby kompozitním strukturám. Druhá skupina sestávala z nástrojů vyráběných z různých výchozích materiálů, které byly před nebo v průběhu tváření svařovány. Nože z kelímkové oceli lze klasifikovat jako další skupinu, ve které kompozitní struktura vykazuje naprosto odlišné složky, vedoucí k rovnoměrnějším mechanickým charakteristikám. V dnešní době nabyly kompozitní materiály velkého významu a díky svým výjimečným specifickým vlastnostem se staly klíčovými materiály strojírenství. Tato studie odhaluje, že zruční seldžučtí kováři volili podobnou materiálovou konstrukci při výrobě železných nebo ocelových předmětů, navzdory omezeným materiálovým a metalurgickým znalostem.*

anatolští Seldžukové – vícefázová ocel – kelímková ocel – hroty šípů – archeometalurgie

1. Introduction

The presence and variety of microstructural phases results in desirable mechanical properties in structural alloys. For example, advanced high-strength steels can be produced by strengthening ductile ferrite and/or austenitic matrix with the existence of martensite, bainite and/or various carbides (*Springer – Tasan – Raabe 2015*) and titanium alloys combine beta and alpha phases (*Zhang et al. 2017*) etc. For industrial applications, rolling is one of the favourable shaping methods for bonding high carbon steel and alumina stabilized ferrite material. This technique provides better uniformity for the deformations of layers than traditional processes like forging and hammering (*Charles 1998*, 501). The concerns for production of steel objects which are easy to form, shock resistant and production of which is cost-efficient by using the available technologies, were in the Middle Ages similar to those in modern times.

In order to determine the technique and materials used by Anatolian medieval blacksmiths, a total number of 21 arrowheads and knives, dated from ca. 12th to 13th century AD was examined. Because of the domino effect created by the Mongol invasion, Central Asian artisans migrated to Anatolia especially during the 13th century (*Arık 2000*). The transitions can be seen in the architectural designs, stone working and ceramic production, though it is expected that the experienced blacksmiths worked during this period in Anatolia as well. Moreover, as Mongol invasion had reached Anatolia, the new habitants had used similar techniques for construction of buildings, production of ceramics and metals but with some major aesthetical and technical changes. Due to this fact, the archaeometallurgical studies of the finds from this period become more interesting.

Examined iron-steel objects, knives and flat bodied (with thin cross-section) arrowheads, come from the excavations at Anatolian Seljuks' cultural layers of Eğirdir (Isparta, Central Anatolian Caravanserai), Kubad Abad (Konya, Central Anatolian Sultan's Palace Complex), and Samsat (Adıyaman, Eastern Anatolian Fortress).

Samsat (known as Samosata and Sümeysat as well; *Demirkent 1979*, 235), which was submerged under the lake of Atatürk dam in 1990, was one of the biggest mounds of lower Fırat region in Southeastern Anatolia. The mound and the lower city of Samsat was an important cultural centre hosting Hittites, Assyrians, Urartians, Persians, Byzantians, Crusaders, Umayyads, Seljuks, Artuqids, Ayyubids, Mongols and Mamluks. In 1978–1989, during the excavations of medieval cultural layers, a huge set of medieval arrowheads was found. The set consisting of 12.200 arrowheads was found hidden in a medieval tower together with pottery and coins dating from the 12th–13th century (*Öney 1982*, 75; *Özgüç 1986*, 445). Because the assemblage contains also semi-finished arrowheads, knives and pieces of blooms, it is assumed that it is a hoard buried by Seljuk blacksmiths during the Mongol invasion to Samsat.

Kubad-Abad which is situated on the coast of Konya-Beyşehir lake in the Central Anatolia, is a huge city-palace consisting of dozens of buildings spread not only on the coast of the lake but also on the islands and the Anamas mountainside. It had been constructed between 1225–1230 by the order of I. Alâeddin Keykubat, the most powerful Sultan of the Anatolian Seljuks period. In the Kubad Abad city-palace complex, reflecting eastern palace models, buildings for production like smithing, pottery, glass and tile workshops were localized as well as constructions for aristocracy (*Arık 2002*, 264). Till now, 59 arrowheads with a large variety in shapes have been found during excavations. Though it is a small number for such a great complex, the hunting garden (Paradaison), where more iron objects related to hunting are expected, has not yet been excavated (*Yavaş 2012*, 125). Moreover, findings such as part-shaped arrowhead, knives, bloom fragments, smithing

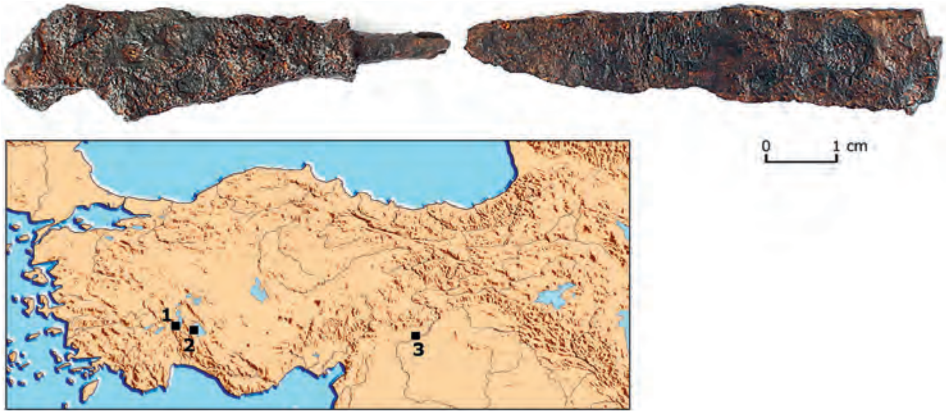

Fig. 1. Examples of the Anatolian Seljuks Iron Objects; flat bodied arrowhead KU.1 no 09 (left) and a small knife KU.1 no 11 (right) from Kubad-Abad. The locations of the sites mentioned in text: 1 – Eğirdir, 2 – Kubad Abad, 3 – Samsat. Map by Ü. Guder.
Obr. 1. Příklady anatolských železných předmětů z období rúmského sultanátu; plochý hrot šípu KU.1 no 09 (vlevo) a malý nůž KU.1 no 11 (vpravo) z Kubad-Abad. Lokality zmíněné v textu: 1 – Eğirdir, 2 – Kubad Abad, 3 – Samsat.

slags etc., proves activity or iron smithing workshop covering needs of the palace (*Güder – Yavaş – Yalçın 2015*).

Sultan II. Keyhüsrev Caravansarai which was constructed in 1237–1238, is the fourth biggest caravansarai of the Anatolian Seljuks period. It is situated on Eğirdir lake shore in the Central Anatolia, which is on the caravan route of Konya-Antalya-Denizli. It fell into ruin for unknown reasons in the second half of the century in which it was constructed (*Bozer 1994*, 98). During the excavations, 62 arrowheads and 2 knives, some of which bore traces of fire which destroyed the building, were recovered.

2. Material and technique

2.1. Samples

Fifteen of the selected objects for material analyses are iron-steel flat bodied arrowheads. Although surfaces of the arrowheads are heavily corroded, they can be classified typologically, and their cores still have solid metal enabling metallography and microhardness analysis. Almost all the arrowheads have tangs circular in cross-section, but their blades differ in shape, thus differences can be seen inside the group. Besides arrowheads with points in the form of a wide angle as seen at *fig. 1*, there are also those ending with sharp spatula-like points and willow leaf-shaped points. According to Mamluk (*Latham – Paterson 1970*, 31), Arabian (*Faris – Elmer 1945*, 107–109) and Ottoman (*Yücel 1999*, 300) treatises, the flat bodied arrowheads were used against unarmoured targets, either during military campaigns (i.e. against horses to take the cavalry down) or for hunting purposes. Contrary to arrowheads with square, round or star cross-sections, flat bodied arrowheads are inefficient for piercing armour and shields.

In total, five knives from three sites were analysed. The blade length of the knives is between 6 and 8 cm. The knives have straight back and their cutting edge rises to meet the back at the tip (*fig. 1*). No or little material remained at the tang part of four knives. Some metallic core survived in all blades, except for the knife SA no 17, which is fully corroded. Considering both the size and archaeological context of the knives[1], it can be assumed that they were used for shaving or similar purposes (*Güder – Yavaş – Yalçın 2015*, 197).

2.2. Analytical techniques

Samples for metallography were taken from the selected objects with air cooled diamond discs. The cutting process was realized with low rotational speeds and with intervals to prevent the distortion of the microstructure by the heat generated during the process. The samples were taken from both tangs and bodies of the arrowheads, and from tangs (when available) and blades of the knives. The samples were mounted in epoxy resin, ground using wet silicon carbide papers with grit sizes from 240 to 1200 and polished using diamond pastes with 6, 3 and 1 micron particle sizes.

The samples were documented at various magnifications by a light microscope before and after etching the samples with 1% Nital etchant. The fully corroded sample from knife (SA no 17) was not etched. Micro-hardness was measured with Vickers hardness tester using a 200 gram load. The micro-indenter was targeted at five different un-corroded and slag inclusion free areas for each sample. Scanning electron microscope was used in the case of the corroded sample (SA no 17) to search for remnants of original metallographic structure possibly surviving in corrosion. High-contrast images created by the Back Scatter Detector (BSD) of the SEM were preferred to detect remnant or ghost structures (*Notis 2002*, 261). Additionally, crucible steel structure elements which were difficult to identify by light microscope, were inspected with SEM and chemical compositions of crucible steel and slag inclusions in arrowheads were checked using EDX instrument attached to SEM.

3. Results and discussion

3.1. Analytical Results

As can be seen from *table 1*, metallographic examinations revealed multi-phased microstructures of the objects, except for three arrowheads. In one of the single phased samples (SA no 25) equiaxial ferrite grains and in two others (EGI no 22 and EGI no 51) elongated ferrite grains are the only structures observed. Micro-hardness tests on SA no 25 gave values corresponding to a soft iron structure, which are between 81 and 87 HV. On the other hand, the hardness values of EGI no 22 are between 160–173 HV which is higher than expected for ferritic structure. The elevated hardness is caused by the deformation of ferrite grains due to cold working (*Sherby – Wadsworth 2001*, 348). The homogeneous structures of samples provide little derivation between minimum and maximum hardness throughout the sample.

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[1] Two knives coming from Kubad-Abad were found where the palace was connected with the hamam (a Turkish bath).

No.	Sample Code	Site	Period (century)	Object Type	Steel Type[1]	Micro-structure[2]	Classification	Hardness[3]
1	SA no 13	Samsat	12th–13th	Knife	Hypereutectoid	Glob. Cementite	(III) Crucible Steel	280–401
2	SA no 17	Samsat	12th–13th	Knife	Hypereutectoid	Cementite Needles	(III)Crucible Steel	N/A
3	SA no 25	Samsat	12th–13th	Arrowhead	Iron	Equiaxial Ferrite	None	81–87
4	EGİ no 02	Eğirdir	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(I) Forging/ Folding	128–234
5	EGİ no 22	Eğirdir	13th	Arrowhead	Hypoeutectoid	Elong. Ferrite	None	160–173
6	EGİ no 51	Eğirdir	13th	Arrowhead	Iron	Elong. Ferrite	None	N/A
7	EGİ no 54	Eğirdir	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	189–249
8	EGİ no 62	Eğirdir	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(I) Forging/ Folding	145–189
9	EGİ no 44	Eğirdir	13th	Knife	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	N/A
10	KU.1 no 04	Kubad Abad	13th	Knife	Hypereutectoid	Glob. Cementite	(III) Crucible Steel	254–380
11	KU.1 no 06	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	171–198
12	KU.1 no 07	Kubad Abad	13th	Knife	Hypoeutectoid	Fer.-Pear.-Mar.	(II) Piled Steel	111–608
13	KU.1 no 08	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	102–213
14	KU.1 no 09	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	125–184
15	KU.1 no 10	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	195–271
16	KU.1 no 11	Kubad Abad	13th	Knife	Hypoeutectoid	Fer.-Pear.-Mar.	(II) Piled Steel	119–543
17	KU.2 no 01	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(I) Forging/ Folding	189–234
18	KU.2 no 02	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	N/A
19	KU.2 no 03	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(I) Forging/ Folding	N/A
20	KU.2 no 04	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(II) Piled Steel	N/A
21	KU.2 no 08	Kubad Abad	13th	Arrowhead	Hypoeutectoid	Fer.-Pear.	(I) Forging/ Folding	184–249

Tab. 1. List of analysed objects from three archaeological sites. [1]Classification according to the carbon content; iron is zero carbon material. Hypoeutectoid steel; carbon content is lower than 0.76 %. Hypereutectoid composition has carbon higher than 0.76 %. [2]Abbreviations: Glob. Cem. Globular Cementite, Elong. Elongated, Fer. Ferrite, Pear. Pearlite, Mar. Martensite. [3]Minimum and maximum Vickers (HV 0.2) hardness values.

Tab. 1. Seznam analyzovaných předmětů ze tří archeologických lokalit. [1]Klasifikace podle obsahu uhlíku; železo je materiál s nulovým obsahem uhlíku. Hypoeutektoidní ocel; obsah uhlíku je nižší než 0,76 %. Hypereutektoidní složení má uhlík vyšší než 0,76 %. [2]Zkratky: Glob. Cem. globulární cementit, Elong. prodloužený, Fer. ferit, Pear. perlit, Mar. martenzit. [3]Minimální a maximální hodnoty tvrdosti podle Vickerse (HV 0,2).

When the existing phases were pearlite and ferrite, alignment of two or more layers parallel to the cross-section were observed. These layers in seven arrowheads and three knife samples (classified as (I)Piled Steel in *tab. 1*) can be easily noticed since they run across the whole cross section, and their borders, rich in slag inclusions, are well defined. The slag-rich lines being well visible in unetched conditions were found to be borders between different structural layers revealed by etching. As seen at *fig. 2*, these borders were also accompanied by welding lines in some examples.

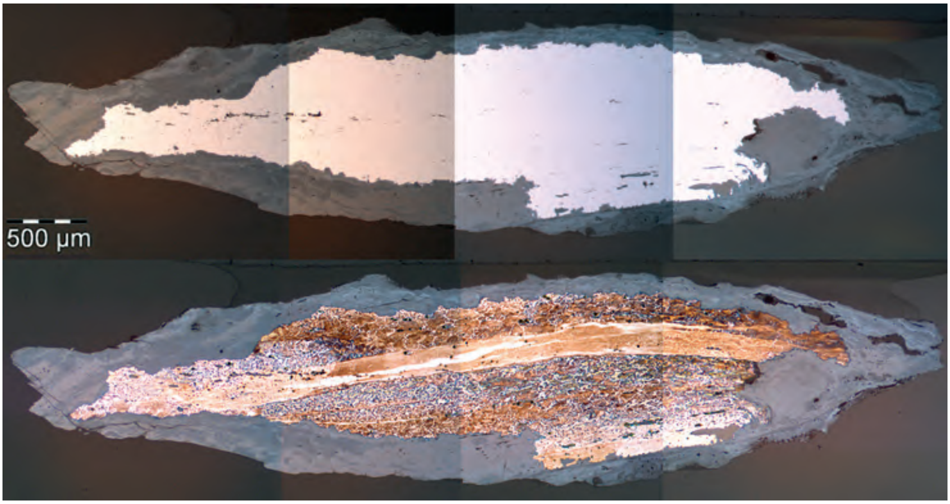

Fig. 2. Polished cross-section of an arrow-head (KU no 10) in unetched state (up) and after Nital etching that revealed two welding lines (down).
Obr. 2. Leštěný řez hrotem šípu (KU č. 10) v neleptaném stavu (nahoře) a po naleptání nitalem, které zobrazilo dvě svařovací linie (dole).

Metallography of the knives EGI no 44, and KU.1 nos. 07 and 11, revealed a sandwich construction consisting of medium- and low-carbon steel layers, with the medium-carbon steel in the centre of the blade. The blade KU.1 no 07 has a welded-on back of soft iron. The small amount of slag inclusions, except the smithing-slag inclusions, points out the use of well refined materials. The microstructure shows also traces of quenching and tempering. The distribution of martensite indicates that the whole of the blade was quenched and hardness measurements indicate slight tempering to relieve some stress and decrease the brittleness of the blade.

The concentration of slag inclusions differs from layer to layer, depending on how well refined was the material used in the particular place. The chemical compositions of slag inclusions from individual layers were measured by SEM-EDX equipment. It is expected that the line in the FeO/SiO_2 ratio graph has a characteristic slope for each material/layer, as it depends on the overall composition of the inclusions analysed (*Buchwald – Wivel 1998*, 77). Values of FeO and SiO_2 obtained by EDX analysis of the arrowhead KU no 08 were plotted in the FeO/SiO_2 graph that shows two lines with different slopes suggesting use of two different materials for the production of the object (*fig. 3* and *4*). The linear distribution of analytical ratios belonging to non-reducible impurities (i.e. Al_2O_3/ SiO_2) was observed as well.

Although layered multi-phase structures were observed also in other five arrowheads (Nos 4, 8, 17, 19, 21) the layers are somehow disordered, in some examples localized, and it is difficult to distinguish their borders. In these samples, mostly welds suggesting folding rather than deliberate construction are observed. To succeed in forge welding, the pieces to be welded must be heated at correct working (welding) temperature which depends on the carbon content, and their surfaces must be kept clean, mostly by means of fluxes

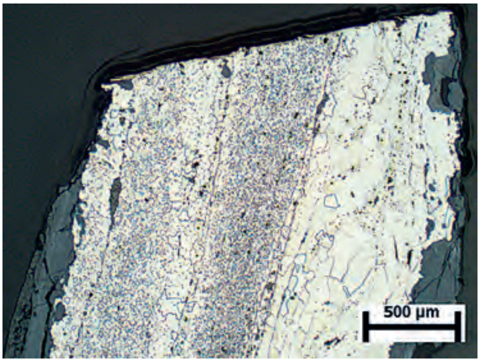

Fig. 3. Etched cross-section of an arrow-head (KU no 08) showing at least four layers.
Obr. 3. Naleptaný průřez hrotu šípu (KU č. 08) s nejméně čtyřmi viditelnými vrstvami.

(*Pleiner 2006*, 59). Welding lines associated with simple folding are thicker and mostly accompanied by corrosion products, since the working temperature was not high enough and/or the necessary flux to clean the surface had not been applied (*fig. 5*).

The micro-constituents in three knives (SA no 13, 17 and KU.1 no 04) from Samsat and Kubad Abad are different. In two of them (SA no 13 and KU.1 no 04) the carbon content can be estimated at around 2 %. In the microstructure pro-eutectoid enormous cementite particles form chains running parallel to the cross sections. In between, globular or semi-globular pearlite as very fine background could only be detected by SEM observations. For the fully corroded SA no 17, SEM images were used to detect the relics of metal, the ghost structures of cementite grain boundary network and cementite needles. A similar structure is observed in one of the Ulfberht swords and described as formed by smithing a crucible steel billet (*Williams 1977*). As a characteristic feature of these objects, EDX analysis on solid metal parts gave high manganese content values between 0.50 % and 2.5 %, which fit the crucible steel batches in historical records which mention manganese as an important ingredient since Zozimos of Panopolis 2nd century AD (*Gilmour 2009*, 139).

Both low and high hardness values, varying from 102 to 608 HV0.2, were recorded in multi-phased steel tools. The hardness of arrowheads showing ferritic and pearlitic layers varies between 30 and 100 HV0.2, depending on the character of the structure (grain size, form and amount of cementite, etc). On the other hand, high hardness values (400–500 HV) were measured in knives KU nos. 07 and 11, which were produced by iron, low carbon and tempered martensite phases. In contrast, the knives made from crucible steel (SA no 13 and KU 1. no 04) have more uniform hardness (depending on the intender targeted for globular cementite background or pro-eutectoid cementite islands) ranging between 254 and 401 HV.

3.2. Evaluation of results and classification of multi-layered steel objects

During the production of blooms consisting mostly of iron and low-carbon steel, parts with a variable carbon content were inevitably formed due to the nature of the smelting process. At the end of the primary smithing of the blooms, semi-finished products are produced with an heterogeneous carbon content, as can be seen from the inspection of medieval iron ingots (*Güder et al. 2015*). It is obvious that multi-phase layers occur when

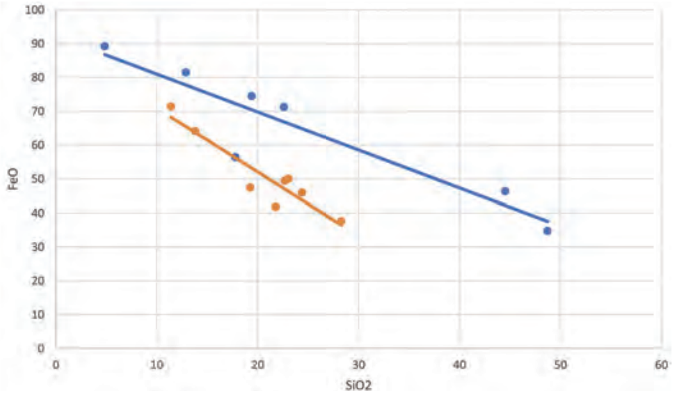

Fig. 4. FeO/SiO_2 chemical composition ratio graph created by SEM-EDX measurements on slag inclusions from two different layers in KU no 08.
Obr. 4. Graf poměrů FeO ku SiO_2 získaných SEM-EDX analýzou vměstků hutní strusky ve dvou různých vrstvách hrotu KU č. 08.

a blacksmith forms a thin sectioned object from starting material with heterogeneous character by continuous forge and folding procedure. Additionally, recycling and repairs of iron objects were common in medieval smithing since the value of the material itself was not negligible. During the recycling process, forge welding was also applied to consolidate small fragments of iron to bigger ones. This is another procedure which creates a material containing different phases. Thus, in some cases it is difficult to distinguish between accidentally or deliberately formed layers (*Lang 1984*, 62). Therefore, it is a good strategy to judge the effect of material design to the functionality of the tool. Inspection of medieval knives shows that blades with cutting edges of steel and backs of softer material, such as iron, were the standard (*Blakelock – McDonnell 2007*, 55). In this case the skill of blacksmiths determines the engagement of different materials, since the welding of mild steel and ferritic iron is difficult to apply (*Light 2000*, 335). Knives with welded-on steel cutting edges cannot function well when the steel part is worn off. So, they have to be either repaired or discarded. Therefore, a material which can combine all the most required mechanical properties, such as hardness, wear-resistance, strength and toughness would be preferred in the whole body of the tool. Crucible steel was an expensive but a very suitable material to solve the problem; this was a high-quality material in terms of mechanical properties, valued also for the possibility to reveal an attractive wavy-patterned surface. Two procedures are known how to make a crucible steel. In the first one which was described by al-Tarsusi in the 12th century, wrought iron is heated by organic matter to increase the carbon content. In the latter, cast iron is used to carburize the wrought iron, as noted by al-Biruni (973–1048) (*Williams 2007*, 234). Evaluation of the analytical study over Seljuks iron objects provide us with understanding the material and technical concerns of blacksmiths to produce the best functioning objects.

First to say; ferritic iron was not a common choice for production of thin sectioned arrowheads, although it was the case for square sectioned ones when other hardening techniques were applied (*Güder 2017*, 24). Excluding three arrowheads consisting mostly of ferritic iron, the artefacts can be divided into three main groups according to the way in which their multi-phase layered structure was formed. Objects in the first group are those whose structure was formed due to the nature of starting material, continuous forging and in some cases folding and forge-welding. The second group features forge welding of dif-

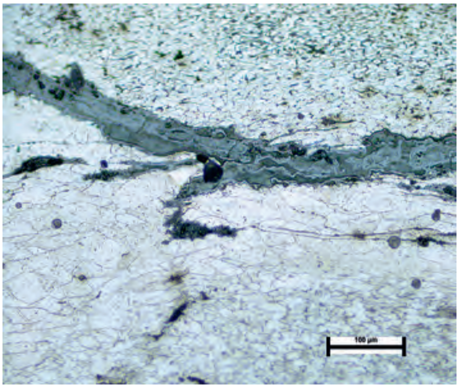

Fig. 5. Folding line and inhomogeneity of the structure in an arrowhead (EGI no 62).
Obr. 5. Překladová linie a nehomogennost struktury v hrotu šípu (EGI č. 62).

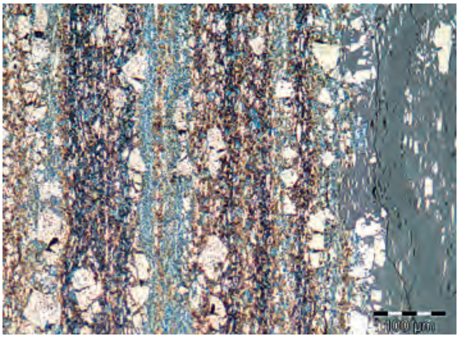

Fig. 6. Layers of large cementite particles in spheroidised pearlite matrix from a crucible steel blade (KU no 04).
Obr. 6. Vrstvy velkých cementitických částic v matrici sferoidizovaného perlitu v čepeli nože z kelímkové oceli (KU č. 04).

ferent starting materials and additional, thermo-mechanical applications such as quenching, tempering. The last group features the smithing of hypereutectoid steels in which the layered micro-structure is a result of forging and tempering cycles.

Five arrowheads, belonging to the first group, are thought to be forged from heterogenous starting material since the different phases are not well layered. Here, simple welding lines inside the structure were observed.

On the other hand, in the second group with seven arrowheads, the layers are clearly bordered with slag stringers which were formed by using fluxes during the forge welding. The stringers can also be seen clearly in the samples in unetched condition. Clear lines of layers with different characters are not a sufficient evidence for deliberate forge welding of materials with different carbon content, since bloomery steel structures can be easily misinterpreted. Further investigations, such as observations of welding lines, different concentration of slag inclusions and the chemistry of slags in different layers, are done on the micro-structures for further clarification. Layer formations caused by the use of recycled material are difficult to recognise, since similar analytical results could be reached. However, using recycled material to forge a nail or a square/round sectioned arrowhead which are consumables in military armoury or constructions, would not be a problem. But if this thin sectioned arrowhead, which needs to have more tensile strength and impact fracture than the rectangular or circular sectioned ones, will be used for Sultan's hunting (in Kubad-Abad), then it is expected that the blacksmith would not leave the success of the tool to chance and would use his experience to produce good-quality arrowheads as well.

The best examples of layered steels were observed in small knife blades of this period. Medium carbon and low carbon steel materials were observed as alternative layers, which were forged in a way that the medium carbon layer stays in the middle and forms the cutting edge. The small amount of slag inclusions shows the use of well refined blooms in the production. Traces of quenching and tempering can be seen in the microstructure as well. As seen from the distribution of martensite, the knives were fully quenched and hardness measurements show slight tempering to relieve some stress and decrease the brittleness.

The last group consists of special layered microstructures observed in the knives made of crucible steel. In the set of Anatolian Seljuks' iron finds, there are not only knives made of crucible steel which is thought to be the most precious forging material of the period, but also smithing evidences such as pieces of crucible steel ingot, high manganese bearing smithing slags and a scrap piece of knife. Skilfully applied forging and cooling cycles on the crucible steel ingots which have a homogeneous high carbon content, turns the microstructure including cementite needles to the layers created with broken cementite particles in a spheroidised pearlite matrix (*fig. 6*). This structure is also the reason of the attractive damask pattern on the surface of the knives (*Verhoeven – Jones 1987*). The chemical and mechanical features of these layered steel objects, which were detected by micro-hardness tests and SEM-EDX analysis, points out the distinctive character when compared to the other products.

4. Conclusions

As a result, this general overview of the iron products from the Anatolian Seljuks' period demonstrate the traces of the variety of the metallurgical materials and skills of the region. On the other hand, the migration of artisans from Central Asia caused the enrichment of the metallurgical knowledge and it is concluded that the production of skilful blade designs with piled steel, usage of piled steel in arrowheads and smithing of crucible steel show the interest of medieval blacksmiths to produce artefacts with composite-like structures having better mechanical properties.

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ÜMIT GÜDER, Laboratory for Archaeometric Studies, Çanakkale Onsekiz Mart University, ÇOBİLTUM, Terzioğlu Kampüsü, 17020 Çanakkale, Turkey; uguder@comu.edu.tr
CEMAL CEM TAŞAN, Department of Materials Science and Engineering, Massachusetts Institute of Technology, 77 Massachusetts Ave., 02139 Cambridge, MA, United States; tasan@mit.edu
ALPTEKIN YAVAŞ, Department of Art History, Çanakkale Onsekiz Mart University, Fen Edebiyat Fakültesi, Terzioğlu Kampüsü, 17020 Çanakkale, Turkey; alptekinyavas@hotmail.com

NOVÉ PUBLIKACE

Daniel Sosna – Lenka Brunclíková (eds.): Archaeologies of Waste: Encounters with the unwanted. Oxbow books, *Oxford – Philadelphia 2017*. 190 str. s 40 obr.

Náplň sborníku tvoří příspěvky přednesené roku 2013 v rámci plzeňského výročního setkání EAA v sekci nazvané „Garbage and (Non)-Humans" a mezi přispěvateli nalezneme čtrnáct badatelů z osmi evropských zemí a z USA. Jedná se tedy o téma velmi závažné, protože konceptuální, teoretické a metodické zacházení s tím či jiným způsobem vyřazenými součástmi lidské kultury lze pokládat za jednu z možných definic archeologie. Recenzent proto tento svazek otevíral se zvědavostí, zda pod obálkou nesoucí mnohoznačný podtitul nalezne konvolut víceméně mimoběžných textů, nebo zda se editorům podařilo zvládnout nelehký dramaturgický úkol a uspořádat výsledný sborník tak, aby poskytoval ucelené sdělení. Tento úkol byl jistě o to náročnější, že příspěvky otevírají témata spojená s neolitem, dobou bronzovou, středověkem, novověkem i archeologií moderní společnosti. Přesto je možné říci, že D. Sosna a L. Brunclíková dokázali texty uvést a strukturovat takovým způsobem, že je třeba publikaci přiznat nejen syntetické, ale i didaktické kvality.

Myšlenkově obohacující a velice čtivé pojetí samozřejmě nemohlo vzniknout bez mnoha kompromisů. Tím nejzřetelnějším je úplná absence příspěvků reflektujících „klasickou" archeologickou práci se sídlištním odpadem (a její metodu), jež v „každodenní" archeologické praxi kvantitativně nesporně převažuje, a která – ve své procesualismem ovlivněné podobě – dnes výrazně formuje konceptuální a teoretický charakter zejména středoevropské archeologie. Editoři sborníku se s tímto tématem vyrovnali jediným odstavcem v úvodní stati, přičemž českou a moravskou stopu na tomto poli (srov. *Kuna 2015*; *Kuna et al. 2012*; *Macháček 2001*) vykazují do bizarně definované badatelské skupiny „*archaeologists from other language communities*" (s. 3). Pro D. Sosnu a L. Brunclíkovou ale představuje procesualistu *sensu lato* např. i behaviorista M. B. Schiffer (srov. *Schiffer 1987; 1995*), takže z jejich pohledu (zejména díky příspěvku P. Květiny a J. Řídkého, inspirovaného Schifferovou klasifikací archeologických transformací) nemusí být „deficit procesualismu" v rámci svazku tak výrazný.

První kapitola knihy pochází z pera editorů (1–13) a podává velmi užitečný, byť nutně zhuštěný nástin současného stavu evropské a severoamerické garbologie (tj. společenskovědní supra-disciplíny studující odpad). V závěru potom podává poměrně rozsáhlý popis struktury a koncepce předkládané publikace. Ta je členěna na tři tematické celky, a sice *Value of the Unwanted, Social Practice: Consumption and Differentiation* a *Positioning Waste: Spatial Nature of Waste.*

První oddíl publikace, který se zabývá *hodnotou nechtěného*, uvozuje teoretický příspěvek, jehož autorem je přední americký garbolog Joshua Reno (18–22). Cílem jeho eseje je poukázat na různé významy slov odpad a hodnota, tedy nejen na význam stanovený lidmi, zpravidla na základě velmi prozaických měřítek, tak i na význam obecnější, ontologický. Následující, materiálově orientovaný text německé archeoložky Laury Dietrich (23–40) tematizuje hodnotu odpadu na ose profánní – rituální, a to na příkladu transylvánského sídliště střední až mladší doby bronzové v Rotbavu. První skupinu pak uzavírá text Rooseho van Oosten (41–56), který na základě písemných zpráv i archeologických dokladů rozebírá různé přístupy k čištění žump v nizozemských městech 17.–19. století. Zatímco některé komunity pokládaly jejich obsah za bezcenný, jiné jej využívaly k zúrodnění svých polí.

Rovněž druhý tematický okruh, který otázku hodnot odpadu překlápí k otázce procesů jeho vzniku a nakládání s ním, rovněž uvozuje teoretická stať, jejímž autorem je švédský kulturolog Anders Högberg (59–64). Všímá si způsobů zacházení s odpadem a jeho vnímáním napříč chronologickými obdobími (od neolitu po současnost) i kategoriemi odpadu (sídlištním počínaje a nukleárním konče). Navazující kapitola je dílem Eda Lyne a Camilly Haarby Hansen (65–82), kteří měli možnost analyzovat mohutné odpadní souvrství v příkopu novověkého opevnění Kodaně. V městském prostředí zůstává též studie Arva Haaka (83–99), který se vrací zpět do středověkého období, konkrétně do estonského Tartu. Díky specifickým podmínkám, které umožňují zachování organických materiálů, bylo možné rekonstruovat způsob výběru vyřazovaných artefaktů a ekofaktů z různých sociálních prostředí středověkého města.

Do českého prostředí nás poprvé na stránkách sborníku přivádí Lenka Bruncliková (100–120), která shrnuje výsledky garbologicko-etnografického výzkumu prováděného ve třech specifických sociálních prostředích Plzeňského kraje. V těch svých partiích, kde se příspěvek drží vymezeného tématu, přináší někdy očekávatelné, ale často překvapivé poznatky o současné české společnosti, které by jinými poznávacími postupy (např. etnografickou dokumentací) zřejmě nebylo možné podchytit. Proto zaráží, že se autorka rozhodla zařadit na úvod a závěr svého textu – s vlastním výzkumem zcela nesouvisející – úvahu, která velmi schematicky a bez jakékoliv materiálové opory předpokládá nástup fenoménu *moderního konzumu* v českém prostředí až v souvislosti se společenskými změnami po roce 1989. Do té doby podle autorky neměl stát v rámci centrálně plánovaného hospodářství, na rozdíl od západních zemí, využívat privátní spotřebu k prosazování své politiky. L. Brunclíkové tak evidentně unikla ta část diskurzu historiografie soudobých českých dějin, která pravidelně upozorňuje na posilování konzumu zejm. v době normalizace jako nepojmenované kompenzace za restrikce v rovině politických a občanských práv (srov. např. *Franc 2005*; *2011*; *Schindler-Wisten 2007*). Doklady, že pohled L. Brunclíkové je příliš zploštělý, lze ostatně vést i na rovině artefaktuální. Čím jiným než alespoň hrou na konzum byly škodovácké maloseriové modely 60. a 70. let Škoda 1000 MBX nebo legendární Škoda 110 R? Ikonické „Erko“ dokonce sehrálo propagandistickou roli v jedné z epizod „konzumního“ seriálu *Žena za pultem*. Nadoborovost garbologie by skutečně neměla být nástrojem k legitimizaci nekontrolovaných extempore na poli jiných disciplín.

I na úvod poslední části sborníku byl zařazen teoreticky laděný text, tentokrát z dílny Sabine Wolfram (123–126), který plní funkci vstupního zamyšlení nad následující trojicí materiálových příspěvků. Hned první z nich, jehož autory jsou Petr Květina a Jaroslav Řídký (127–144), se vrací k české problematice, konkrétně k výpovědním možnostem sídlištního odpadu o prostorovému chování neolitických populací v Bylanech na Kutnohorsku. Jedenáctá kapitola (145–161) přenese čtenáře do Irska, konkrétně na ohrazené sídliště Stamullin z pozdní doby bronzové. Clíodhna Ní Lionáin rozlišuje hned několik symbolických rovin hodnocení a na něj navazujícího vyřazování artefaktů a upozorňuje na skutečnost, že archeologické nálezy procházejí v principu obdobným procesem znovu po svém vyzvednutí, tj. v rukách archeologů, jejichž přístup k jednotlivým kategoriím a typům nálezů rovněž nepostrádá značné množství selektivnosti. Všechny tyto procesy evaluace a selekce (minulé i recentní) pak přirozeně výrazně ovlivňují výsledky archeologického poznání.

Poslední kapitola je dílem Daniela Sosny (162–178). Její jádro představují výsledky několikaleté garbologické studie, kterou autor realizoval na skládce komunálního odpadu, kam je vyvážen odpad z plzeňské aglomerace. Na rozdíl od L. Brunclíkové, jež se zaměřila na výběr materiálu, který se dostává do sběrných nádob, D. Sosna si vybral jako předmět svého výzkumu samotnou skládku. Jelikož se na první pohled zdá, že se jedná o zcela statický fenomén (opak se však nakonec ukáže pravdou a D. Sosna identifikuje hned trojí plynutí času na skládce: s. 168–169), je úložiště komunálního odpadu uchopeno prostřednictvím svého prostorového kontextu, ovšem nikoliv ve smyslu geografickém, nýbrž významovém. D. Sosna netematizuje moderní skládku jako svérázný nadkomunitní areál, nýbrž prostřednictvím konceptu heterotopie *M. Foucaulta* (*1998*, zvl. 181) jako místo, jež je mimo veškerá jiná místa, které *„má tedy schopnost klást vedle sebe na jednom reálném místě prostorové vazby, které jsou samy o sobě nekompatibilní.*“ Jako gordický uzel je tak přeťata vazba mezi předměty, které se společně ocitly v jediném kontextu, takže jejich role již není dokumentovat proces, jímž se pospolu v odpadovém areálu ocitly (což v případě soudobé skládky beztak nezakládá smysluplnou badatelskou otázku), nýbrž symbolicky reprezentovat své původní významové vazby, které naopak mohou odhalovat ty aspekty života soudobé společnosti, které jinak zůstávají mimo pozornost a poznávací možnosti společenských věd. Příspěvek tak velmi kultivovaným způsobem otevírá pro archeologické studium moderní a soudobé společnosti celou řadu otázek, např. problém přiměřeného konceptu strukturování industriální krajiny obecně.

O závěrečné shrnutí editoři požádali Claudii Theune-Vogt (179–183) a její shrnující text korunuje míru serióznosti, s nímž editoři ke svému počinu přistupovali. Bez ohledu na jisté redakční nedodělky (např. vadné psaní velkých písmen v českých titulech citovaných prací či kolísání zkratky LBK a LPC) nelze než pokládat celý publikační záměr za výbornou vizitku editorů i názornou demonstraci pozoruhodných výsledků, jichž mohou tuzemské badatelské instituce působící v oblasti společenských věd dosahovat na mezinárodním vědeckém fóru.

Jan Hasil

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Ivan Lehký – Milan Sýkora (eds.): Kalich a Panna. Hrady Jana Žižky. Ústav archeologické památkové péče severozápadních Čech, *Most 2016*. 313 str.

Monografie o Kalichu a Panně jak celkovou koncepcí, tak grafickou úpravou přesně koresponduje s o rok starší publikací o Oltáříku, dalším severočeském hradu s kališnickou minulostí, konkrétně spjatou s hejtmanem Jakoubkem z Vřesovic (*Lehký – Sýkora eds. 2015*). Trojice sídel v Českém středohoří se už symbolikou svých názvů řadí mezi ukázkové příklady hradních novostaveb husitské doby. Po stránce architektonické se od sebe v mnohém liší, také ale vykazují řadu společných znaků. Signifikantní je jejich shodná poloha na vrcholcích výrazných homolovitých kopců, těžko ohrozitelná palbou z velkých děl, která doznala prudkého zdokonalení právě v 1. polovině 15. století.

Kalich a Panna jsou v jednom ohledu dosti výjimečné, a sice neobvykle krátkou vzájemnou vzdáleností, jež vzdušnou čarou obnáší necelé 2 km. Příčinné souvislosti této skutečnosti detailně rozkrývá Milan Sýkora v úvodních kapitolách recenzované knihy, pojatých hlavně jako ucelený přehled vývoje držby obou hradů. Jejich dějiny autor barvitě zasazuje do širokého kontextu politických a válečných událostí severních Čech, se zvláštním zřetelem k Litoměřicku a Ústecku. Vychází z bohaté literatury i vlastní kritické analýzy písemných pramenů, které nepříjemně často dovolují různé interpretace.

Hlavní postavou Sýkorova výkladu paradoxně není Jan Žižka, nýbrž jeho nepřítel, katolík Zikmund Děčínský z Vartenberka, což přirozeně vyplývá z životních osudů protivníků. Zatímco husitský hejtman umřel r. 1424, Vartenberk patřil k hlavním aktérům dění v severozápadních Čechách po celou dobu husitských válek, které tu víceméně bez přerušení trvaly do samého konce 30. let. Císařovu straníku je v závěru knihy věnován biografický exkurz sepsaný Markem Rubešem.

Zkoumané hrady, které se nacházely v zásobovacím okruhu Litoměřic, vznikly v podstatě současně. Žižkou založený Kalich vyrostl v průběhu léta 1421. Už v této fázi byl dobře hájitelný, neboť v září stejného roku odolal obléhání, které bylo součástí druhé křížové výpravy. V této kampani se na Litoměřicku proti husitům silně angažoval zmíněný Vartenberk, jenž patrně na podzim 1421 vybudoval hrad Pannu jakožto opěrný bod speciálně namířený proti Kalichu. Ze vzájemného měření sil však poměrně rychle vyšli vítězně husité, kteří Pannu dobyli r. 1423. Nezbořili ji, nýbrž obsadili a patrně výrazně stavebně upravili, resp. posílili její fortifikační systém. K tomu Milan Sýkora podotýká, že pro husity muselo být vydržování dvojice hradních posádek v těsném sousedství po řadu let velmi náročné. Za trvalým obsazením Panny proto shledává silný důvod. Konkrétně se domnívá, že kališničtí vojevůdci nechtěli připustit, aby se kopce znovu zmocnili Lucemburkovi přívrženci. Posádky Kalichu a Panny kapitulovaly až v r. 1437, kdy císař inicioval po celém království kampaně proti posledním představitelům radikálního husitského křídla. Panna byla po dobytí zbořena, Kalich naopak přetrval do konce 15. stol., do kdy fungoval jako centrum nepříliš rozsáhlého panství.

Po podrobném vylíčení dějin obou hradů následuje nejobsáhlejší oddíl knihy, a sice zevrubný popis a interpretace terénních útvarů a zbytků zdiv. Autorem příslušných kapitol je znovu Milan Sýkora, tentokrát ve spolupráci s Ivanem Lehkým. Oba jsou zároveň hlavními tvůrci plánové dokumentace, jejíž detailnost a přehlednost vzbuzuje velký respekt. Přesná zobrazení stavebních pozůstatků a celkového terénního reliéfu vznikla kombinací klasického geodetického měření s leteckou fotogrammetrií. Nutno dodat, že autoři jsou průkopníky této efektivní dokumentační metody. Za ocenění stojí i početné fotografie, které spolu s plány rychle a velice dobře evokují celkovou terénní situaci.

Z hlediska problematiky fortifikační architektury husitské doby představuje Panna mnohem vhodnější předmět studia než Kalich, který prošel řadou úprav, jejichž periodizace vyžaduje – vzhledem ke stavu dochování stavebních reliktů a absenci pevných opor absolutního datování – složitou diskusi, často ovšem bez vyhlídky jednoznačných závěrů. Totéž se však týká i pozůstatků Panny, na povrchu terénu nesrovnatelně hůře „čitelných“ oproti Kalichu, což je ale vlastně skutečnost svým způsobem výmluvná. Obecně totiž platí, že v rámci fortifikačního stavitelství husitské doby se ve vysoké míře uplatňovaly konstrukce kombinující dřevěné prvky, náspy a na sucho kladené zdivo (resp. plenty náspů). Takové spíše terénní úpravy poměrně snadno podléhaly samovolné destrukci. Jak autoři připomínají, nešlo o konstrukce provizorní, nýbrž cíleně budované jakožto vhodné platformy pro lafetované zbraně i střelce z ručních zbraní, případně jakožto tělesa, která dělostřelbě účinně odolávala. Jedním dechem pak dodávají, že významnou roli hrály i jiné faktory, zvláště úspornost a konstrukční jednoduchost fortifikací budovaných bez malty.

Výsledky povrchového průzkumu zříceniny Kalichu jsou od r. 2015 prohlubovány archeologickým odkryvem realizovaným v závislosti na postupu konzervačních úprav reliktů zdiva. Výsledky dvou prvních výkopových sezón v knize zevrubně prezentují Milan Sýkora s Martinem Volfem. Plošně omezenými sondami se podařilo upřesnit představu o podobě a vývoji hradního jádra a formě jeho obvodové fortifikace. Po svazích kopce se vinulo několik linií terasových a valových náspů zpevněných kamennými, na sucho kladenými plentami. Ivan Lehký s Milanem Sýkorou předpokládají, že to byly platformy srubových konstrukcí, snad komorových a s kamennými výplněmi. Alternativně uvažují o existenci zdvojených palisádových stěn s meziprostorem vyplněným rovněž kameny. K uvedeným interpretacím je přivedlo studium dobových obrazových pramenů, většinou zahraniční provenience.

Dosti intuitivně formulované závěry ohledně konstrukčního rázu zmizelých nástaveb obvodových fortifikací Kalichu a Panny zasluhují zvláštní ocenění. Vzápětí totiž byly v podstatě verifikovány díky publikaci archeologického odkryvu vnějšího opevnění moravského hradu Skály, který v průběhu husitských válek sloužil jako útočiště lapkovských družin a v polipanské době i táboritů (*Belcredi 2017*). Nejspíš právě ve 30. letech se jeho opevnění rozrostlo o řadu bašt a dalších obranných prvků, jež v principu vykazují stejné konstrukční řešení, o jakém uvažují I. Lehký s M. Sýkorou. Vnější opevnění hradu Skály lze mimořádně uceleně rekonstruovat podle rozsáhlých zbytků dřevěných prvků zakonzervovaných požárem, který vypukl v souvislosti s dobytím v r. 1440.

Na fortifikačním systému Kalichu je nejpozoruhodnější mohutná zemní bašta, vysunutá před hradní jádro, aby flankovala přístupovou komunikaci. Otázkou ovšem je, ke které stavební fázi tento vývojově vyspělý objekt, k němuž scházejí přímé analogie, náleží. Autoři jej hypoteticky kladou do 40.–60. let 15. stol. a ryze spekulativně rekonstruují jeho roubenou vícepodlažní nástavbu, která měla zabírat celé temeno (dochovaného) kónického náspu s kamenným pláštěm.

Některé závěry Ivana Lehkého a Milana Sýkory ohledně stavebního vývoje jádra Kalichu se mi jeví jako příliš hypotetické, resp. nedoložitelné. Takto na mě působí jejich představa, že hrad už ve 20. letech plnil úlohu plnohodnotné rezidence, resp. rodového sídla Jana Žižky. I po prvních sezónách exkavace totiž scházejí opory bližší absolutní datace zbytků zástavby. Ještě menší důvěru mám k prezentované rekonstrukci podoby Panny, jež vychází pouze z povrchového průzkumu. Nenápadné terasy a destrukce několika zídek ve svazích pod hradním jádrem se v očích autorů stávají pozůstatky důmyslného a půdorysně poměrně komplikovaného fortifikačního systému s řadou záhybů a bašt – prvků aktivní obrany. Mimochodem, předchozí bádání registrovalo pouze relikty zástavby na samém vrcholu kopce, o pozůstatcích vnějšího opevnění nemělo potuchy. Proto je nutné vysoce ocenit výsledky nejnovějšího průzkumu, zároveň je ale třeba mít na paměti, že už do kresebné dokumentace terénních útvarů se mohla ve významné míře promítnout kýžená představa o vzhledu husitské pevnosti. Mám zkrátka dojem, že obrysy umělých teras a dalších objektů, situovaných v silně erodovaných svazích, autoři zčásti nakreslili odhadem.

Jestliže už samotná dokumentace terénních a stavebních reliktů Panny vyvolává otázky, při diskusi nad předloženými rekonstrukcemi zmizelé podoby obou hradů se jen těžko hledají nějaká objektivní hodnotící kritéria. Ivan Lehký s Milanem Sýkorou vytvořili pomocí počítače odvážné hyperrealistické vizualizace, jejichž výtvarný styl a míra detailnosti vzbudí protichůdné, na individuálním vkusu závislé reakce. Obrázky z ryze odborného hlediska – jak se domnívám – postrádají význam, evidentně cílí na laiky. Proto vyvstává otázka, do jaké míry má archeologie (kastellologie) reagovat na aktuální trendy populární kultury, a nyní tedy hledat inspirační zdroje ve vizuálním stylu počítačových her, které vytvářejí iluzi středověku. Mému vkus odpovídají mnohem více rukodělné výtvarné techniky (hlavně akvarel a kvaš), které dodnes představují naprosto dominantní směr tvorby rekonstrukcí pro západoevropskou kastellologickou literaturu, v čele s britskou, jejíž velká část je určena právě pro širokou veřejnost. Na vizualizacích dávného vzhledu Kalichu a Panny mi přijde zavádějící hlavně jejich detailnost, byť právě díky tomu budou pastvou pro oči asi mnoha laiků. Serióznější by také bylo, kdyby autoři předložili několik rekonstrukčních návrhů, a nikoli pouze jeden, který efektně natáčejí z různých úhlů.

Podstatnou součástí knihy je vyhodnocení nálezů militarií z bezprostředního okolí hradů. Získány byly dvěma způsoby. Jednak při řádném detektorovém průzkumu, který lze ale označit za paběrkování. Obě lokality totiž vyrabovali tzv. detektoráři, kteří sice nemalou část svých nálezů s odstupem let poskytli archeologům, u mnoha však nebyli schopni upřesnit lokalizaci. V souboru militarií standardně převažují hroty kušových šípů spolu s válečkovými a kulovými projektily malých ráží.

Na základě lokalizovaných nálezů střel se Milan Sýkora pokusil postihnout průběh dobývání obou hradů, resp. odkud a kam stříleli obránci a útočníci. V případě Panny vyšel z polohy pouhých deseti šipek a šesti projektilů, což považuji za příliš malý vzorek pro – byť jen hypotetické – závěry o postupu dobývání a bránění hradu. Faktem je, že tyto nálezy se koncentrují na jednom místě, a sice na přirozené terase ve svahu kopce těsně pod hradem. Milan Sýkora z toho vyvozuje hypotézu, že terasu využili útočníci k vybudování tábora. Já tuto možnost považuji naopak za prakticky vyloučenou, a to hlavně kvůli terénní konfiguraci. Daná plošina, od jádra hradu vzdálená zhruba 120 m a navíc oproti jeho jádru položená podstatně níže (až o 70 m), byla doslova vystavena střelbě z hradu. Což ostatně vyplývá z rozptylu střel. Jejich koncentraci tedy pokládám pouze za ukazatel směru, kudy vedli obléhatelé zteč – logicky trasou přístupové cesty, a tedy nejschůdnějším způsobem. Dlužno dodat, že Milan Sýkora tuto interpretaci také připouští. Co mi na jeho vyhodnocení rozptylu střeliva připadá vyloženě závadné, je čárové zobrazování směru a délky letu kušových šípů u všech lokalizovaných hrotů. Některé z nich mohly až dodnes zůstat ve stejné poloze jako v momentě dopadu. Ve většině případů to ale – myslím – nejsme schopni zjistit, a to kvůli přírodním procesům. Na hradních svazích mohly být nevelké hroty v důsledku eroze nejen výrazně posunuty, ale také jinak natočeny, což mohly během staletí stejně snadno vykonat i kořeny stromů.

Přestože monografie o Kalichu a Panně obsahuje několik dílčích závěrů, které bude zapotřebí prověřit dalším terénním výzkumem a diskusí, jedná se o mimořádně hodnotnou práci, jež skokovým způsobem posouvá poznání fortifikační architektury a obecně vojenství husitské doby. Ze všeho nejvíce je třeba vyzdvihnout velký soubor instruktivních plánů a další dokumentace (např. detailní zákresy torz zdí Kalichu), reprodukované ve velkorysém měřítku. Díky publikacím této kvality a koncepce se česká kastellologie může směle srovnávat se špičkovými výsledky evropského bádání.

Jan Kypta

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Lehký, I. – Sýkora, M. eds. 2015: Oltářík. Hrad Jakoubka z Vřesovic. Most: Ústav archeologické památkové péče severozápadních Čech.

Der Erdstall. Beiträge zur Erforschung künstlicher Höhlen 44, 2018. Vyd. Arbeitskreis für Erdstallforschung e. V. ISSN 0343-6500. 127 str.

Časopis s dnes již dlouhou tradicí sdružující zájemce o lidmi vyhloubené podzemní prostory (Erdställe, lochy) především z Německa a Rakouska, spolupracuje s podobně zaměřenými spolky z Francie a Belgie. Je otevřen spolupráci s dalšími zájemci také z východní Evropy. Každé číslo obsahuje dokumentaci těchto podzemních prostor i příspěvků zaměřených historicky. Díky spolupráci s odborníky je v časopise zveřejněna celá řada článků s archeologickou tématikou. Toto číslo je uvedeno vzpomínkami na výraznou badatelku v oboru podzemních chodeb Edith Bednarik, která zemřela ve věku 82 let.

Z obsahu: *René Kaiser – Gunnar Lenhard – Martin Strassburger*: Sicherung eines Erdstalls unter Berücksichtigung denkmalpflegerischer Belage (9–21). Zpráva o zabezpečení podzemní chodby, datované do doby od poloviny 11. do 13. stol., objevené v hloubce 3,4 m v Ayng u Mnichova. Jednalo se o chodbu s původním vstupem v kostele sv. Ondřeje (Andreas) končící po 50 m trojitě rozvětvenou komorou. Náklady na zabezpečení dosáhly 235 tis. Euro. *Otto Cichocki*: Inquisitionstexte – Hinweise auf eine mögliche Funktion der Erdställe? (46–67). Článek uvedený podrobným úvodem do problematiky interpretace podzemních chodeb, včetně definice, ohraničení i typů, nastiňuje další možnosti. Velmi přínosné je převzetí typologie podzemních chodeb podle *H. Wimmera* (*2000*), při interpretaci účelu ovšem bude nutné postupovat různě u jednotlivých typů. Autor dále kriticky hodnotí šest možností výkladu rozdělených do účelu obydlí či přežití (obydlí, úkryt) a kultu (potřeba průlezu, prázdné hroby, místa pro duše zemřelých, místa meditace). Poněkud stranou zůstal hospodářský účel těchto prostor, které mohly sloužit jako sklepy, případně ledárny (*Unger 2014*). Autor nastínil možnost souvislosti některých podzemních prostor s praktikami kultu valdenské sekty, poměrně silně rozšířené ve 12. a 13. stol. v Podunají. Svůj názor dokládá citací inkvizičních zpráv, v nichž jsou ojedinělé zmínky o provozování kultu v podzemních prostorách (speluncam suam sub cellarium), kde se odehrávaly i sexuální praktiky (Viri et mulieres … in noctis medio in locum quendam subterraneum convererunt … Extinctis luminibus quilibet proximam cognoscebat). Mapa rozšíření valdenské sekty je srovnána s mapou podzemních chodeb (Erdställe) v jižním Německu, Rakousku a na Moravě. *Heike Gems-Müller*: Die Eignung von Erdställen zur Vorratshaltung am Beispiel von Eicheln als Lagergut (68–89). Žaludy, patřící k důležitým plodům sbíraným a shromažďovaným ve venkovském prostředí, mohly být ukládány také v podzemních prostorách. Tuto hypotézu verifikovali *Heike Gems-Müller – Martin Müller*: Ein Experiment zur Langzeitlagerung von Eicheln unter erdstalltypische Unweltbedingungen (90–94). *Otto Cichocki* Zur Datierung von Erdställen – Teil 2 (95–98) stručně popisuje metody dendrochronologie, typologie, termoluminiscence a TNC-Methode (Terrestrial Cosmogenic Nuclidemeasurement). Metoda TNC, kterou byly některé podzemní prostory datovány do pravěku, je z hlediska archeologie problematická. *Birgit Symader*: Erdstallabsicherung in Neukirchen-Balbini, Lkr. Schwandorf (99–104). Zajištění podzemní chodby v souvislosti s budováním Centra pro výzkum podzemních prostor (Erdstallforschungszentrum), které úspěšně pokračuje. *Peter Forster*: Das seltsame Loch von Unterlappach, Gde. Maisach, Lkr. FFB (105–109). Kromě zprávy o nálezu studny pro napájení dobytka, datované dendrochronologicky do roku 1817, článek obsahuje zprávu o starším nálezu „lochu“ za oltářem filiálního kostela sv. Silvestra, u nějž se může jednat o sakrarium nebo o počátek chodby.

Josef Unger

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Wimmer, H. 2000: Die Regional-Typisierung der Erdställe. Der Erdstall 26, 54–56.

Alena Kalinová: Novokřtěnská, habánská a posthabánská fajáns v Moravském zemském muzeu (1600–1765). Anabaptist, Haban and Post-Haban Faience in the Moravian Museum (1600–1765). Moravské zemské muzeum, *Brno 2017*. 288 str.

Jádrem knihy je komplexní katalog jedné z kvantitativně i morfologicky nejbohatších sbírek novokřtěnské a habánské fajánse, což platí i v přeshraničním měřítku. Soupis čítá 263 položek, přičemž ze dvou třetin je tvořen výrobky z tzv. habánské vývojové fáze, tj. z konce 17. století a z pozdějšího období. Ve sbírce tedy dominuje fajáns západoslovenské provenience, naopak raná etapa, kam spadá produkce jihomoravských dílen, je zastoupena pouze šesti výrobky, ovšem včetně několika unikátních kusů. Autorka se přidržuje terminologického pojetí, které rozlišuje fajáns novokřtěnskou od habánské podle věroučného hlediska. Jako mezník je brán rok 1690, kdy novokřtěnci ve větší míře konvertovali ke katolictví. Druhý zásadní periodizační mezník spadá do 20. let 16. století, kdy došlo k vynucenému hromadnému odchodu novokřtěnců z jižní Moravy na západní Slovensko a do dalších oblastí (především v dnešním Rumunsku). Úplný počátek výroby fajánse na Moravě spadá do přelomu 80. a 90. let 16. století. Periodizace novokřtěnské a habánské fajánse je usnadněna relativně častým vročením výrobků; nejstarší přesně datovaný výrobek z prezentované sbírky pochází z roku 1617.

Úvodní kapitoly stručně shrnují dosavadní poznání novokřtěnských dějin, pochopitelně se zvláštním zřetelem k proslulé produkci fajánse. Nové poznatky obohacující specializované bádání obsahuje hlavně nástin vývoje výzkumu novokřtěnců v instituci nazývané dnes Moravské zemské muzeum. Tato kapitola je velice důležitým příspěvkem k dějinám moravské archeologie a etnografie. Na půdě muzea se terénní výzkum novokřtěnců rozvinul hlavně v letech druhé světové války. Důvod, proč se výzkum novokřtěnců stal tehdy prioritou, je očividný (přesto je autorka v daném hodnocení nepochopitelně zdrženlivá): jednalo se o německy hovořící minoritu, nadto proslavenou technickými dovednostmi. Za pozornost stojí, jak úzce na výzkumu kooperoval německý ředitel muzea, archeolog původem z Vratislavi, se svými českými podřízenými v etnografickém oddělení. Autorka v archivních fondech muzea dohledala útržky informací o překvapivě velkém rozsahu vykopávek prováděných za protektorátu v desítkách lokalit s novokřtěnskou minulostí. Muzejní badatelé se paralelně věnovali etnografickému sběru, ovšem i zkoumání fyziognomie obyvatel ve sledovaných obcích.

Materiály shromážděné za války se však z naprosté většiny ztratily, kvanta střepů z vykopávek zmizela zcela. Totéž platí o ještě větším množství střepů vykopaných v místech zaniklých i dochovaných novokřtěnských dvorů na jižní Moravě a západním Slovensku, které muzeu – zdá se, že vynuceně – za války prodal Heřman Lansfeld, profesí keramik a zájmem svérázný archeolog a etnograf. Autorka zmiňuje „objev“ většího souboru fotografií z terénních výzkumů ze 40. let, který se v muzeu podařilo učinit před pár lety. Jeho součástí jsou i záběry na archeologické situace a dokumentace atraktivních nálezů. Je škoda, že autorka do knihy nezařadila větší počet snímků z této kolekce, která by jistě zasluhovala publikaci v úplnosti či formou reprezentativního výběru.

Po roce 1945 muzeum na terénní výzkum novokřtěnců rezignovalo. Dochovaná kolekce tedy čítá většinou celé výrobky, muzeu prodané či darované sběrateli; nejstarší akvizice pocházejí hluboko z 19. století, nejmladší přírůstky jsou čerstvé pár let. Krom toho v letech 2015–2017 sbírky muzea zásadním způsobem obohatila objemná kolekce materiálu z archeologických výzkumů Jiřího Pajera, prováděných od roku 1983 v asi 15 jihomoravských lokalitách, v nichž existovaly novokřtěnské dvory. Tyto soubory jsou z nemalé části již publikovány, ovšem některé klíčové Pajerovy výzkumy zatím čekají na souborné zhodnocení (např. ve Strachotíně). Doufejme, že pod hlavičkou Moravského zemského muzea se brzy dočkáme dalších zásadních publikací o novokřtěnské keramice.

Ostatně stále schází syntetické pojednání, které by tento fenomén uchopilo v širším kulturněhistorickém (a mezinárodním) kontextu a celkově jinou optikou než veškeré dosavadní badání, dodnes silně svázané sběratelskou tradicí. Terénní výzkumy byly primárně zaměřeny na rozpoznávání produkce z jednotlivých lokalit podle detailů výzdoby. Naproti tomu o fyzické podobě dílen stále víme málo. Je nepochopitelné, proč se při průzkumu novokřtěnských lokalit dosud neuplatnily geofyzikální metody – jako předstupeň následné cílené sondáže, aby se výrazněji zvýšil počet odkrytých vypalovacích pecí, které musely být konstrukčně mimořádné.

Jan Kypta

Lisa C. Nevett: Theoretical Approaches to the Archaeology of Ancient Greece. University of Michigan Press, *Ann Arbor 2017*, 338 p.

V roku 1972 vydal Colin Renfrew svoju prelomovú publikáciu *The Emergence of Civilisation* (*Renfrew – Chery 1972*), ktorá nadviazala na dialóg medzi klasickou archeológiou (egejskej oblasti) a kultúrnou antropológiou. Táto práca významným spôsobom ovplyvnila predovšetkým disciplínu egejskej prehistórie, ktorá sa začala čoraz viac otvárať metodológii prírodných vied a aplikovať nové teoretické modely pri vlastnom bádaní. To však nemožno povedať o klasickej (gréckej) archeológii prvého tisícročia pred n. l., ktorej smerovanie bolo po dlhú dobu prevažne empirické. Archeológovia sa zameriavali prevažne na materiál a otázky štýlu, pôvodu alebo chronológie, no menej na spoločnosti a jednotlivcov, ktorí tento materiál tvorili.

Táto koncentrácia na štúdium archeologického materiálu, často na úkor antických písomných prameňov, sa dostala na úroveň, ktorú Anthony Snodgrass v roku 2002 hodnotil ako zmenu paradigmy (*Snodgrass 2002*). Výsledné teoretické vákuum bolo odrazom vysporiadavania sa s dlhou históriou oboru a jeho blízkym vzťahom k ďalším disciplínam, predovšetkým ku klasickej filológii. Tieto faktory totiž do veľkej miery určovali možné výskumné otázky, metódy alebo typy materiálu, ktoré boli vhodné na výskum. Aj napriek kontinuálnym snahám o aktualizovanie metodologického rámca klasickej archeológie prebiehajúcich už od 70-tych rokov minulého storočia, až v priebehu posledných dvoch dekád možno zaznamenať akýsi teoretický obrat. Odborníci si stále častejšie uvedomujú, že pri hlbšom skúmaní materiálu je určitý teoretický základ nevyhnutný a hlasy presadzujúce tzv. ateoretické prístupy (napr. *Bintliff – Pearce eds. 2011*) nenachádzajú silnejšiu podporu.

Na rozdiel od príbuzných disciplín v rámci gréckej archeológie prvého tisícročia pred n. l. tak stále existuje medzera, ktorá je evidentná aj v učebných textoch, kde býva tomuto obdobiu venovaný, najmä z metodologického hľadiska, užší priestor. K zaplneniu tejto medzery sa snaží prispieť aj recenzovaná publikácia vydaná Michiganskou univerzitou pod editorským dohľadom Lisy Nevett. Kniha predstavuje zborník príspevkov z konferencie *Theory in (Ancient) Greek Archaeology [TiGA],* ktorá sa konala v roku 2012 na pôde Michiganskej univerzity v Ann Arbor. Jednotlivé príspevky sa sústreďujú na oblasť gréckeho vplyvu v prvom tisícročí pred n. l. a venujú sa témam materiálnej reprezentácie spoločenských štruktúr, politickej organizácie alebo kultúrnych noriem. Rovnako sa sústreďujú aj na formy akými jednotlivci i skupiny vyjadrovali svoju vzájomnú odlišnosť, prípadne podobnosť a spôsob, akým možno pristupovať k materiálnej kultúre za účelom skúmania týchto procesov v priestore a čase. Kapitoly tak ponúkajú rôzne prípadové štúdie s aplikáciou rozličných teoretických prístupov a modelov ako napr. sieťová teória, fenomenológia, *entanglement* (teória spletitosti), *chaine opératoire* alebo *spatial turn* (obrat k priestorovosti). Táto rôznorodosť aplikovaných prístupov je silnou stránkou publikácie. Z metodologického hľadiska sú zaujímavé predovšetkým kapitoly ponúkajúce nové vnímanie otázok priestorovosti.

Aplikácii sieťových prístupov sa vo svojich príspevkoch venujú autori David Small (kapitola 3), Jessica Paga (kapitola 9) a Michael Scott (kapitola 10). Sieťová teória (analýza), ktorá sa v posledných rokoch teší pomerne veľkej popularite v rámci historických vied, ponúka nové možnosti vnímania a interpretácie materiálnej kultúry, najmä z hľadiska interakcie a konektivity. V rámci disciplíny archeológie možno, okrem analýzy sociálnych sietí, zaznamenať dva prístupy k aplikácii sieťovej teórie: *formálna sieťová analýza*, ktorá stavia priamo na matematických základoch sieťovej teórie a sieťovom modelovaní jednotlivých interakcií a *sieťový prístup*, ktorý siete chápe len ako metaforu interakcie alebo spôsob vyjadrenia vzájomnej spojitosti. Všetky príspevky v recenzovanej publikácii spadajú do druhej kategórie aplikácie sieťovej teórie.

David Small sa vo svojej kapitole venuje problematike mestských štátov a možnostiam, akými môže grécka archeológia prispieť k výskumu ďalších oblastí s existenciou mestských štátov. Primárnym argumentom opodstatnenosti podobného prístupu je podľa autora široká pramenná báza poznania fungovania mestských štátov v gréckom prostredí, ktoré môže pomôcť vyplniť chýbajúce miesta v iných oblastiach. D. Small k mestským štátom pristupuje cez optiku „small polities“ (malé politické zriadenia), pričom si všíma povahu vlastných sietí, ktoré tieto zriadenia vytvárali. Existenciu lokálnych sietí tak autor vníma ako vyjadrenie otvoreného charakteru mestských štátov a ich interakcií.

Zaujímavú aplikáciu sieťovej teórie ponúka Jessica Paga, ktorá sa vo svojej kapitole venuje otázkam vnímania priestoru a priestorovosti. Na príklade starého *bouleuterionu* na athénskej Agore analyzuje úlohu priestoru ako agenta spoločenských zmien v rámci širších lokálnych sietí. Autorka tu demonštruje aktívny vplyv a význam architektúry pri šírení demokratických myšlienok v Athénach a zároveň poukazuje na existenciu sietí podporujúcich šírenie podobných využití architektúry v širšom regionálnom kontexte.

Michael Scott sa vo svojej kapitole sústreďuje na mapovanie náboženského života Athén na príklade uctievania Pana. Autor sa tu odkláňa od stále viac problematického modelu *polis religion*, pri ktorom bol náboženský priestor spolu s praxou formované elitou mestských štátov a skúma možnosti sieťového prístupu pri tejto problematike. Zameriava sa tak na šírenie náboženských myšlienok prostredníctvom rozličných typov prepojení. Výsledkom je flexibilnejší a dynamickejší obraz náboženských interakcií, ktorý zároveň poukazuje na hranice poznania komplexnosti náboženského života. Kapitola vníma vzájomné prepojenia medzi jednotlivými oltármi ako sieť, ktorá sa vyvíja a reaguje na nové náboženské prejavy ďalších sietí (iných božstiev).

Ďalšou prínosnou stránkou publikácie je kapitola aplikujúca niektoré koncepty hnutia *spatial turn* (obrat vo vnímaní priestoru). Spatial turn predstavuje tendencie k rekonceptualizácii priestoru v rámci prechodu od modernizmu k postmoderne, ktoré sa prejavili v odklone od tradičných geografických prístupov k topologickému vnímaniu priestoru. V rámci spoločenských vied išlo najmä o prijatie tézy, že ľudské konanie sa nielen odohráva v priestore, ale ho aj vytvára a určuje. Tento spoločenský rozmer je teda produktom spoločenského konania a zámerov, ktoré napĺňajú fyzický priestor obsahom (*Lefebvre 1974*, 34). Na takýto model priestoru nadväzuje Soi Agelidis vo svojom príspevku (kapitola 11), kde sa sústreďuje na athénske festivaly (predovšetkým sprievody) a spôsoby, akými spoločnosť formuluje náboženský rozmer niektorých verejných priestorov. Autor si všíma predovšetkým mestské hradby, brány a budovy Prytaneion a Pompeion, ktoré, okrem iných funkcií, zohrávali dôležitú úlohu aj pri festivalových sprievodoch. Aj napriek skutočnosti, že kapitola stavia len na niektorých konceptoch spatial turn-u, ide o mimoriadne prínosný príspevok k aplikácii spoločensko-priestorovej dialektiky v historických vedách.

Celkovo je publikácia veľmi vhodne rozdelená do 5 častí (*Disciplinary Context, Artifacts, Civic and Religious Landscapes, Funerary Landscapes* a *Responses*), pričom každá obsahuje príspevky z príslušných oblastí metodologickej aplikácie. Obohacujúcou je aj posledná časť (*Responses*), ktorá ponúka hodnotenie súčasného stavu metodológie gréckej archeológie prvého tisícročia pred n. l. Z perspektívy teoretickej aplikácie publikáciu nemožno považovať za definitívnu, keďže chýba priestor venovaný prístupom ako napr. *formálna sieťová analýza* (napr. *Knappett ed. 2013*) alebo modelu *time geography* (napr. *Mlekuz 2010*), ktoré čoraz častejšie prinášajú sľubné výsledky. Napriek tomu možno knihu hodnotiť ako prínosnú publikáciu k diskusii o teoretickom smerovaní gréckej archeológie (prvého tisícročia pred n. l.), ktorá zároveň podáva aktuálny obraz o jeho súčasnom stave a nedostatkoch.

Denis Hakszer

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Karel Nováček – Miroslava Kubatová Pitrová (edd.): Devět století kláštera v Kladrubech 1115–2015. Národní památkový ústav, územní památková správa v Českých Budějovicích, *České Budějovice 2017*. 408 str.

V oborově i chronologicky širokém rozponu sborníku příspěvků z konference konané v kladrubském klášteře u příležitosti jeho devítistého výročí založení nechybí ani archeologie, byť zastoupená pouze jedním příspěvkem. V něm *L. Foster* (135–148) shrnuje výsledky záchranných akcí z let 2003–2015, realizovaných v areálu kladrubského kláštera většinou při liniových výkopech. Tyto výzkumy přinesly jen málo doplňků dosavadního poznání středověkých stavebních etap, důležitá zjištění se však týkají barokní éry, např. kanalizačního systému konventu. Toto však není jediný důvod, proč by po publikaci měli archeologové sáhnout. Jistě je zaujme příspěvek *K. Nováčka* (25–33), který přesvědčivě dospěl k novému zjištění, že kladrubský areál ve 12. století fungoval jako dvojklášter – vedle benediktinských mnichů zde působilo i ženské řeholní společenství. Své vývody rozvíjí na základě českým bádáním dosud nepovšimnuté noticky v jedné z redakcí životopisu biskupa Otty I. Bamberského. V prameni je konkrétně uvedeno, že budoucí světec roku 1124 v Kladrubech vykonal obřad zasvěcování panen. Doklad o existenci dvojkláštera klade K. Nováček do širších souvislostí šíření hirsauského reformního hnutí, resp. vazeb mezi benediktinskými domy v Kladrubech a Zwiefalten. Jak autor připomíná, nově doložený dvojklášter představuje v českých zemích třetí známý příklad svého druhu v knížecím období (po Sázavě a Podlažicích).

Archeologům také stojí za pozornost tři příspěvky, které se nevztahují ke Kladrubům. *J. Anderle* (245–256) předkládá cenná zjištění o dosud neznámé románské etapě farního kostela v Liticích u Plzně. Jeho dnešní loď spolu s presbytářem vznikly jakožto novostavba kolem roku 1400, přičemž materiál použitý na zdivo lodi z převážné části pocházel ze zbořené románské svatyně. Autor po plošném osekání vnějších omítek identifikoval vedle spousty pískovcových kvádrů i několik architektonických článků charakteristického tvarosloví (např. díly obloučkového vlysu či díly podřímsí zdobené zubořezem). Podle těchto zbytků autor spekuluje o možných genetických souvislostech zaniklého litického kostela se stavbami tzv. kladrubského okruhu, přičemž jistou spojitost shledává pouze u známého kostela ve Svojšíně.

J. Slavík (257–270) objevným způsobem nastiňuje středověký stavební vývoj benediktinského proboštství v Broumově. Při komplexním průzkumu obnovovaného areálu se mu v posledních letech podařilo shromáždit celou řadu zásadních a nečekaných poznatků o gotických fragmentech ve hmotě silně barokizovaného komplexu. Ve shodě s dosavadní literaturou zdůrazňuje naprosto výjimečnou architektonickou formu tohoto řeholního domu, který lze bez rozpaků označit i za hrad. Důležitý je zvláště Slavíkův půdorysný plán středověkého konventu s kostelem včetně mohutného obvodového opevnění. Prezentovaný výběr fotografií nálezových situací vzbuzuje velká očekávání od budoucí – doufejme, že brzké a podrobné – prezentace výsledků průzkumu.

M. Kovář a *R. Bláha* (271–292) zevrubně informují o početném souboru architektonických článků, čerstvě nalezených při povrchovém průzkumu v moderní zástavbě na místě zaniklého benediktinského kláštera v Opatovicích nad Labem. Ke zde objeveným tesaným prvkům raně gotického tvarosloví dohledali přímé analogie mezi fragmenty z lapidária královehradeckého muzea, jež snad pocházejí z tamního mendikantského kláštera, načež uvažují o původu článků ve stejné stavební huti. Otázkou je, zda lze na základě shody několika článků používat termín huť, když obecně víme pramálo o mobilitě kameníků v daném období.

Jan Kypta

Máté Szabó: Archaeology from Above. Episodes from the History of Aerial Archaeological Archive of Pécs. Archaeolingua, *Budapest 2016*, 304 str. s 339 obr.

Před více než dvaceti roky se uskutečnil první praktický kurs letecké archeologie na území té části Evropy, která se prakticky od konce druhé světové války nacházela v područí nedemokratických režimů, politicky a ekonomicky pevně ovládaných komunistickou stranou někdejšího Sovětského svazu. Organizátorem onoho meetingu, který se konal v červnu 1996 na letišti poblíž Balatonského jezera u obce Siófok (*Bewley – Braasch – Palmer 1996*), byla univerzita v Pécsi (Pětikostelí). Na tamní katedře historie se již od poloviny 70. let rozvíjela práce s leteckými – jak historickými, tak dostupnými poválečnými – fotografiemi, ale první průzkumný let, jehož účastníkem byl profesionální archeolog, se uskutečnil až v roce 1985. Za uvedenými aktivitami stál hlavní protagonista letecké archeologie v Maďarsku, pozdější profesor a zakladatel katedry archeologie na uvedené univerzitě, Zsolt Visy. Ke studiu a analýze převážně měřických leteckých fotografií jej přivedlo jednak setkání s ikonou německé Luftbildarchäologie O. Braaschem, jednak jeho hlavní celoživotní specializace – výzkum římského limitu na maďarském území (zejm. projekt *Ripa Pannonica)*. Již dva roky před uvedeným kurzem v Siófoku byla kolekce leteckých fotografií pořízených podél Dunaje a částečně i v samotném jádru někdejší provincie Panonie nejrozsáhlejším souborem tohoto druhu pramenů na archeologickém pracovišti v Maďarsku. Visy velký počet těchto fotografií analyzoval a využil jako dokumentační doprovod ke své první monografii o panonsko-dunajské hranici římského impéria (*Visy 1988*).

Siófok se stal významným impulsem k zahájení praktického zavádění letecko-archeologické prospekce v zemích bývalého sovětského bloku a pro Visyho znamenal především navázání několikaleté spolupráce s O. Braaschem, jehož průzkumné lety ve výsledku znamenaly objevy stovek do té doby neevidovaných lokalit a obrovské množství nových snímků, takže v roce 2004 mohl vzniknout oficiální (s licencí veřejné muzejní instituce) *Letecko-archeologický archiv Pécs* (LAAP) jakožto součást tamní univerzity. Dlužno dodat, že dynamicky se začala letecká archeologie v téže době rozvíjet také ve druhém hlavním centru tohoto oboru v Maďarsku, na univerzitě Eötvöse Loranda v Budapešti. Konečně v poněkud menší míře, nicméně stejně významně se na rozvoji témat dálkového archeologického průzkumu (DAP) podílel také Archeologický ústav Maďarské akademie věd (zejm. péčí Z. Miklósové).

Již od druhé poloviny 90. let začal s Visym spolupracovat jeho student G. Bertók, o němž je – pokud jde o Maďarsko – v mezinárodní komunitě specialistů na DAP nejčastěji slyšet. Kromě konferencí se za tým jihomaďarských badatelů nejčastěji zúčastňoval velkých mezinárodních oborových projektů (naposledy ArchaeoLandscape Europe: www.archaeolandscapes.eu) a je také spoluautorem vlastně první monografie, která představuje výsledky letecko-archeologického průzkumu a na ně navazujících terénních výzkumů dosažených od 90. let specialisty z Pětikostelí (*Bertók – Gáti 2014*). Nejmladší generaci pak reprezentuje autor recenzované knihy M. Szabó, který se donedávna jako své hlavní činnosti věnoval zpracování kolekce Braaschem pořízených diapozitivů. V posledních letech se tento dnes již lektor univerzitní katedry archeologie (Visy odešel do důchodu roku 2014) – zběhlý v používání softwaru k práci s prostorovými daty (zejm. GIS) a s leteckými/družicovými snímky a schopný integrovat jejich využití spolu s uplatňováním moderních technických zařízení (GPS, drony atd.) do teoretické a praktické výuky studentů archeologie – věnoval také vlastnímu vizuálnímu průzkumu z malého letounu, a to nejen na maďarském území, ale také v sousedním Rumunsku, resp. v Transylvánii. U příležitosti desetiletého výročí založení LAAP v roce 2014 začal pracovat na knize Archaeology from Above.

Kniha je členěná do tří částí. V první je pozornost věnována – jak to u monografií tohoto druhu bývá zvykem – stručné historii letecké archeologie a jejím principům, a především sumarizovanému příběhu více než desetileté historie LAAP. Druhá část je nazvána „Epizody z historie LAAP“ a obsahuje celkem 20 kapitol, v nichž autor přináší poměrně široký výběr témat – od jím aplikovaných způsobů sběru dat přes jejich zpracování a integraci do výzkumu konkrétních kategorických a chronologických témat až po představení nejzajímavějších objevů. Namátkou uveďme názvy několika kapitol: Drones in archaeology, The hidden third dimension of photographs, An aerial archaeologist over the Hungarian Plain, The *Ripa Pannonica* from the air, Vanished settlements. Poslední kapitoly této části představují uplatnění fotoletecké dokumentace archeologických výzkumů odkryvem, zajímavé objekty z nejmladší historie a současnosti, příklady pozoruhodných přirozených komponent krajiny. Každou kapitolu uvedenou spíše stručným textem doprovází velký počet kvalitních fotografií s podrobným, nicméně v několika případech poněkud nesrozumitelným popiskem. U mnohem většího počtu snímků, než je tomu ve skutečnosti, by bylo užitečné, kdyby na ně byly umístěny indikátory (např. šipky), které by lépe umožňovaly pochopit, co z často nezřetelných struktur je na fotografiích to podstatné, resp. v popisce uváděné.

V závěru monografie je připojen glosář a legenda k několika (v GIS vektorizovaným) plánům vybraných lokalit. Poněkud netradičně pracuje autor s bibliografií: za každou kapitolou je umístěn výběr publikací k danému tématu, zatímco na samém konci knihy je v chronologickém pořadí uvedena bibliografie všech, kteří se podíleli na projektech LAAP, a to od roku 1995 do roku 2014. Znamená to, že většina titulů je totožná s bibliografickými odkazy za kapitolami.

V každém případě je tato již druhá souhrnná knižní monografie o archivních fondech LAAPu, o aktivitách a dosavadních výsledcích tohoto progresivně fungujícího pracoviště počinem, který je třeba náležitě ocenit. Tím spíše, že jej napsal jeho nejmladší člen.

Martin Gojda

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