

Bloomery ironmaking in Latvia – a comparative study of Iron Age and medieval technologies

B Rundberget, A Vasks, I M Gundersen, R Brūzis, J H Larsen, V Bebre, I Doniņa and A Viksna

ABSTRACT: The technology of bloomery iron production in Latvia is a little-studied topic. Only a few excavations have been undertaken, mostly during the 1950s and 60s in connection with hydropower development along the river Daugava. Sources from archives and collections have been reviewed, re-studied and re-interpreted in the light of current knowledge, as part of the TechTrans research project. Visual studies have also been performed to clarify whether the slag was tapped, as previously interpreted, or whether production could be related to the more common slag-pit technology. Archaeometallurgical samples from four of the excavated sites have been analysed to obtain information on the technology, development, processes and the quality of production. The results of this study are set in the context of the technical development of bloomery practice in neighbouring regions to identify influences that may have affected the development of bloomery iron production in Latvia during the Iron Age and medieval period.

Introduction

Within the area of present-day Latvia there are finds of iron objects from the pre-Roman Iron Age (500–1 BC), but there is currently no evidence for local production, and iron may have been imported from other areas during this period. The production of iron from bog ore began during the Early Iron Age (AD 1–400). Production continued through the Middle Iron Age (AD 400–800), the Late Iron Age (AD 800–1200) and the Middle Ages (AD 1200–1500), before developing on a large scale during the time of the Duchy of Courland (1562–1795). Evidence for iron bloomery practice in Latvia is known from several sites; furnaces from the Iron Age and the medieval period have been identified at eighteen different locations, and there is slag related to prehistoric production on several more sites. The known distribution of bloomery sites, as well as that of excavated sites, is mostly connected with the river Daugava, largely as a result of studies undertaken during hydropower development in the 1950s and 1960s (Mugurēvičs 1999). The results of these excavations have been published only briefly, and there has not been

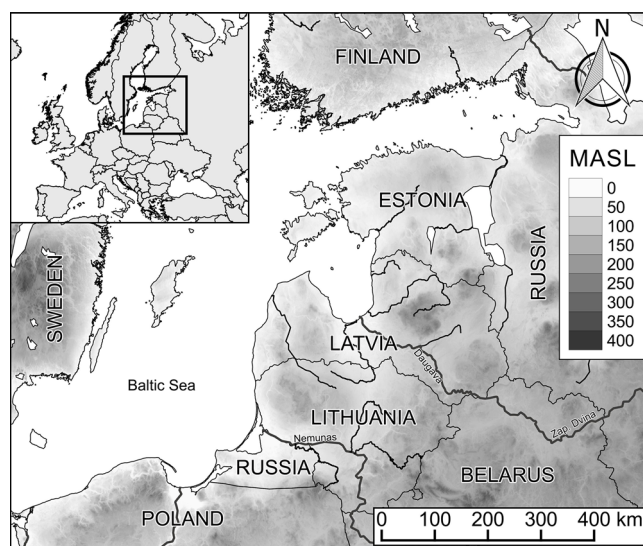


Figure 1: The Baltic region and river Daugava.

any particular focus on this aspect of Latvian history in recent decades. Bloomery iron production has been taken up for discussion in a broader perspective as part of the TechTrans research project (<http://www.lvi.lv/techtrans/en/start.html>). TechTrans focuses on the technologies used for the processing of mineral resources im-

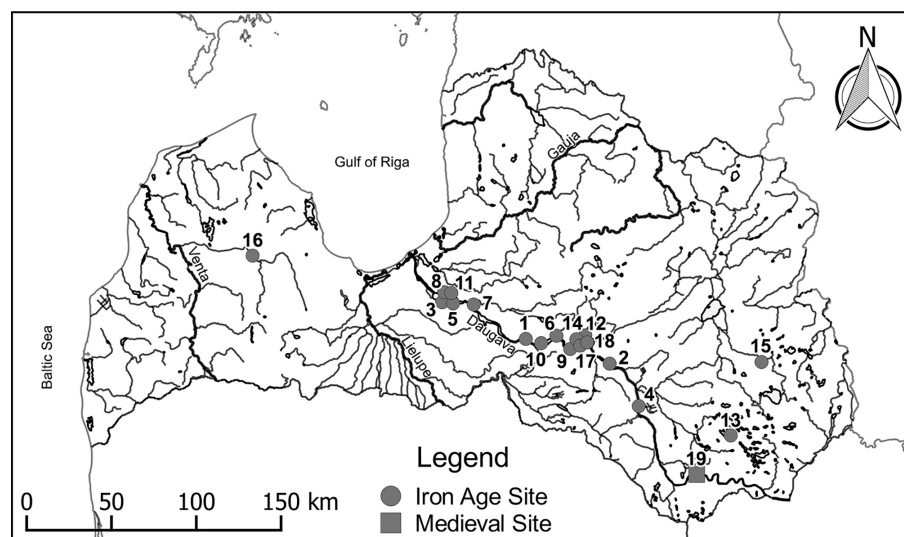


Figure 2: Iron Age bloomery furnaces in present-day Latvia. 1: Aizkraukle, 2: Asote, 3: Daugmale, 4: Dignāja, 5: Jaunlīve, 6: Koknese, 7: Ķente, 8: Laukskola, 9: Lejasdopeli (Pigēni), 10: Lejasziedi, 11: Lipši, 12: Lokstene, 13: Madalāni, 14: Oļņkalns, 15: Rēzekne, 16: Sabile, 17: Sēlpils, 18: Spietīņi, 19: Dinaburga. Nos 1-2, 6-7 and 12-15 are hillforts, Nos 3 and 16 are early town sites, Nos 4-5, 8-11 and 17-18 are settlements and No 19 is a castle settlement.

portant both in prehistory and in historical times, giving particular attention to questions relating to the transfer of technology between different societies and cultures. The objective of this aspect of the project is to contribute to the general understanding of bloomery practice and its development in Latvia in the pre-industrial age.

The research questions are twofold. Firstly, what information can the old excavations give about furnace form, type and operation? Secondly, there are the questions about development and affiliation, related to the main objective of the *TechTrans* project, that require putting these results for Latvian iron smelting technology into a wider European context. To reach these goals, it has been necessary to review archive documents and to undertake optical and archaeometallurgical analyses of the material in the collections of the National History Museum of Latvia and the Museum of the History of Riga and Navigation.

Previous understanding of prehistoric and medieval bloomery iron production in present-day Latvia

Latvia lies on the eastern shore of the Baltic Sea, and most of its territory is less than 100m above sea level. The longest river flowing through the country is the Daugava (Fig 1). As Latvia has a flat landscape, there is no mining activity. Bog, meadow or lake iron ore

(limonite, a mixture of iron hydroxides) is found in the wetlands and lakes but nowadays does not have any economic significance.

Iron ores within the territory of present-day Latvia are mentioned in the literature of the 18th century and, from the 19th century onwards, ore sources have been noted and published by the geologists Constantin Grewingk, Margers Gūtmanis and Pēteris Nomals (Mellis 1938, 105–106). Analysis was carried out on 37 samples of bog iron ore from the Sārņate deposit (Nomals 1933, 896) and a major study including chemical analyses of limonite sources in Latvia was published by Oto Mellis in 1938. The major gangue constituent is quartz sand, with other minerals providing calcium and aluminium in some samples, along with minute amounts of potassium, sodium, magnesium and manganese. The ores do not contain sulphur, and phosphorus concentrations are varied. The iron content in the analysed ores varies between 43.3% and 51.7%.

Iron ore has been recovered in small amounts in the course of archaeological excavation but has not always been clearly distinguished from slag. There is a definite find of enriched iron ore from the settlement next to Mežīte hillfort, and analyses performed at the Faculty of Chemistry of the University of Latvia show it to be a phosphorus-rich bog ore (Table 1).

Table 1: XRF analyses of Latvian bog ore samples.

Site	Fe ₂ O ₃ ^a	SiO ₂	P ₂ O ₅	CaO	Al ₂ O ₃	K ₂ O	MgO	BaO	MnO	ZnO
Puze	32.31	52.81	0.30	1.77	7.19	3.14	0.63	0.09	0.63	<0.01
Madona	89.52	5.13	2.22	1.45	0.33	0.06	0.28	0.22	0.59	<0.01
Mežīte hill-fort	61.03	22.40	11.16	2.51	1.44	0.54	0.38	0.21	0.20	0.12
Mežīte hill-fort	48.06	25.65	17.25	5.00	1.91	0.62	0.35	0.46	0.49	0.20
Mežīte hill-fort	44.67	28.76	16.91	5.67	1.48	0.71	0.39	0.53	0.66	0.20

Table 2: Bloomery sites mentioned in the text or shown on Figure 2.

Site name	Site type	Date of iron smelting	Figs
Aizkraukle	Hill fort	10th–12th century	2.1
Asote	Hill fort	10th–11th century	2.2; 3
Daugmale	Early town	10th–12th century	2.3
Dignāja	Settlement	6th–11th century	2.4
Dinaburga	Castle settlement	15th–16th century	2.19; 4
Jaunlīve	Settlement	1st–4th century	2.5
Koknese	Hill fort	5th–6th century	2.6
Ķenteskalns	Hill fort	6th–9th century	2.7
Laukskola	Settlement	10th–13th century	2.8
Lejasdopēli (Piģēni)	Settlement	10th–13th century	2.9
Lejasziedi	Settlement	10th–13th century	2.10
Lipši	Settlement	10th–13th century	2.11
Lokstene	Hill fort	14th–15th century	2.12
Madalāni	Hill fort	10th–13th century	2.13
Oliņkalns	Hill fort	10th–12th century	2.14
Rēzekne	Hill fort	10th–12th century	2.15
Sabīle	Early town	12th century	2.16
Sēlpils	Settlement	10th–12th century	2.17
Spītiņi	Settlement	1st–4th century	2.18; 3; 5

Note: Early Town = urban site pre-dating the 13th-century German conquest

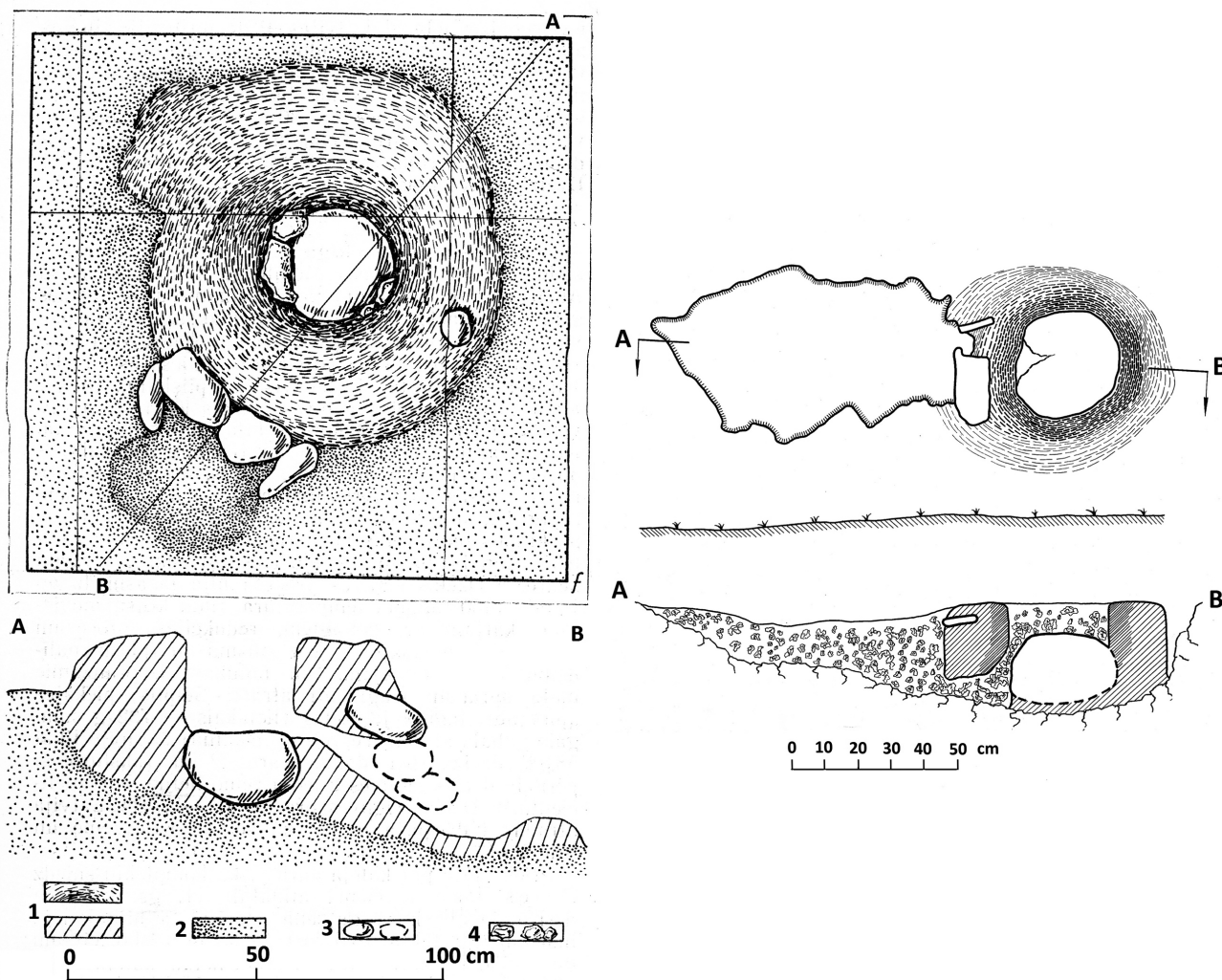


Figure 3: Plan and section of (left) bloomery furnace 22, Asote hill-fort (Latvijas PSR arheoloģija 1974, fig 154) and (right) furnace 4, Spītiņi settlement (Repository of Archaeological Material, Institute of Latvian History, University of Latvia).

The most important evidence for iron production is provided by the remains of bloomery furnaces on settlement sites. The furnace remnants mainly consist of fragments of cylindrical clay shafts, shallow slag pits with a stone forming the furnace base, and adjacent pits, as well as furnace-related finds, such as clay tuyères and slag. Based on these characteristics, bloomery activity has been identified at eighteen Iron Age sites and one medieval settlement site mainly along the river Daugava (Fig 2, Table 2). A broader spatial picture of iron production and smithing activity is also provided by finds of slag from 115 sites: 46 hillforts with adjacent settlements, 64 open settlements and five burial sites. In general, the amount of slag from these sites is small, but at the Spietiņi settlement about 1.5 tonnes of iron slag was recovered (Daiga 1964). The slag is not well described, but has been interpreted previously as having been tapped from the furnaces. In addition, several hundred pieces of slag and a bloom, with a total weight of 110kg, were found at a bloomery furnace on the Sabile early town site (Mugurēvičs 1984, 73). However, there has been no detailed, modern analysis of the slag from these sites to determine what processes it represents. It is likely that most of the dispersed slag finds are connected with smithies rather than smelting sites.

The best-preserved example of a Latvian bloomery furnace is furnace A22 at the Asote hillfort, dated to the 10th century AD (Šnore 1957, 15–16). The remains of its cylindrical clay shaft had an external diameter of 1.0 m and an internal diameter of 0.3 m. A large granite block with a flat surface formed the base of the furnace, and an opening in the lower part of the furnace was constructed from dolomite cobbles (Fig 3, left).

During excavation on the Spietiņi settlement site, six shaft furnaces were documented. The Spietiņi furnaces were in use from the 1st–4th century AD and are the earliest known furnaces of this type in Latvia (Daiga 1964). However, features such as their size, the stones that form the base and an opening in the lower part of the furnace show that the technological principles at these two sites were similar (Fig 3, right). Indeed, the general interpretation has been made of the Iron Age furnaces in the eastern part of Latvia, along the river Daugava, that they were shaft furnaces with a flat stone as the base, the outer diameter of the furnace shaft measuring 0.6–1.0m, the internal diameter between 0.2–0.3m, and with an opening constructed near the bottom of the furnace for tapping slag into an external pit.

A 12th-century furnace uncovered on the early town site of Sabile provides an exception to this general

description, as it had a base of fired clay (Mugurēvičs 1977a). This is so far the only bloomery furnace known in western Latvia, so it would be premature to say if this is a regional variant.

The bloomery furnaces at Spietiņi were concentrated in an area of about 20×20m at the periphery of the settlement. A furnace excavated at the settlement of Jaunlīve had likewise been built at the edge of the settlement (Atgāzis 1994). In the case of Asote hillfort, Šnore (1957) notes that there were no buildings in the vicinity of the furnaces. In a few cases hearths for roasting ore have been detected near to furnaces.

Tuyères constitute a common find in metallurgical complexes and suggest artificial draught and bellows in the bloomery process. Four conjoining tuyère fragments were found within a small area at the open settlement of Sēlpils, together with iron slag. These fragments form the preserved section, 62mm long, of the tip of a cylindrical tuyère with an inner diameter of 26–28mm and an outer diameter of 62–72mm.

Iron blooms are not very common finds, but a bloom is recorded as part of a large hoard which also included smithing tools and weapons from Kokmuiža, and blooms have been recovered from eleven settlement sites (including Daugmale, Kārļa kalns, Mežotne, Oliņkalns and Sabile). Semi-products have been found on three sites (Spietiņi, Ķenteskalns and Oliņkalns). The only find identifiable as wrought iron or a worked bloom is from Mežotne hillfort (13th century; 0.8 kg). This iron billet has the same form as Russian examples from the 11th–13th centuries: it is shaped like a rounded, flat cake (140×160mm; 50–60mm thick) and weighs about 5kg.

A large number of 13th–16th century sites in Latvia have also yielded slag and blooms from ironmaking or refining. However, only a small number of these finds can be identified as relating to the process of ironmaking, and in fact most of the slag derives from smithy activities.

Evidence of ironworking is better preserved at the early town sites (defined as urban sites pre-dating the 13th-century German conquest). Most commonly this relates to blacksmithing, but evidence for ironmaking has been found on the castle settlement of Dinaburga, where large-scale excavation has been undertaken, and a metallurgical activity area including a bronze foundry and the remains of a bloomery furnace was discovered outside the castle (Mugurēvičs 1982, 13). In plan, the furnace has the rounded form delimited by remnants of clay walls (Mugurēvičs 1982, Plan 53), representing

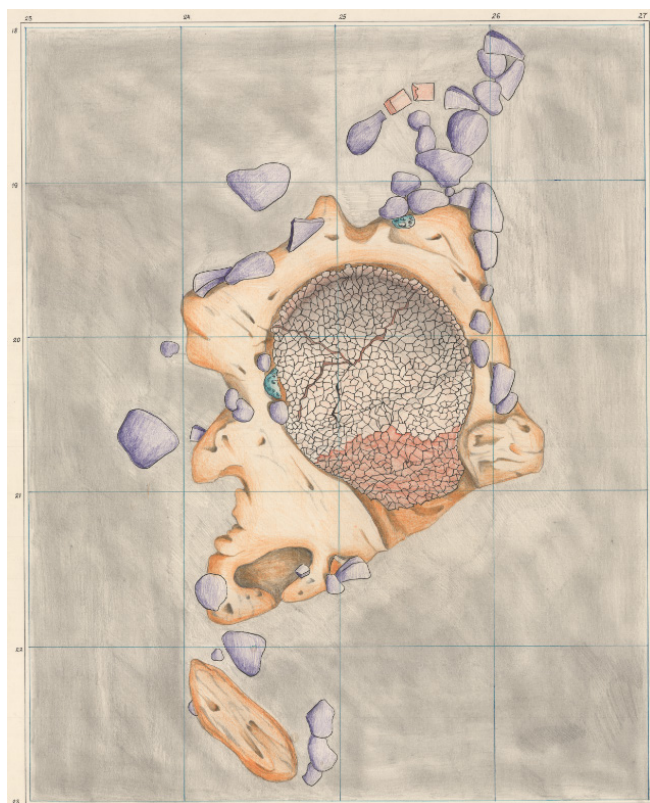


Figure 4: Plan of the bloomery furnace uncovered on the early town site of Dinaburga (Mugurēvičs 1982, plan 53). Grid is 1m squares.

the lower part of a cylindrical furnace (Fig 4). An air inlet at the side and a tapping hole near the bottom were also described (Mugurēvičs 1982, Plan 55). Slag and a bloom were found inside the furnace, next to the opening interpreted as a tapping hole.

Forges and smithing slag dominate the evidence from medieval castles. The only castle in Latvia where smelting is thought to have taken place is Lokstene, where a rounded furnace was uncovered, containing several burned layers, along with structures of granite and dolomite. It had been constructed next to a wall of the castle (Mugurēvičs 1977b, 90), perhaps for fire safety reasons. Slag, probably from the ironmaking process, was found south of the furnace. The centre of the structure contained a round area of grey, charcoal-rich soil, with a diameter of 0.3m, containing a large lump of iron and sintered clay. The furnace shaft, with an external diameter of 1.8×2.5m, was constructed of granite boulders. The base of the furnace was built up as a regularly-arranged circle of dolomite and granite boulders, measuring 0.4×0.5m. A block of iron slag still remained within a 0.2m wide opening, interpreted as a tapping hole (Mugurēvičs 1977b, 91).

The later towns (founded on the European model from the 13th century onwards) were the medieval centres of

crafts, and ironworking activities had a prominent place. Waste from blacksmithing activities has been found at several places in the historical centres of Riga (Vilsona 1963, 18), Valmiera and Ventspils. At a site in the town of Kuldīga, pieces of iron ore and slag were found in layers dating from the second half of the 13th and the early 14th century (Lūsēns 2010, 148–150), possibly indicating that ironmaking was undertaken here.

New perspectives on Latvian bloomery ironmaking

In the course of the *TechTrans* project old excavation material from archives and collections from settlement sites by the river Daugava, from several hillforts and from the old town of Riga has been re-studied and re-interpreted. The available documentation is varied: from the excavations of sites along the river Daugava there are drawings, some photos and reports, in the case of the hillforts and Old Riga, the re-interpretation relies mainly on the slag finds.

In the case of the settlements along the river Daugava, which include Spietiņi, Koknese and Asote, documentation and slag studies confirm the previous interpretation that there had been bloomery ironmaking activities on the sites over a period lasting nearly 1000 years, with a very similar technology. In addition, there are lesser amounts of slag indicating that there may also have been some smithing activity, but only on a minor scale. The slag is typical for iron production; it is homogeneous, blue-grey to black in colour and has clearly been molten. Many of the pieces have traces of charcoal trapped in the slag (Fig 5). Unlike earlier investigations, where the furnaces were interpreted as tapping furnaces, the new study shows that the slag had solidified within the bottom of the furnace. The best-preserved furnaces are from Spietiņi and Asote. For the medieval period, the only well-documented furnace is the one at Dinaburga. This furnace shows some similarities to the older technology, but the description



Figure 5: Slag from Spietiņi. Image width 320mm.

may point to the use of a tapping technology (see also the archaeometallurgical investigations below).

The slag from hillforts of the 11th–13th centuries is significantly different from that of the settlement sites along the river Daugava, with only a small proportion characterizable as bloomery slag. Most is heterogeneous, porous and rusty brown, and indicative of blacksmithing. A question must be raised about whether it was common practice to produce iron at the hillforts at all.

In the old town of Riga, slag samples have been collected from seven contexts. As at the hillforts, the slag had previously been interpreted as resulting from ironmaking, but the new studies indicate that all the slag from Old Riga derives from blacksmithing. The material we studied consisted of several more-or-less identical calotte-shaped slags. Hammerscale has not been recorded, but suitable samples may not have been taken. Bloomery ironmaking is almost never recorded in the medieval cities of Northern Europe, probably due to the risk of fire, but probably also because of lack of access to nearby resources. The evidence from Old Riga is therefore compatible with this more-or-less universal pattern of organization.

The results of the study lead to the conclusion that iron production in Latvia, both in the Iron Age and in the 13th–16th centuries, took place mainly outside, but close to, the open or fortified settlement sites. In urban areas,

usually only blacksmithing was undertaken. Limitations of space, the risk of fire (although fires could also occur in smithies – a fire destroyed the smithy on the hillfort site of Aizkraukle; Urtāns 1960, 21–23) and lack of nearby resources are probably some reasons for such an organizational pattern. However, we do find two exceptions to this rule, namely Asote and Dinaburga, where bloomery ironmaking was undertaken in the hillfort and within the castle settlement respectively.

Archaeometallurgical analysis

The samples for analysis were selected from the collections based on the identification of bloomery slag by visual means (generally blue-grey, homogeneous, dense slag with evidence of fluidity, which either has solidified within the furnace or has been tapped from it). Archaeometallurgical analyses were performed at the Departments of Analytical and Physical Chemistry, University of Latvia. Analyses have been made of 18 samples of slag and one sample of clay from a furnace shaft from four prehistoric and one medieval site (Table 3). The slag samples were homogenized in an agate pestle and the powder obtained analysed by X-ray diffraction spectrometry (XRD) and wavelength dispersive X-ray fluorescence spectrometry (WDXRF). XRD was undertaken with a Bruker *D8 ADVANCE* diffractometer using Cu K α radiation ($\lambda = 1.54\text{\AA}$ generated at 40mA and 40kV) and diffraction patterns were recorded from 5° to 60° 2-theta with a step size of 0.2°. WDXRF

Table 3: XRF analyses of slag from four bloomery sites

Site	Sample	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	K ₂ O	MgO	Na ₂ O	P ₂ O ₅	TiO ₂	MnO	BaO	SO ₃	ZrO ₂	SrO
Spietiņi	N9	71.61	6.08	12.00	2.01	4.08	1.56	0.88	0.92	0.57	0.07	0.07	0.04	0.05	0.01
Spietiņi	N1	23.50	62.50	5.32	2.68	1.21	0.89	0.48	2.93	0.16	0.22	0.06	0.03	0.02	0.01
Spietiņi	N2	14.05	73.89	1.99	5.16	0.57	0.46	<0.01	3.36	0.07	0.21	0.07	0.06	0.01	<0.01
Spietiņi	N3	17.27	68.22	4.01	2.99	0.94	0.65	0.33	5.14	0.11	0.09	0.14	0.08	0.01	0.01
Spietiņi	N4	15.84	70.04	3.26	2.86	0.86	0.53	0.42	5.75	0.10	0.09	0.14	0.04	0.01	0.01
Spietiņi	N5	23.43	57.58	3.88	8.37	1.16	0.83	0.38	3.68	0.16	0.33	0.08	0.09	0.02	0.01
Spietiņi	N6	23.28	57.13	4.15	8.55	1.19	0.84	<0.01	4.11	0.16	0.33	0.08	0.12	0.02	0.01
Spietiņi	N7	24.21	55.54	5.44	6.71	1.43	1.06	0.36	4.42	0.16	0.43	0.07	0.09	0.02	0.01
Spietiņi	N8	25.31	58.27	5.12	5.28	0.99	1.40	<0.01	3.10	0.15	0.23	0.07	0.06	0.01	0.01
Koknese	N10	24.79	58.46	4.86	4.25	1.76	0.94	0.58	2.63	0.17	1.35	0.13	0.06	0.01	0.01
Koknese	N11	25.16	58.71	5.06	4.94	1.43	1.86	0.58	1.39	0.14	0.50	0.04	0.12	0.01	0.01
Asote	N12	29.30	48.41	3.67	11.51	1.17	0.66	0.29	2.15	0.14	2.17	0.43	0.08	0.01	0.01
Asote	N13	23.80	65.95	4.83	1.67	1.47	0.53	0.53	0.83	0.13	0.12	0.06	0.05	0.01	<0.01
Asote	N16	25.74	62.83	5.07	1.54	0.78	0.84	0.87	1.71	0.13	0.29	0.05	0.07	0.01	<0.01
Asote	N17	24.00	63.74	4.90	1.67	1.90	0.61	0.99	1.77	0.10	0.12	0.05	0.09	0.01	<0.01
Asote	N18	21.69	59.74	5.82	3.38	0.83	2.00	<0.01	0.71	0.15	5.39	0.14	0.09	<0.01	0.01
Dinaburga	N14	32.41	48.91	6.27	2.57	1.17	0.90	0.52	1.10	0.18	5.00	0.86	0.03	0.01	0.01
Dinaburga	N15	39.89	37.34	8.09	2.35	1.75	1.48	1.24	1.81	0.28	5.07	0.54	0.07	0.02	0.01

measurements were made using a Bruker *S8 TIGER* spectrometer, in best-detection mode using helium conditions with a 28mm collimator and X-ray foil as powder support material.

Only two bog ore samples have been analysed in this study, neither of which is from an ironmaking site, and they have not been roasted (Table 1). In addition, there is, as mentioned above, an analysis of the ore from Mežīte hillfort. As part of the *TechTrans* project, several ore samples have also been analysed in connection to the ironworks from the Courland era (Jakovļeva *et al* 2019). These are not part of the research described here, but demonstrate what seems to be a general problem, namely the low iron content of the Latvian ore. However, in some cases, such as the ore from Madona, the Fe_2O_3 content is nearly 90%. The ore is in general rich in phosphorus but, as the analyses show, there are some exceptions which can be based in local compositions (Modena) or material which is contaminated with sand (Puze). High calcium and aluminium content is also commonly found.

The slag may be interpreted as being from bloomery ironmaking, based on the elemental composition and the crystalline phases. Comparison of the analyses shows both variability between sites and a high degree of similarity between samples from individual production sites. There are two groups within the slag from Asote, but because the context of the finds is not well documented, the cause of the variation is difficult to determine (Table 3). In general, we can see a pattern where there is a higher content of iron in combination with lower silicon content at the oldest bloomery sites. A high content of iron in bloomery slag is both normal and necessary for successful ironmaking. However, a statistical trend showing a lower proportion of iron in the slag at the later sites may suggest changes and improvements in the process over time. However, we cannot exclude the possibility that lower-grade ores were being employed. The slag from Dinaburga (15th–16th century) shows an iron content that approaches that of the slag from blast furnace production in Courland in the 16th–18th century (Jakovļeva *et al* 2019).

The content of other elements follows a pattern at the individual sites, most probably based on the ore used. However, one exception is the large variation in the calcium content at Spietiņi. Because no ore from the site has been analysed, it is not possible to say whether the calcium derives from the ore, or whether a flux has been used in production.

The semi-quantitative XRD patterns suggest that the slag mainly consists of wüstite (FeO). The apparent complete lack of magnetite (Fe_3O_4) in the slag suggests that it was not exposed to air during the forming process and solidified inside the furnace. The dark surface colour of the flow lobes of these slags also supports the interpretation that the slag has not been tapped.

Latvian production in a comparative perspective

The Baltic

Iron metallurgy has been a little-researched theme in the Baltic (Peets 2003, 18–20; Salatkienė 2008), but the limited archaeological evidence for iron production in Estonia and Lithuania shows some resemblance to that from Latvia.

Forty extraction sites were known in Estonia by 2003, and 24 of them had been investigated (Peets 2003, 18). Production seems to have started around the 1st century AD and declined in the mid-14th century. More than 200 sites are known in Lithuania, but only 40 have provided useful information. The great majority of finds date from the 2nd–6th centuries AD, including 20 sites with furnaces (Navasaitis and Selskienė 2007; Zalnierus *et al* 2007). All the production sites in Lithuania are associated with settlements (Salatkienė 2008), seemingly a feature in common with Latvia.

According to Peets (2003, 23), there are considerable technological differences between the evidence from Estonia when compared to the neighbouring areas of Finland, Karelia, Latvia, Lithuania and northwest Russia. He has identified at least two different types of furnace in the Roman Iron Age and Migration period, but the material is mostly fragmented, causing considerable uncertainty (Peets 2003, 68). The lower part of a furnace with a circular ground plan, built on a large granite stone, was found at Tartu. The timber-curbed furnaces from Metsküla and Tindimurru were better preserved, but it is unclear how widespread this kind of furnace was. The reconstruction has a slag pit with a frontal pit. Two furnaces have been excavated at Raatvere, with channels having a diameter of 70–80mm, interpreted as ventilation channels. The channels seem to be part of a frontal pit with reddish clay (Peets 2003, 74, fig 24). Slag-tapping furnaces are known at the end of the Iron Age and in the Middle Ages, both an above-ground type and a partly sunken type (Peets 2003, 127, fig 66).

The Virbaliūnai site has yielded the best-preserved remains of an iron smelting complex in Lithuania

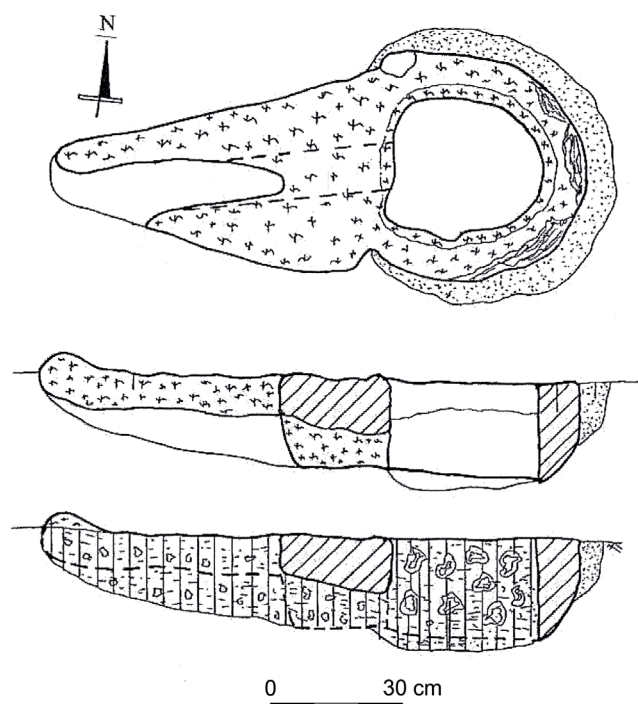


Figure 6: Plan and section of a bloomery furnace in the Virbaliūnai settlement, Lithuania (Žalnierius *et al* 2007, 382, fig 6).

(Navasaitis and Selskienė 2007; Zalnierius *et al* 2007). Nine furnaces, two pits for charcoal burning and one pile of clay for the furnaces were uncovered among various settlement remains dated to the 4th or 5th century AD. One of the furnaces had larger dimensions than the rest, with an internal diameter of 550–600mm and a depth of 460mm. The remaining parts of the other furnaces reached 300mm depth and had an internal diameter of 250–440mm, with *in situ* slag weighing 12–16kg (Fig 6). The furnaces had a slag pit and stones supporting the clay shaft, and a channel which seems to resemble the frontal pits documented at Spietīni in Latvia. Other furnaces of a similar type have been uncovered at Kereliai hillfort, Lazdininkai (Kalnalaukis, Kretinga district) and the Pajauta valley in Kernavė. They were probably in use from the 1st century BC, although most of them are dated to the 2nd–5th centuries AD (Navasaitis and Selskienė 2007, 387; Zalnierius *et al* 2007, 383f). A furnace at the Semenīškės settlement in Kernavė also seems to have a frontal pit that resembles the examples documented at Spietīni and the channels at Virbaliūnai (Jouttijärvi and Voss 2013a).

Eastern Europe

Across Eastern Europe, the similarities in terms of geographical conditions and major natural resources also determined to some degree the similarity of iron production processes. The basic research methods for studying ancient metallurgy were developed by Russian

archaeologists Boris Aleksandrovich Rybakov (1908–2010) and Boris Aleksandrovich Kolchin (1914–1984). Bringing together an enormous quantity of archaeological evidence, Rybakov produced a fundamental opus on the development of crafts in Ancient Russia up to the 15th century (Rybakov 1948). Kolchin (1953; 1959) focused on ferrous metallurgy and the metallographic study of iron artefacts.

Samples from several archaeological sites in Russia, Belarus and Ukraine indicate that the best bog ore (35.7–53.0% Fe) comes from the region of Volhynia (Ukraine), with only 11.6–17.0% SiO₂. In the north-eastern part of Eastern Europe, too, in the Ladoga (Russia) and Gomel (Belarus) areas, the ores are relatively rich in iron: 35% Fe in Ladoga, 43.18% Fe in Gomel (Kolchin 1953, 36, table 1).

Archaeologically excavated bloomery sites in the territory of ancient Russia number more than a hundred. Several types of furnace occur in Russia, differing in construction and technology. The earliest ironmaking sites, dating from the early 1st millennium AD, have been discovered in the basin of the Southern Bug, in present-day Ukraine. They employed a single-use furnace with a small, cylindrical above-ground shaft and a shallow pit for collecting the slag. Anteins (1976, 74) refers to these as pit furnaces. The mode of air supply is unclear, but they were placed in areas with relatively strong air flow – on exposed hills or slopes. Furnaces of this type have generally been found in large groups (Bidzilia and Pachkova 1969).

Another type represented in Ukraine is the above-ground shaft furnace with artificial draught and a basal slag pit, with an external air channel from the ground surface into the slag pit. In Cherkasy Oblast, present-day Ukraine, more than ten furnaces of this type have been discovered, all of them from the 3rd–4th centuries. They are cylindrical, extending 550mm into the natural subsoil, the walls lined with dolomite blocks and covered with clay. A preserved furnace base is 0.8m in diameter, the furnace narrowing towards the top (0.75m) (Kropotkin and Nakhapetian 1976, 318–319, fig 7). Starting from the 5th/6th century, this furnace technology dominated throughout Eastern Europe.

From the 7th–8th centuries, with the increasing demand for iron, the dimensions of bloomery furnaces increased: they became higher and with a larger diameter (0.8–1.0m). These were permanent, above-ground furnaces, built for long-term use, with an opening for slag tapping and for obtaining the maximum draught.

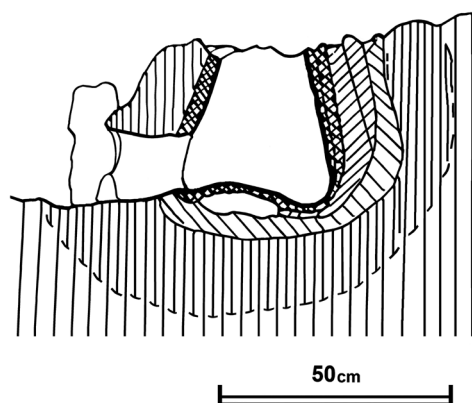


Figure 7: Furnace remains from Grigorovka hill-fort, Ukraine (Artamonov 1955b; cf Pleiner 2000, 171).

The development of skills and production methods in present-day Russia led in the 13th century to a more developed type of ironmaking, the *domnitsa*, regarded as a transitional stage to blast furnace technology (Kolchin 1953, 34, fig 11). The term *domnitsa* is first mentioned in Russian peasant farm tax lists of the late 15th century. The name refers to a stationary, repeatedly used shaft furnace, built in an above-ground or semi-subterranean building, which gave the ironmaster protection from the weather so that he could continue working the whole year round.

A good analogy for the smelting furnaces at the Asote hillfort (Latvia) may be found in the more than 23 furnaces excavated at the Grigorovka hillfort and the adjacent settlement (Vinnytsia Oblast, Ukraine). The furnaces at Asote and Grigorovka (Fig 7) are similar in form and construction: sunken shaft furnaces with a flat boulder and a covering of clay providing the base, and a specially formed mouth for the air supply and for slag extraction. They are also approximately contemporaneous, dating from about the 10th century (Šnore 1957, 18–19; Artamonov 1955a, 107–109, figs 44–45).

Dozens of tuyères have been found in or near furnaces in ancient Ryazan, Chervonnaya Gora (Zhytomyr Oblast, Ukraine), Progonnoye Pole (Leningrad Oblast, Russia) and the hillforts of Raikovets and Grigorovka, among others. The tuyères include cylindrical, conical as well as prismatic forms. The above-mentioned Sēlpils tuyère corresponds to the 9th–13th century Russian examples of cylindrical tuyères (Šnore and Zariņa 1980, 171, fig 148: 14). Blooms are very rare finds. They have been recovered mainly on hillforts (Knaiazheia Gora, Vyshgorod and Raikovets) and in some medieval towns, such as Novgorod (Kolchin 1953, 44; Kolchin 1985, 247).

Central Europe and Scandinavia

The evidence for early iron production in Central Europe is characterised by technological variation, both in geographical and chronological terms (Pleiner 2000). There is, however, considerable uncertainty associated with the many different reconstructions of furnace types, as the quality of preservation and documentation varies. Because of this, it is possible that an overly large number of furnace types have been distinguished (Jouttijärvi and Voss 2011). The present evidence can, according to Guntram Gassmann and Andreas Schäfer (2014), be basically divided into two technological categories or traditions: furnaces that could be reused, and slag-pit shaft furnaces that had to be moved or destroyed after each smelt. The first group is characterised by slag-drain furnaces with openings for slag-removal from the slag pit, often in combination with a frontal working pit, while the remains of single-use furnaces have remained in situ in the ground, forming slag-pit fields, often with a seemingly irregular layout.

The difference between the two groups is also a matter of chronology, as the first group of furnaces seems to be related to the late Hallstatt and early La Tène culture of the 6th and 5th centuries BC (Gassmann and Schäfer 2014; Jouttijärvi and Voss 2011; Pleiner 2000, 163), although different variants have been found in the pre-Roman Iron Age of Denmark and Germany. Evidence seemingly representing a very early example of this reusable furnace type has also come to light in the Röda Jordan area of southern Sweden (Grandin and Hjärthner-Holdar 2003; Hjärthner-Holdar *et al* 2013). The radiocarbon dates indicate iron production in the early part of the pre-Roman Iron Age – possibly as early as the transition between the Late Bronze Age and Early Iron Age.

In the 1st–2nd century AD this furnace type was found across a wide area, including Dacia, Bohemia and England (Sussex) (Jouttijärvi and Voss 2013a with references) and locally survived into the 3rd century (Bielenin 2011; Jouttijärvi and Voss 2013a with references). Nonetheless, the type seems to have been progressively replaced by slag-pit furnaces of the second type throughout northern Germany, Denmark and Eastern Europe from the 1st century AD onwards (Gassmann and Schäfer 2014; Jouttijärvi and Voss 2013a, 41; Jouttijärvi and Voss 2013b). It is the first group of reusable furnaces that will be emphasised in this article, as it shares some basic features with the Latvian types.

Good examples of early iron production are found at Neuenburg and St Johan-Würtigen in south-west

Germany, dating from the 6th–3rd century BC (Gassmann *et al* 2005; Gassmann and Schäfer 2014). They have been reconstructed with a cupola, like Radomir Pleiner's domed furnaces (Pleiner 2000, 163f), because heavy clay packing is observed at the base. The Siegerland region of western Germany has provided evidence of major iron smelting activities in the middle and late La Tène period, 3rd–1st centuries BC. These furnaces are also reconstructed as a domed type with an integrated front pit and added shaft (Gassmann and Schäfer 2014, 23). Numerous remains of domed furnaces with an integrated front pit are known from this period in the Alpine foothills along the Danube as well. Evidence for La Tène iron production in northern Germany has come to light in recent years, but seems to relate more to the Scandinavian types.

The early Danish furnaces share several features with the south German technology of the La Tène period, but were quite small, with a furnace chamber approximately 0.3m in diameter (Andersen *et al* 1987, 178; Jouttijärvi and Voss 2011). Important finds have been made at Skovmarken, Espevej and Sønder Holsted, representing what is often referred to as the 'Skovmarken type'. They belong to the period between the 5th century BC and 3rd century AD, and the construction is characterised by a shaft of burnt clay built over a slag pit, with an opening leading to a working pit. Excavations at Sønder Holsted show that the entire shaft and air supply was above ground level (Fig 8). The Skovmarken type was previously often interpreted as a slag-tapping furnace, but is now understood to be a 'slag-drain' furnace like the southern and western German counterparts (Jouttijärvi and Voss 2011; Jouttijärvi and Voss 2013a). The furnaces have been detected at settlement sites – probably from the same period – but are often in poor condition because of ploughing.

Most iron production sites in Norway are, by contrast, found on uncultivated land in the outfields, but many are slag-pit furnaces that were used only once. However, in recent years a few early furnaces have emerged even in agricultural and settlement areas. A small bloomery site near an Iron Age settlement at Holen in Gausdal could be comparable to the Skovmarken type, but the interpretation is insecure due to heavy ploughing (Rundberget and Larsen 2017).

The Roman Period 'Trøndelag' furnaces of middle Norway have slag pits usually built of slabs dug into the ground, with a diameter of 0.65–0.9m and a depth of 0.65–1.0m. The slag could be removed through an opening (Rundberget 2010; Stenvik 2003; Stenvik 2013),

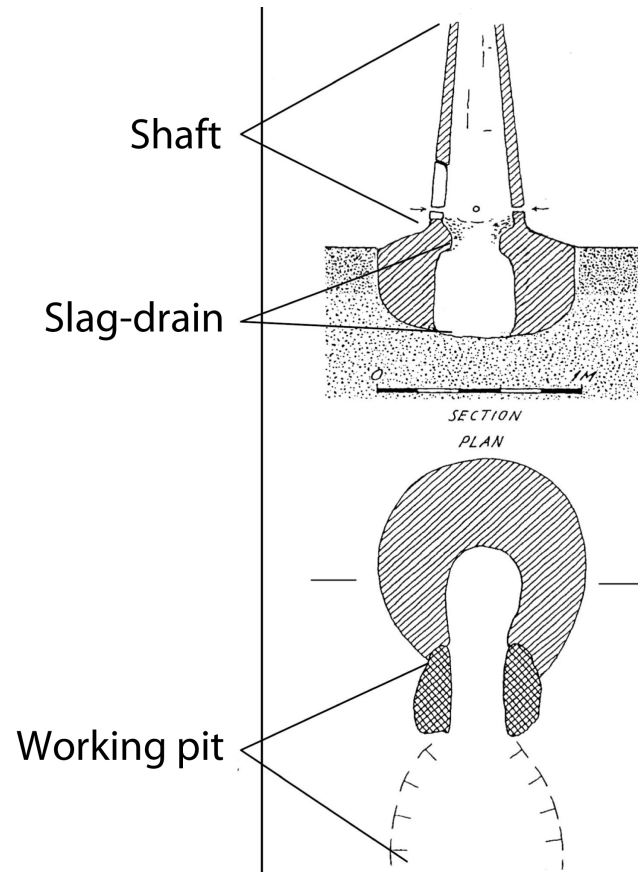


Figure 8: Reconstruction of the 'Skovmarken' furnace based on the find from Sønder Holsted and earlier finds (Jouttijärvi and Voss 2013a, fig 8). Scale bar 1m.

but often around 50–150kg of slag is found in the pit. The clay shaft seems to have been funnel-shaped.

Recently excavated furnaces in Gästrikland in Sweden dated to the 4th–5th century share some similarities with the 'Trøndelag' furnaces (Hjärthner-Holdar *et al* 2014). The three shaft furnaces had an internal diameter of 0.7–0.8m and slag pits containing slag blocks weighing 150–250kg. The stone-built pit functioned as the foundation for the shaft and had an opening on one side for iron and slag to be taken out. Other reusable furnaces have been documented throughout the Iron Age, like the pre-Roman Iron Age (400–200 BC) furnace at Söderåkra in Kalmar (Hjärthner-Holdar *et al* 2013). A close parallel to the Skovmarken type is a furnace in Fyllinge from the late pre-Roman Iron Age, and a furnace in Åbyggja, Uppland, which is dated to AD 550–1000. Best known are the 'shorebound' furnaces in Jämtland that Gert Magnusson (1986) interpreted as pit furnaces, but which have a clear parallel to the Trøndelag furnace (Stenvik 2003, 78; Hjärthner-Holdar *et al* 2013).

Discussion – unique or part of a community?

Our knowledge of prehistoric and medieval ironmaking in Latvia is based on relatively sparse data. The excavations took place a long time ago and are poorly documented by modern standards. However, the research and interpretations from several decades ago are still in use and show a somewhat inaccurate picture of the activity. The *TechTrans* project has therefore made an important contribution, both in revitalizing and reinterpreting this old material, and in providing new knowledge of this aspect of Latvian history.

The bloomery technology must be reinterpreted in the light of the documentation and material from just a few excavations, with the ironmaking sites of Spietiņi (1st–4th century), Asote (10th–11th century) and Dinaburga (15th–16th century) being the most important ones in this respect. It is mainly the lower parts of the furnaces that remain, including the lower shaft, the base, and the opening for removal of slag. The internal diameter of the furnaces has been measured as about 200–300mm, while the total diameter can be up to 1.0m. The height of the furnaces is unknown, but the inner diameter suggests that it may have been approximately 600–700mm. There is no in situ evidence of air inlets or tuyères, but several finds of tuyères suggest that these were placed above the surviving parts of the furnaces. That the bore of the tuyères was only 10–20mm suggests that more than one bellows was used.

Previously, the furnaces have been interpreted as slag-tapping shaft furnaces, where the slag was tapped through the opening in the bottom and into the adjacent pit. However, there are no characteristics indicating this. Clearly, the slag had been flowing and formed a draining structure before it solidified, but this process happened in the lower part of the furnace, as indicated by the occurrence of both small and larger charcoal imprints in the slag, and supported by the lack of magnetite in the slag analyses. Instead, after the slag had solidified, it was taken out through the opening and into the pit in front of the furnace. Accordingly, this type of furnace is described as a slag-drain furnace.

When compared with western and central Europe, the technological principles of the Neuenburg, Skovmarken and Trøndelag furnaces seem to have been similar, with the possibility of removing the slag from the slag pits without destroying the shaft, but there are also several differences. The shafts of these types are suggested as having been domed, cylindrical or funnel-shaped.

The German re-usable furnaces are from the 5th–1st centuries BC, as are most of the Skovmarken furnaces, although some could be from the 1st century AD, while most of the Trøndelag furnaces seem to be somewhat later, from the 1st–6th centuries AD. They are, in other words, not contemporary, but seem to follow the same technological principles for iron production. Those same technological principles are also identifiable in central Europe – in Austria, Moravia, Hungary and Poland (Pleiner 2000, 172–179 with references).

East of the Baltic states, it seems that the bloomery technology is varied. It is not easy to find parallels for the slag-draining technology in the material reviewed. The development and influences in these regions seem to have different origins, which did not have an impact on development in the west. However, one exception is the Grigorovka hillfort furnace (Ukraine), which has much in common with the slag-draining technology.

Coming back to the Baltics, the Lithuanian bloomery technology seems to show close similarity with that of Latvia, while the Estonian evidence is different and probably influenced by other impulses. In Lithuania, the shaft furnaces at the Virbuliunai and Semeniškės settlements (Navasaitis and Selskienė 2007; Žalnerius *et al* 2007), share distinct features with the more-or-less contemporary Spietiņi furnaces in Latvia, having an internal diameter of approximately 300mm and shallow slag pits leading to a front pit through an opening in the slag pit. The furnace at Semeniškės has also previously been compared to the Skovmarken type in Denmark (Toreld and Wranning 2005; Jouttijärvi and Voss 2013a).

However, the places of origin and the way technology spread are challenging to determine with any degree of certainty based on this study alone. What we can see clearly from comparative studies is that ironmaking in Latvia and Lithuania does not have much in common with the regions further east, such as Russia and Ukraine, or with Estonia to the north. The bloomery technology in Latvia is clearly not unique to this area, but has to be seen as part of a European technological development which spans the pre-Roman Iron Age and most of the Iron Age. However, in a chronological perspective, this technology is most common in western Europe in the earlier parts of the Iron Age. By the 6th–8th centuries AD, slag-tapping shaft furnaces were increasingly being used, especially in Scandinavia (Rundberget 2016, 48–67). Ironmaking in Latvia seems to have been more conservative when it comes to development and technological transfer. Thus, it is perhaps only with the medieval period that we can talk about a clear change

in technology, and the early modern ironmaking at Dinaburga may be an expression of this. The Dinaburga technology was probably based on the tapping principle, employing a furnace of more robust size and structure, and the technology may have developed to a stage nearer to the blast furnace technology, as also expressed in the Russian *domnitsa*. A similar development is also seen in Skåne in southern Sweden, where the more efficient so-called timber-clad furnace (Strömberg 2008, 138–9; Rundberget 2016, 39) came into use in the 14th and 15th centuries.

Conclusion

The paper has focused on re-examining older archaeological studies of bloomery iron practice in Latvia. Approaching older material can be challenging, because of interpretation problems and because the documentation needs to be reconsidered in light of contemporary knowledge. Nevertheless, this study shows that it may be possible to get new and useful results in terms of technological, morphological and metallurgical aspects of iron smelting. These results were linked to a general goal of the *TechTrans* research project, namely to look at technological development in a broader context. The comparative studies presented show that bloomery iron production in Latvia in the Iron Age has clear parallels with central and northern Europe, but that eastern and northern affiliations seem less likely. The study also shows that the smelting technology may be characterized by conservatism, and that its development did not follow the patterns seen to the west in the later Iron Age and the Middle Ages. Even so, there is evidence that methods became more refined, with better dividends during the latest part of the time period.

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The authors

Bernt Rundberget, PhD, is Head of the Department of Archaeology and Cultural History, NTNU University Museum. His main area of research covers Iron Age and medieval iron production technology, with a focus on the extent, distribution as well as economic and political conditions of iron manufacture.

Address: Department of Archaeology and Cultural History, NTNU University Museum

N-7491 Trondheim, Norway

Email: bernt.rundberget@ntnu.no

Andrejs Vasks, Dr habil hist, Professor, is a senior researcher at the Institute of Latvian History, University of Latvia. His research focuses on the Bronze and early Iron Age in the eastern Baltic.

Address: Institute of Latvian History, University of Latvia, Kalpaka bulvāris 4, LV-1050 Rīga, Latvia

Email: andrejs.vasks@lu.lv

Ingar Mørkestøl Gundersen is a doctoral research fellow at the University of Oslo. He is currently working on a PhD on the 6th-century climate crisis in Scandinavia. He has also been working on settlement archaeology and exploitation of outfield resources.

Address: Museum of Cultural History, University of Oslo, PO Box 6762, St Olavs plass, N0130 Oslo, Norway

Email: i.m.gundersen@khm.uio.no

Rūdolfis Brūzis, Dr hist, is a researcher at the Institute of Latvian History, University of Latvia. His research theme is weaponry in medieval archaeological material.

Address: Institute of Latvian History, University of Latvia, Kalpaka bulvāris 4, LV-1050 Rīga, Latvia

Email: semigall@hotmail.com

Jan Henning Larsen is Professor Emeritus at the Museum of Cultural History, University of Oslo. He has investigated iron extraction sites in southeast Norway for more than 30 years and has several publications on production in Iron Age and medieval times that focus on typology and chronology.

Address: Museum of Cultural History, University of Oslo, PO Box 6762, St Olavs plass, N0130 Oslo, Norway

Email: j.h.larsen@khm.uio.no

Viktorija Bebre, Dr hist, is a researcher at the Institute of Latvian History, University of Latvia. Her research covers medieval and post-medieval archaeology and leatherwork.

Address: Institute of Latvian History, University of Latvia, Kalpaka bulvāris 4, LV-1050 Rīga, Latvia

Email: bebre-v@inbox.lv

Inga Doniņa, Mg hist, is a research assistant at the Institute of Latvian History, University of Latvia, currently writing a PhD on Couronian material and spiritual culture in the Late Iron Age and Middle Ages.

Address: Institute of Latvian History, University of Latvia, Kalpaka bulvāris 4, LV-1050 Rīga, Latvia

Email: inga.donina@inbox.lv

Arturs Vīksna is Professor at the Faculty of Chemistry, University of Latvia. His research includes soil science, food science and agricultural plant science.

Address: Departments of Analytical and Physical Chemistry, University of Latvia, Jelgavas Street 1, LV-1004 Riga, Latvia

Email: arturs.viksna@lu.lv