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Examination of smelting and smithing slags formed in bloomery iron-making process

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The results of a study of chemical and phase composition and the microstructure of iron smelting and smithing slags from three iron producing sites in Lithuania from the Old Iron-Age are discussed. Slag affinities and differences are analysed in order to make the identification of the findings more reliable.

The results of chemical analysis revealed that the smithing slags contained lower concentrations of phosphorus and manganese but a slightly larger amount of potassium as compared to the smelting slags. Ores rich in phosphorus have been used for iron-making in many sites in Lithuania; thus, the concentration of phosphorus can be quite a reliable indicator in the identification of the kind of slag in these sites. The examination of phase composition and microstructure has revealed that smelting and smithing slags can be composed of the same phases. However, some peculiarities of the microstructure of the smithing slags, which can be used to identify the slags of this kind, have been observed: remnants of added flux (sand), partially dissolved hammerscales and layered constitution of a slag lump with streaks containing quartz grains.

Key words: Old Iron-Age, bloomery iron, smelting slags, smithing slags, chemical composition, phase composition, microstructure

INTRODUCTION

In ancient times iron was made in solid state by direct smelting at a temperature of about 1200 °C in bloomery furnaces. The product was a porous mass of iron and slags called "bloom" which was further heat-treated in hearth and hammered on anvil.

Slags were the main waste of the metallurgical processes. Smelting slags (tap slags, furnace bottom slags, slags adhering to wall, etc.) was produced in the iron-making process in a furnace, while smithing slags (called "smithing hearth bottom" [1] or "plano–convex bottom" [2]) was formed in the iron-working process in a smithy hearth. These remnants is a valuable archaeological material, since their composition and structure are closely related to the materials used and the conditions of slag formation. The examination of chemical and phase compositions as well as the microstructure of slags can give the answers to many questions of archaeology and history of technology (such as performed activities, raw materials, fuel, type of equipment, quality of the product, etc.) [1–4].

The study of smithing slags had its start later than the study of smelting slags, in the 1960's [2, 5]. The kind of slags can be determined depending on archaeological context (e. g., extant equipment). Slags can be also recognised by their typical morphological characteristics [2, 4, 6, 7]. However, no elements of installation except some fragments of slags were normally found in many of the excavations. Furthermore, furnace-bottom slags and plano–convex smithing slags can be externally quite similar. Hence, the visual evaluation of slags can be insufficient for a reliable determination of their kind. In addition to the morphological characteristics, different chemical composition [8–10] as well as other phase composition and microstructure of smelting and smithing slags are presented in literature [2, 8, 11, 12]. However, the constitution of slags varies as a result of distinct composition of raw materials, also due to different technologies of iron-making and iron-working processes in different regions. Therefore, it is important to determine compositional and structural affinities and differences of various kinds of slags in many sites. This can enable researchers to identify the kind and origin of the findings and to estimate the technological processes of formation reliably, even when only a separate fragment is available. The researchers of the development of metallurgical techniques in Lithuania are especially interested in these points.

Smelting slags of various periods from about 20 Lithuanian sites have been investigated in the last ten years [4, 13, 14], whereas smithing slags from only two sites have been examined [15, 16].

The aim of this work was to examine the chemical and phase composition and microstructure of smelting and smithing slags found in three sites in Lithuania dating from the Old Iron-Age. Depending on the obtained data, slag affinities and differences were analysed for making a reliable identification of the kind of the findings.

EXPERIMENTAL

Slags found in Aukštadvaris hill-fort, Trakai district (2nd–4th cent. A. D.), Bakšiai ancient settlement, Alytus (3rd–4th cent. A. D.) and Lieporiai ancient settlement, Šiauliai (3rd–5th cent.

A. D.) were chosen for the analysis. Smelting and smithing slags possessing typical morphological characteristics were picked out for determining their affinities and differences. In Table smelting slags, i. e. tap slags are numbered AT1–AT3, BT1–BT3 and LT1–LT3. These findings are 2–5 cm in length with dark grey, smooth surface and have an obvious indication of flow – solidified slag trickles. Most probably, they had formed during tapping out from the furnace or the flow to its bottom. Findings AF1, BF1–BF2 and LF1–LF2 were smelting slags of another kind, called furnace-bottom slags. They are grey or brown without any obvious indications of flow. Most likely, those slags had formed on the furnace bottom during smelting. Findings LT3-W and LF3-W were smelting slags adhered to the furnace wall. Typical smithing slags formed in a hearth are for the most part plano–convex or convex–convex lumps ranging in size from 5 to 20 cm (on the average 11 cm) in diameter and from 3 to 6 cm in depth [2, 4, 5, 7]. Aukštadvaris' slags AS1 and AS2 have the following specific features: they are grey-brown, about 10 cm (AS1) and 14 cm (AS2) in diameter, the undersides of both lumps are convex, their upper surfaces – slightly concave. Sample AS3 looks like a fragment of plano–convex smithing slag. Bakšiai slag BS1 is 8 cm in diameter and about 5 cm of thickness. Lieporiai slag LS1 is a convex–convex lump, about 11 cm in diameter, whereas sample LS2 is smaller like a plano–convex slag fragment.

The elemental composition of slag specimens was determined by optical emission spectroscopy using a direct current plasma emission spectrometer Beckman SpectraSpan VI. The quantities of oxides were calculated by the elemental composition of the specimens. The oxidation state of iron was not determined and total iron was listed as iron (II) oxide.

The samples were characterized by powder X-ray diffraction analysis (XRD) performed with a D8 Bruker AXS powder diffractometer using CuKα1 radiation.

In order to investigate the microstructure, polished sections were prepared. The microstructure of the samples was examined on an optical microscope Olympus BH2.

RESULTS AND DISCUSSION

Chemical composition

The chemical composition of slags of various kinds from three sites in Lithuania are given in Table. Iron oxide (53–74% FeO) and silicon oxide (9–29% SiO_2) are predominant in all the slags. This indicates that all the findings are metallurgical slags produced during a bloomery iron-making process [1, 4]. The reliance of Fe and Si quantity on the site or on the kind of the slag was not observed. The quantities of other elements, such as Al, Ca, Mg, Na, Ti and Ba also vary in different findings and identification of the

Table. **Chemical composition of smelting and smithing slags, weight %**

Site and century	Kind of slag	Sample	Finding	Fe	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	MnO	P_2O_5	K_2O	Na_2O	TiO_2	BaO	Total*	Reference
Aukštadvaris hill-fort, Trakai distr., 2nd–4th cent. AD	Smelting	AT1	A (I) 11-1	44.72	49.82	8.57	27.66	4.01	4.78	0.94	0.27	4.63	0.90	1.19	0.16	0.15	102.2	[14]
		AT2	A (II) 11-1 (000509/3)	51.03	65.65		19.92	1.49	4.45	0.52	0.46	8.45	0.87	0.77	0.06	0.23	102.9	[14]**
		AT3	A (II) 11-2	46.83	60.24		17.47	1.38	6.41	0.41	0.42	10.72	1.55	0.25	0.05	0.25	99.2	
		AF1	A (II) 11-3 (000509/4)	45.88	59.02		19.12	2.07	7.73	0.61	0.43	11.00	1.32	0.85	0.06	0.26	102.5	[14]**
	Smithing	AS1	A 62-1	43.01	55.33		27.40	4.29	3.16	0.96	0.23	0.96	2.44	0.36	0.15	0.06	95.3	
		AS2	20050126/1	54.78	70.47		24.48	1.80	1.75	0.50	0.16	0.64	0.83	0.12	0.08	0.12	100.9	
		AS3	20050126/3	52.28	67.25		21.71	3.03	1.80	0.90	0.19	0.87	1.42	0.13	0.14	0.05	97.5	
Bakšiai settlement, Alytus, 3rd–4th cent. AD	Smelting	BT1	B 11-1	53.33	56.86	13.05	18.40	2.11	4.86	0.54	0.78	2.35	0.48	0.07	1.12	0.42	101.0	[14]**
		BT2	B 11-2	49.87	64.16		23.55	1.91	5.72	0.76	0.96	2.79	0.53	0.31	0.14	0.30	101.1	[14]**
		BT3	B 11-6	41.25	53.06		28.31	3.52	2.28	0.46	7.45	2.37	0.79	0.20	0.20	0.42	99.1	
		BF1	B 13-1	43.11	9.91	50.62	25.89	3.32	2.02	0.50	2.46	4.32	0.54	0.89	0.13	0.20	100.8	[14]**
		BF2	B 12-1	42.61	54.81		23.95	2.65	3.85	0.73	9.57	2.25	0.85	0.17	0.12	0.58	99.5	
	Smithing	BS1	20050126/5	45.67	58.75		28.89	2.87	2.63	0.65	2.60	1.09	0.96	0.32	0.11	0.15	99.0	
Lieporiai settlement, Šiauliai, 3rd–5th cent. AD	Smelting	LT1	L 11-1	50.83	65.39		26.07	1.24	3.21	0.40	0.39	1.96	0.65	0.20	0.06	0.18	99.8	[14]**
		LT2	L 11-2	52.26	67.23		22.93	2.36	4.37	0.86	0.34	2.64	0.81	0.51	0.12	0.19	102.4	[14]**
		LT3-W	L 11-3	50.26	64.66		23.09	2.72	4.12	0.87	0.26	2.77	0.80	0.22	0.08	0.19	99.78	
		LF1	L 14-1	56.00	72.04		20.56	1.98	5.18	0.66	0.27	1.17	0.68	0.75	0.12	0.08	102.8	[14]**
		LF2	L 04.12-2 (000603/18)	48.69	62.64		26.89	3.64	3.02	0.81	0.29	1.44	1.29	0.25	0.11	0.31	100.7	
		LF3-W	L 04.12-3 (000603/19)	55.87	71.88		18.96	2.41	2.20	0.63	0.17	1.48	0.53	0.14	0.05	0.14	98.6	
	Smithing	LS1	20040329/6	49.46	63.63		22.53	4.68	2.31	0.87	0.05	0.59	1.99	0.33	0.11	0.02	97.1	
		LS2	20040329/4	57.85	74.42		9.55	1.62	0.54	0.40	0.02	0.64	0.31	0.16	0.20	0.01	87.9	

* Sum of oxides without L.O.I. ** Excluding quantity of K_2O.

A – Aukštadvaris, B – Bakšiai, L – Lieporiai, T – tap slag, F – furnace bottom slag, S – smithing slag, W – wall.

kind of slag by them is not possible. However, certain regularity of P, Mn and K quantities in the slags has been observed.

The results of the chemical analysis revealed that the smelting slags contained higher concentrations of phosphorus as compared to the smithing slags. The smelting slags from Aukštadvaris hill-fort contained an extremely large amount of phosphorus (4.63–11% P_2O_5), whereas those from Bakšiai and Lieporiai settlements contained lower concentrations of only this element – 2.25–4.32% and 1.17–2.46% of P_2O_5, respectively. However, only insignificant concentrations of P were detected in Aukštadvaris, Bakšiai and Lieporiai smithing slags, 0.64–0.96%, 1.09 % and 0.59–0.64% P_2O_5, respectively.

The quantity of manganese in the smelting slags of Aukštadvaris (0.27–0.46% MnO) and Lieporiai (0.17–0.39% MnO), similar to other sites in Lithuania [4], is insignificant. However, some slags from Bakšiai (BT3 and BF2) contain even 7.45–9.57% of MnO. The smithing slags contain lower concentrations of Mn than the smelting slags from the same sites: 0.16–0.23%, 0.02–0.05%, 2.60% MnO in Aukštadvaris, Lieporiai and Bakšiai slags, respectively.

The differences in P and Mn quantities in the smelting slags from Aukštadvaris, Bakšiai and Lieporiai are quite conspicuous and related to the composition of the ore used for iron-smelting. The differences of these elements in the smithing slags from various sites are less noticeable. This shows that the smithing slags had formed in a different way [2] as compared to the smelting slags, and in this case, the influence of the ore used for smelting was insignificant. Only Bakšiai smithing slag BS1 contained more manganese that could have originated from the residual smelting slag with a larger quantity of this element to have dropped from the bloom during heating.

The values of the potassium oxide quantity in slags are more scattered. Nevertheless, the largest quantities of K_2O are observed in some plano-convex smithing slags, e. g., 2.44% in slag AS1 and 1.99% in slag LS1. The average quantity of K_2O in the smithing slags from one site is also greater as compared to those of the smelting slags: 0.96–1.56% and 0.64–1.25%, respectively. A larger content of potassium in the smithing slags could be related to a larger quantity of charcoal used in the formation of the smithing slags [17] or to a possible supply of ash as flux during the iron-working process [2].

Some authors investigating slags note that the smithing slags contain lower concentrations of phosphorus and manganese as compared to the smelting slags [8, 9, 16]. The data obtained in this work have confirmed their proposition. In this work [8] the results of chemical analysis indicate that the smithing slags contain a smaller amount of aluminium and larger amount of calcium than the smelting slags. The slags analysed in this work demonstrate a rather opposite tendency.

The investigation of the chemical composition of the slags from Aukštadvaris hill-fort, Bakšiai and Lieporiai ancient settlement indicates that the smithing slags contain lower concentrations of phosphorus and manganese as well as a slightly higher concentration of potassium as compared to the smelting slags from the same site. It should be noted that ores rich in phosphorus were exploited for iron making in many sites in Lithuania, as a significant amount of phosphorus (~2–12% P_2O_5) was detected in the smelting slags [4, 13, 14]. Hence, the concentration of phosphorus could be a reliable indicator for the identification of the slag kind in these sites.

Phase composition

The phase composition of the slags was examined by X-ray diffraction analysis and similarly by optical microscopy. The investigation results indicated that the essential phase of the studied smelting slags is fayalite. The presence of other compounds in these slags in particular depended on the differences of their chemical composition. In Aukštadvaris' slags AT1–AT3, fayalite, glass phase, a comparatively large amount of calcium–iron phosphate and a small amount of wustite and hercynite were detected (Fig. 1a). In Bakšiai and Lieporiai slags BT1, BT2, LT1, LT2, the same phases were observed, only the amount of calcium–iron phosphate was rather smaller, while the concentration of wustite was higher (Fig. 1c). Only in Bakšiai tap slag BT3, which contained 7.45% MnO, wustite was not detected (Fig. 1b). The phase composition of Aukštadvaris' furnace-bottom slag AF1 was similar to that of the tap slags of this site, while in the furnace bottom slags BF1, BF2, LF1, LF2 from Bakšiai and Lieporiai, in addition to the above-mentioned phases, some other compounds were detected: magnetite, leucite, metallic iron, iron corrosion products and charcoal. Quartz grains were found only in the smelting slags adhered to the furnace wall (LT3-W and LF3-W), in the area of the wall.

All the above-mentioned phases, except calcium–iron phosphate and hercynite, were found in the smithing slags. It should be noted that in many smithing slags (AS2, AS3, BS1, LS1) a larger quantity of wustite and leucite as compared to the smelting slags was detected. Nevertheless, it is difficult to identify the kind of the slag by phase composition since phosphate and hercynite have been found in the smelting slags from one site

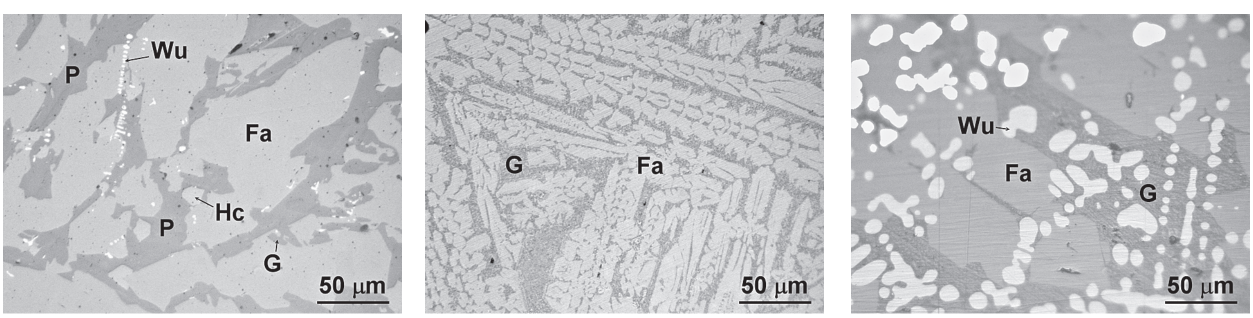

Fig. 1. Microstructure of smelting slags: a) tap slag AT2 from Aukštadvaris; b) tap slag BT3 from Bakšiai; c) tap slag LT2 from Lieporiai. Fa – fayalite, Wu – wustite, P – calcium-iron phosphate, G – glass phase, Hc – hercynite

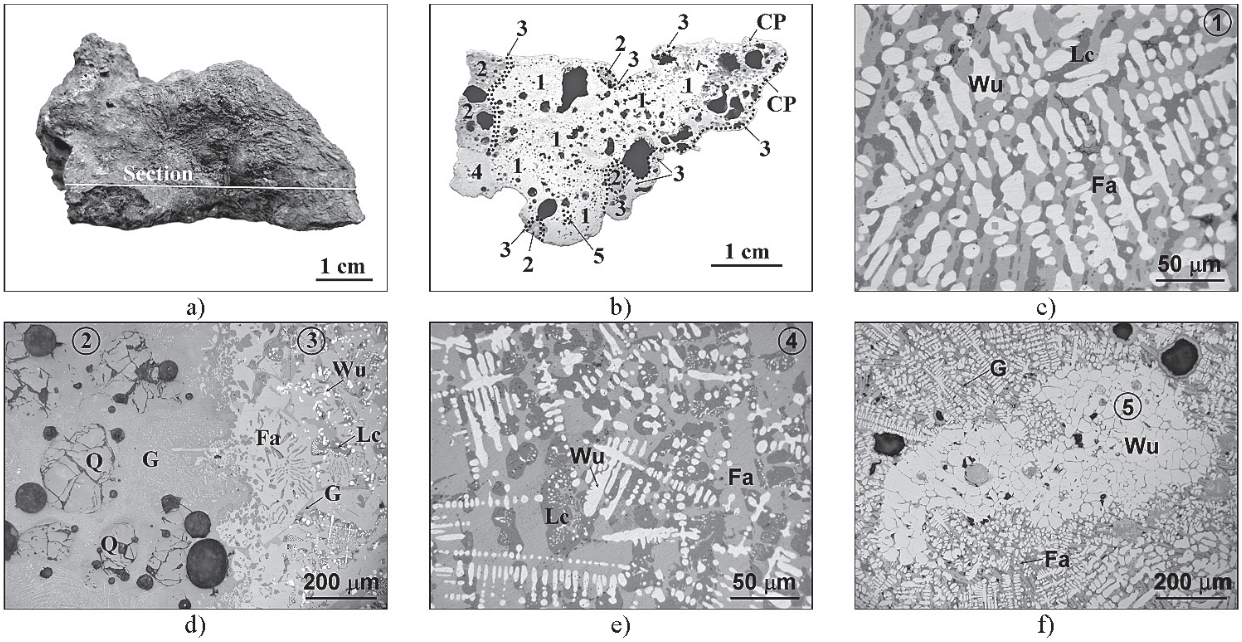

Fig. 2. Smithig slag AS3 from Aukštadvaris (a), polished section (b) and microstructure in different areas of the sample (c–f). Fa – fayalite, Wu – wustite, G – glass phase, Lc – leucite, Q – quartz, CP – iron corrosion products. 1 – Wu, Fa, Lc, (G); 2 – Q, G; 3 – Fa, Lc, Wu; 4 – Fa, Wu, Lc; 5 – Wu

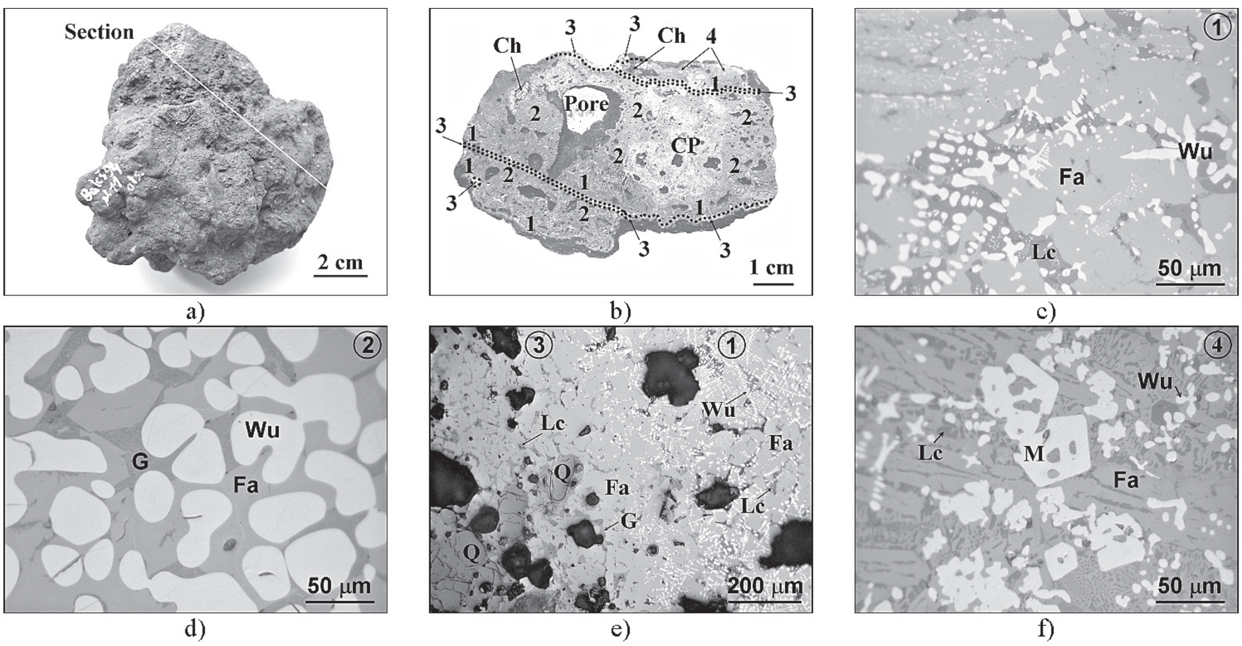

Fig. 3. Smithig slag BS1 from Bakšiai (a), polished section (b) and microstructure in different ar as of the sample (c–f). Fa – fayalite, Wu – wustite, G – glass phase, Lc – leucite, Q – quartz, M – magnetite, Ch – charcoal, CP – iron corrosion products. 1 – Fa, Wu, Lc; 2 – Wu, Fa, G; 3 – Fa, Q, Lc, G; 4 – Fa, Wu, M, G

only (Aukštadvaris), while significant quantities of wustite and leucite have also been found in some smelting slags (LF1, LF3-W). Therefore, the examination of the phase composition and microstructure revealed that generally both smelting and smithing slags could be constituted of the same phases.

Microstructure

The examination of the microstructure of the findings revealed some differences in slags of various types. One or several separate trickles were observed in the structure of the tap slags. The structure of separate trickles differed in the wustite amount and/or in the crystal size, whereas the structure of the same trickle was quite homogeneous, though towards the margin of the trickle it became slightly finer. Bottom slags were heterogeneous, and the crystal size and phase distribution varied noticeably in a relatively small area of the polished section. Trickles or layers with clear boundaries have not been observed in the furnace-bottom slags.

The microstructure of the smithing slags can be either homogeneous or heterogeneous due to the position of the examined area in a slag lump. For this reason, the smithing slags were analysed very thoroughly.

Small pieces from the underside and from the rim of plano-convex smithing slags AS1 and AS2 from Aukštadvaris hill-fort

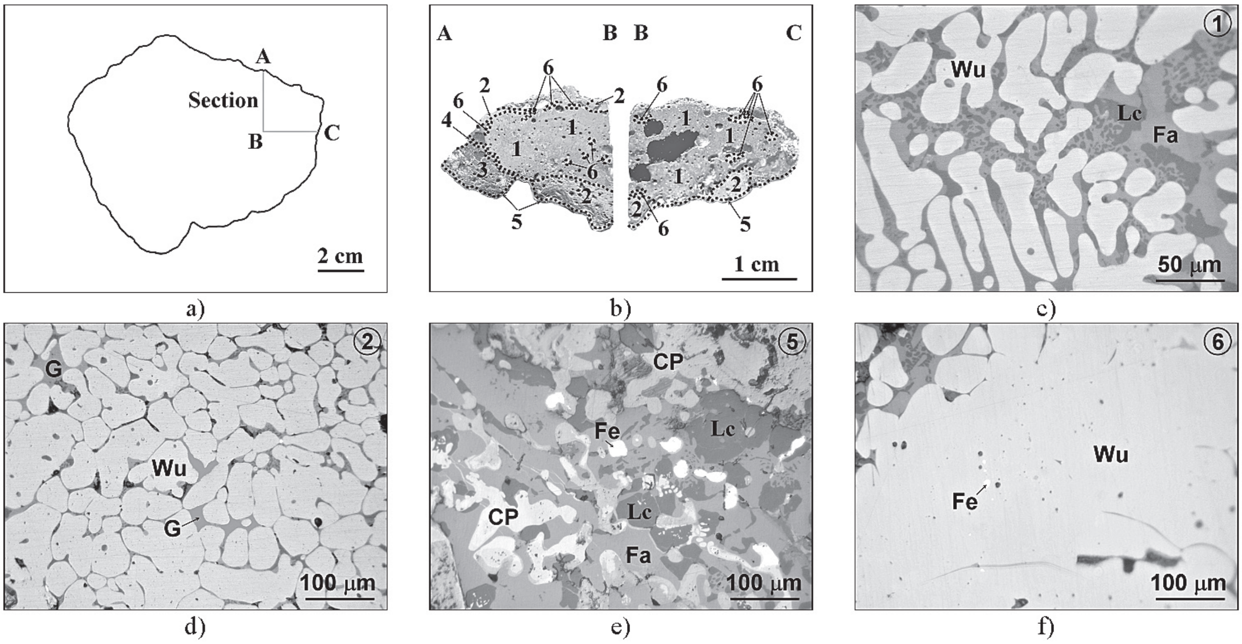

Fig. 4. Smithing slag LS1 from Lieporiai settlement: scheme (a), polished section (b) and microstructure in different areas of the sample (c–f). Fa – fayalite, Wu – wustite, Lc – leucite, G – glass phase, Fe – metallic iron, CP – iron corrosion products. 1 – Wu, Fa, Lc, (G); 2 – Wu, G; 3 – Q, G; 4 – Fa, Lc; 5 – Fa, Lc, CP, Fe; 6 – Wu

were cut for the analysis. It was determined that the underside of the lumps was covered with a 1–2 mm thick layer composed of quartz grains and glass phase. Above it, a layer of the same thickness, composed of fayalite, glass phase and/or leucite was observed. The major part of the lump consisted of fayalite, glass phase and a large amount of wustite. An inclusion of metallic iron of about 3 mm in diameter was found in slag AS2.

The top view and the cut line of slag AS3 are presented in Fig. 2a, the polished section – in Fig. 2b. It can be seen that the slag is not homogeneous; some areas of different composition and structure can be identified. The major part of the sample is formed of a material composed of a considerable amount of wustite and other constituents, such as fayalite, glass phase and/or leucite (Fig. 2b and c, No 1). The sizes of wustite crystals vary – they grow towards the upper surface in most parts of the slag. There is a darker area composed of quartz grains and glass phase in the left margin of the slag (Fig. 2b and d, No 2). It seems likely that this side of the slag was moulded by a melting hearth wall. Quartz grains in the matrix of the glass phase are also observed in some other places of the slag lump (Fig. 2b, No 2). It is likely that quartz has got into and on the top of the slag by using sand as flux during the iron-working process. The areas possessing SiO_2 grains are mostly surrounded by a 0.5–1 millimetre thick layer composed of fayalite, leucite and a small amount of wustite (Fig. 2b and d, No 3). A slag of such composition is spotted in some other areas, mostly in the margins of a lump and as a continuous 1 mm thick layer in the underside lump surface (Fig. 2b, No 3). Presumably, during the contact of the slag with charcoal ashes, the latter dissolved in the slag and the amount of potassium increased in the lowest layer of the lump. A dense area composed of fayalite, leucite and wustite is seen in the lower part of the left margin of the section (Fig. 2b and e, No 4). Some accumulations of wustite crystals are detected in the lower part of the sample (Fig 2b and f, No 5). Some authors have observed similar rounded or band-shaped accumulations in the investigated plano–convex smithing slags [18, 19]. The structure of these accumulations is very similar to that of the hammer scale [20]. Probably these accumulations of wustite are not fully dissolved fragments of the oxidized crust of iron [2]. In these accumulations iron particles of several micrometers in diameter are traced inside and between the wustite crystals.

The picture and cut-line of smithing slag BS1 are presented in Fig. 3a, the polished section – in Fig. 3b. A large pore is seen near the centre of the specimen, where a piece of charcoal could have been earlier. Smaller inclusions of charcoal are also detected in the slag (Fig. 3b). The investigation of the microstructure indicated that the slag lump is comprised of three separate layers. The major part of the finding, i. e. all three layers, is composed of wustite, fayalite, glass phase and/or leucite. It should be noted that the lower parts of all three layers consist of smaller quantities of wustite crystals, which are finer there (Fig. 3b and c, No 1) as compared to the upper parts (Fig. 3b and d, No 2), i. e. the quantity and size of wustite crystals grow gradually towards the upper part of the layers. In the middle layer, a considerable quantity of iron corrosion products is seen (Fig. 3b). In between of these layers, 1–2 mm thick seems consisting of fayalite, quartz grains, leucite and glass phase are observed (Fig. 3b and e, No 3). Magnetite crystals are detected in the upper part of the slag lump (Fig. 3b and f, No 4). No remnants of hammer scales have been found in this finding.

It is supposed that the described constitution of slag lump BS1 reflects the sequence of forge operation. In this case, each layer can be a result of a session of hot forging in order to shape an object followed by a shorter phase, where sand is used. Finally, oxidizing conditions prevailed in the hearth, and the wustite present in the upper surface of the slag lump was oxidized to magnetite.

The scheme and cut-lines of smithing slag LS1 are presented in Fig. 4a, the polished section – in Fig. 4b. The major part of this specimen is formed of a material consisting mainly of coarse globular wustite, fayalite and a big amount of leucite (Fig. 4b and c, No 1). In some areas an extremely large amount of wustite is detected (Fig. 4b and d, No 2). Quartz grains are seen in the matrix of glass phase on one side of the slag (Fig. 4b, No 3). This area is surrounded by a 2 mm thick layer consisting mainly of fayalite and leucite (Fig. 4b, No 4–5). It shows that these quartz grains were rather added as flux than originated from a melted ceramic wall. A similar continuous 1–2 mm thick layer composed of fayalite, leucite and iron corrosion products with remnants of metallic iron (Fig. 4e, No 5) is observed over the whole bottom surface of the sample. Many band-shaped and rounded wustite accumulations of a size from 0.2–0.4 to 0.8–1 mm are detected in this finding, especially in the upper part near the surface (Fig. 4b, No 6). Iron particles of several micrometers in diameter are seen inside and between the wustite crystals in these accumulations (Fig. 4f) similar to those in Aukštadvaris' slag AS3.

The structure of smithing slag LS2 is comparable to slag LS1, except that a smaller amount of wustite and much larger quantity of metallic iron and its corrosion products have been detected.

The investigation of the microstructure of the smithing slags has revealed that each finding can be quite different. However, some peculiarities of the microstructure of smithing slags reflecting the particularity of their formation [2, 11] are observed and can be used for the identification of this kind of slag. In the matrix of the glass phase, quartz grains can be found not only in the adhered hearth wall, but also inside or on the upper surface of the lump of the smithing slag. It is possible that they were supplied as flux during the iron-working process. Other evidence of smithing slags is that there are partially dissolved hammerscales composed of very closely situated wustite crystals. They were formed during iron heating in the air, broken away from the surface of iron and fallen down into the hearth contributing to the formation of the slag [2]. One lump of the analysed smithing slags consisted of three layers. Streaks containing the quartz grains are observed between the layers. They probably reflect the sequence of three stages of work and the supply of sand at the end of each operation. Such constitution of a slag lump can be also used for the identification of the kind of slags.

CONCLUSIONS

The results of the chemical analysis revealed that the smithing slags from Aukštadvaris hill-fort, Bakšiai and Lieporiai ancient settlements contained lower concentrations of phosphorus and manganese, but a slightly larger amount of potassium as compared to the smelting slags from the same site. Ores rich in phosphorus were used for iron-making in many sites of Lithuania, thus, the concentration of phosphorus could be quite a reliable indicator for the identification of a slag kind in these sites.

The examination of the phase composition and microstructure revealed that both smelting and smithing slags could be composed of the same phases (fayalite, wustite, magnetite, glass phase, leucite, metallic iron, corrosion products and charcoal). Nevertheless, in some smithing slags as compared to the smelting slags, a larger amount of wustite and leucite was detected.

Some peculiarities of the microstructure of the smithing slags reflecting the particularity of their formation were observed, namely, the remnants of the supplied flux (sand) into and on the upper surface of the slag, partially dissolved hammerscales composed of very closely situated wustite crystals and a layered constitution of a slag lump with streaks containing quartz grains. This evidence can be used to identify smithing slags.

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TIESIOGINĖS GAVYBOS GELEŽIES LYDYMO IR KALVIŠKŲJŲ ŠLAKŲ TYRIMAI

S a n t r a u k a

Straipsnyje pateikiami senojo geležies amžiaus geležies lydymo ir kalvės žaizdro šlakų iš trijų Lietuvos vietovių (Aukštadvario piliakalnio, Bakšių ir Lieporių senovės gyvenviečių) cheminės ir fazinės sudėties, taip pat mikrostruktūros tyrimų duomenys. Remiantis gautais rezultatais apibūdinami skirtingų šlako rūšių bendrieji bruožai ir skirtumai, leidžiantys patikimiau identifikuoti radinių rūšį.

Kalvės žaizdro šlakuose aptikta mažiau fosforo ir mangano, tačiau kiek daugiau kalio, nei tos pačios vietovės lydymo šlakuose. Kadangi geležis daugelyje Lietuvos vietovių buvo lydoma iš fosforingų rūdų, tai šiose vietovėse fosforo kiekis yra vienas gana patikimų kriterijų šlako rūšiai identifikuoti. Nors skirtingų rūšių šlakų fazinė sudėtis yra gana panaši, pastebėti keli kalvės žaizdro šlakų mikrostruktūros ypatumai, kurie gali būti naudojami identifikuojant šiuos šlakus: naudotų fliusų (smėlio) liekanos šlako viduje ir viršuje, iš tankiai susiglaudusių viustito kristalų sudarytos nuodegų dalelės, taip pat sluoksninė šlakų su apsilydžiusių kvarco grūdelių turinčiais tarpsluoksniais sandara.