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Medieval metallurgy of iron (XIth – XIIIth Centuries) in Slovakia

Introduction: After decomposition of Great Morava Empire in the X[th] century A.D. present territory of Slovakia was gradualy incorporated into medieval Hungarian state. Metallurgy of iron in post Great Morava period on present Slovakia territory developed in accordance with developments in other regions of Hungarian state typical for metallurgical activity. Progress in mining and metallurgy was affected by German immigration that started in the XIII[th] century after raids of Tatars, when economy of the state was seriously destroyed. The progress of economic revitalisation culminated in metallurgy by invention of so called Slovak furnaces for iron smelting, the high shaft furnaces with bellows driven by water energy. Such furnaces were put to production in the XIV[th] and XV[th] centuries.

This paper presents a short version of archaeometallurgic research results of samples related to metallurgy of iron, that were found at three different archeologic sites, dated to the XI[th] – XIII[th] centuries (Furyová, 1991, s.107; Mihok, 1993, s.46; 1996, s.61). The sites Gemerský Sad, Svinica and Sitno are shown on the map of Slovakia (Fig.1).

Iron smelting in Gemerský Sad.

Gemer region in south – east Slovakia was well known for its iron ore resources and metallurgical activity till ancient times. In Gemerský Sad the workshop for iron smelting was uncovered during 1984 – 1985 excavations. Ten furnaces, working in pairs, were discovered in the first part of the excavations. They were dated to the XI[th] – XII[th] centuries A.D. The furnaces, built-in in terraine steps, were situated in gentle slope near the water source. The furnaces IX and X are in Fig.2, outline and reconstruction of the furnace I is in Fig.3. The furnaces with pear – shaped cross – section were in relatively well preserved state. Preserved heights of the furnaces, measured from the hearth bottom, were about 50 cm, reconstructed heights were about 70 to 80 cm. Charging opening at the shaft top had round or oval shape with diameter about 30 cm. The furnaces had round or irregular working opening in the front wall with diameter about 30 cm. The furnaces had perfect smooth refractory lining of 1 to 1,5 cm thickness. The lining was made of refractory clay and little silica pebbles.

The furnaces in Gemerský Sad were compared with other ones of the similar date in Czech Republic, Hungary and Austria (Souchopová, 1986, s.24; Gomori, 1985, p.323; Mayerhofer, 1958, s.51). The closiest analogies to the furnaces in Gemerský Sad were found at sites Imola, Trisz and Felsokelecsény (Heckenast, 1968, old.21) in Hungary, situated on the south border of the same iron ore region.

More than 180 pieces of clay tuyeres or their fragments were found spread around the furnaces (Fig.4). The tuyeres were made of the same material as the

refractory lining. They were placed in tuyere bricks and positioned in the working opening in the front wall. Besides tuyeres also pieces of charcoal, slag and spongy iron were found in round shallow holes situated in front of the furnaces. Tho heaps of iron ore pieces were also excavated. The floor in front of the furnaces was reinforced by small rocks. Remnants of wooden poles were also found around the furnaces suggesting construction of a shelter over the workshop.

Chemical and mineralogic analysis of iron ore found in the site showed that most of it was of limonite type. It is important to note, the large deposits of limonite ore are distant only about 6 km. Fe content in limonite ore was about 40 to 45 wt%. In addition to limonite also hematite and specularite with siderite ores were found in the site. The presence of various iron ores at the site may speak for importance of the smelting workshop using iron ores from different sources.

An information concerning method of smelting in the furnaces can be taken from results of chemical and structural analysis of slag. High contents of Fe (up to 55 wt%) and FeO in slag samples confirmed very inefficient way of smelting, typical for low shaft furnaces. CaO and MgO contents in slag samples were low and excluded intentional additions of basic constituents into the charge. Regarding structural composition, most of slag samples had olivinic structure, wustite occurred only in little dendrites, Fig.5. Two olivinic components were found in the structure with the help of X-ray diffraction structural analysis: $2/Fe_{0.34}Mg_{0.66}/O.SiO_2$ and $CaMgSiO_4$. The slag that penetrated into the tuyere cracks was also analysed. This slag had fully olivinic character, high fluidity and low melting point.

The results of chemical, microscopic and mineralogic analyses have permitted some conclusions concerning the ways of iron making in the locality. Iron was made by reduction of iron ore in small shaft furnace of a built-in construction. The furnace charge consisted of roasted and crushed iron ore and charcoal. Reduction of iron oxides took place at high and elevated temperatures inside the shaft. Two types of reduction were effective inside the shaft: direct reduction by solid carbon, and indirect reduction by CO gas. While descending down the shaft a matter of a dowghy consistence was formed, containing iron oxides, slag and granules of metallic iron. Lower down in the shaft , with higher temperatures and lower slag viscosity, the iron granules agglomerated and formed spongy iron, the yield of smelting. A part of slag filled the voids in spongy iron, most of slag was separated from the iron yield. Burning of fuel was intensified by air blowing through the tuyere positioned over the hearth.

Besides air blowing one important factor contributed to an effective course of reactions inside the furnace. The entire furnace was constructed in the ground, hence, it was properly insulated and heat losses from the stack were at minimum.

Smithy production in medieval village Svinica.

Medieval village Svinica was situated in East Slovakia region about 60 km far from Ukraine borders at the slopes of Slánske mountains. Social environment of the village was typical Slav. Archaeologic excavations of the medieval village, dated to the XIII[th] and 1[st] half of the XIV[th] centuries resulted in numerous finds of economic character, many of them were related to production of iron and iron objects (Mihok, 1988, s.676; Čaplovič, 1983, s.357).

Archaeologic research didn't reveal remnants of iron smelting furnaces but production of iron on the site was confirmed by finds of furnace slag. Chemical and microscopic analysis of the slag samples showed they were similar to the slags found in Gemerský Sad, i.e. they had olivinic rather than wustitic character. On the basis of MgO and MnO contents the slags were divided into two groups confirming the use of iron ore from two sources. The closest iron ore deposits were located on the other side of the Slánske mountains about 15 to 20 km far from the village, that were exploited till the XIXth century.

Twelve iron objects were analyzed by methods of metallography to recognize manufacturing technology of medieval smiths. The samples were taken by cross – section cuts of the objects: lock, curb (an essential piece of a horse gear), spurs, horse shoes, sickles, knives, sleeve, rake.

The lock was coated by copper. A thin copper sheet was also found in the site and its analysis revealed it was the semiproduct used for coating preparation. The structure, that prevailed on analyzed metallographic surface, was coarse grained ferrite, indicating non – carburized iron. The sides of analyzed surface contained small amount of pearlite, resulting from light surface carburization of the lock. Production of the lock from tough and soft non – carburized iron material and subsequent increase of surface hardness by carburization indicated proper smithy production technique. Similar iron material with ferritic structure was used for production of the curb (Fig.6). Analyzed metallographic surface was divided into two parts by crack, filled with glassy silicate. It was probably the place of welding of two iron semiproducts. Two places with pearlitic – ferritic structure of deep carburized iron were also found on both parts of the surface. The sense of this intentional carburization was not clear. Two kinds of non – metallic inclusions were found on analyzed surface, the smithy ones and the furnace slag ones. Both kinds are shown on photographs in the Figure.

The group of objects made from non – carburized iron material included also the spur and the rake. None of those objects was exposed to excess strain and wear in course of their use. Selection of non –carburized iron material for their manufacture was suitable.

Characteristic feature of next four analyzed objects was a blade. The set of objects contained two sickles, each of them was produced by different way. One of the sickles was prepared from non – carburized iron material, next its blade was deep carburized. Carburization of the edge was uneven. Metallographic analysis of the second sickle is in Fig.7. Its body was prepared from non – carburized iron material, next, separately prepared and deeply carburized edge was welded on the body. Boundary between both structures is clearly indicated on the left photograph in the Figure. The method of separate preparation, carburization and welding of blades, points, brits etc. is well known from medieval (Mihok, 1988, s.471). Distribution of structures on metallographic surface is documented by microhardness measurements, also presented in the Figure. None of the sickles was

quenched. The set contained also two knives. Both of them were produced by the similar way as the first sickle.

An interesting information resulted from metallographic analysis of the horse shoe. The object was produced from two thin iron plates joined by welding. One of the plates had fine – grained ferritic structure of non – carburized iron, the second one had fine – grained pearlitic – ferritic structure of carburized iron. Described manufacturing technology was purposeful. The softer ferritic plate was on the side of hoof, the harder pearlitic – ferritic one was in contact with ground. This way of manufacturing could enhance the utility value and durability of the horse shoe.

Smithy production in fortified settlement in Sitno.

Sitno hill is situated in central Slovakia near town Banská Štiavnica, well – known for its Mining Academy, the first Mining and Metallurgical University in the world. Very intensive medieval metallurgy (both ferrous and non – ferrous) was strongly influenced by German immigration, but roots of local metallurgy can be traced till the Bronze Age. Archaeologic excavations of fortified settlement in Sitno near village Ilija confirmed its permanent inhabitation till antiquity (Žebrák, 1990, s.87). Excavation of medieval castle and connected residential and economic buildings dated to the XIIth – XIIIth centuries resulted also in many finds characteristic for production of iron and iron objects.

Iron smelting at the locality was proved by bloomery slag finds, ten of them were analyzed. One of the slags had extremely high iron content (65.34 wt%), the structure consisted mainly of wustite (79.17 area%). This fact suggested very inefficient way of smelting that corresponded to very beginnings of iron smelting. Results of analysis of this slag corresponded to archaeologic date, when the layer with slag was saturated with antique pottery. The other finds of slag had structure with olivinic character, that contained only small amount of wustite (Fig.8).

The collection of analyzed iron objects contained four knives, key, horse shoe and nails. All iron objects were dated to medieval but one knife with antique date. The samples were taken by cross – section cuts.

The knife dated to antiquity was produced from soft non – carburized iron. It was only mildly and unevenly carburized on edge, its utility value was very low.

One of the medieval knives (Fig.9), after preparation of a final shape, was deep carburized that resulted in pearlitic structure in the whole object. The final step of manufacturimg was quenching of the edge. Quenching was confirmed by martensitic and troostitic structures on the edge (Fig.10-11), places A, B, C. The body of the knife preserved pearlitic structure, place D.

The second medieval knife was in well – preserved state and bore a pattern in the back side (Fig.12). The edge was flat without pattern. The knife was prepared from non – carburized ferritic iron material. Metallographic surface after etching is in Fig.13, documenting the production of pattern by welding of thin iron strips. Microstructures in places A, B, C, D in Fig.13 are in Fig.14. After forging the final shape of the knife the edge was carburized. Next the pattern was made by welding of thin strips of ferritic and pearlitic – ferritic iron on ferritic bottom material. After reheating the edge was quenched. The structures after quenching are showed in places A and B Fig.14. As the heat treatment in this case was characteristic by lower temperature gradient, resulting structure was bainite. Fig.14 C shows production of pattern by alternating of pearlitic – ferritic and ferritic iron strips. The strips were welded on original non – carburized ferritic material of knife, that was neither carburized nor quenched (Fig.14 D). By this way of manufacturing the knife had both high utility value and aesthetic properties.

The third medieval knife was made of two iron semiproducts. The one from non – carburized ferritic iron was used for preparation of knife back. The other one with ferritic – pearlitic structure of carburized iron was used for preparation of edge. The production method was standard.

The nails and horse shoe, that were analyzed by methods of metallography, are in Fig.15. The smiths used two different methods for production of nails. Some nails were manufactured from non – carburized ferritic iron material, next, after finishing the final shape, they were caburized on the whole surface. The other analyzed nails were manufactured from mildly carburized ferritic – pearlitic iron semiproducts. The horse shoe was made by the same method as the one found in Svinica, described above, i.e. from two iron plates with different carbon contents.

Conclusions.

This paper wants to contribute to understanding of iron metallurgy of the XI^{th} – $XIII^{th}$ century on the territory of Slovakia. It is remarkable that this period of subjugation of Slavs in Carpathian basin by newly formed medieval Hungarian state is from metallurgy developments point of view not satisfactorily studied.

Analysis of finds from three different archaeologic sites showed that the methods of iron smelting didn't change from the ones used in Slavs in Great Morava Empire. Iron was smelted in low shaft furnaces, either of built-in or of free standing types. Those types were used both in Great Morava Empire in the IX^{th} – X^{th} centuries and in Hungarian state till the XIV^{th} century, when they were replaced by more effective high shaft furnaces. Smelting in furnaces described in this paper was relatively more efficient, most of iron from iron oxides in iron ore reduced into iron yield of furnace, slag contained mostly iron olivines and ferrous glass. Higher efficiency of furnaces was enhanced by good heat insulation in case of built-in furnaces.

Medieval smiths from this period used all smithy methods for production of iron objects, that were developed in earlier periods: forging, welding, carburization, quenching etc. Very important was their detailed knowledge of iron material properties, how to select the most suitable material and how to transform it into iron object with high utility value. The smiths used deep carburization and intensive forging when prepared the sickle edge instead of quenching as they recognized the edge prepared by this way was easily restorable. Manufacturing of horse shoe from two iron plates of different properties, found at two 250 km distant sites, proved both high skills of medieval smiths and spread and exchange of skills among medieval smiths.

Typical features of described period on the territory of Slovakia are specialized mining and metallurgical settlements. The towns with prevailing

mining and metallurgical activity are known from the end of this period and their foundation is closely related to German immigration.

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(Summary)

The paper presents results of archaeometallurgic research of medieval iron metallurgy on the territory of Slovakia. Finds related to production of iron and iron objects in three different sites dated to XI^{th} – $XIII^{th}$ centuries were analyzed. Research results showed iron was smelted in low shaft furnaces of built-in in terraine steps type or of free standing type, i.e. in similar types of furnaces as were used in Great Morava Empire (IX^{th} – X^{th} centuries). Medieval smiths at the analyzed sites used all contemporary methods for production od iron objects: forging, welding, carburization, quenching, pattern welding. They had a very good knowledge of iron material properties and they knew how to select proper material and proper method to reach maximum utility value of produced objects. The analyses also showed exchange of metallurgical knowledge and skills among regions and settlements on medieval territory of Slovakia.

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