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BEGINNINGS OF IRON SMELTING IN THE CENTRAL CARPATHIANS REGION

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ABSTRACT

The paper presents information about early methods of iron smelting in the Central Carpathians region. Presented facts are based on study of early iron smelting furnaces excavated on the territory of Slovakia and cover time range from Hallstat to Migration periods. Method of iron smelting in bowl furnace dated to Hallstat period is described. Character of iron bloom, yield of bowl furnace smelting, is presented. Next, the process of iron smelting in LaTéne dated small shaft furnaces is discussed. Two kinds of more effective smelting furnaces, dated to Roman period, are described in the second part of the paper: slag pit shaft furnace and cupola furnace.

Key words: Bowl furnace; Shaft furnace; Cupola furnace; Bloom; Slag

INTRODUCTION

The oldest iron object found on the territory of Slovakia is the dagger hilt, discovered in Gánovce ritual well, east Slovakia. The hilt was dated to the 15th century B.C. and undoubtedly it was import. The second oldest one was Radzovce knife, south – east Slovakia, dated to the 8th century B.C.

As generally accepted, methods of iron smelting and working spread into the Central Europe in the 6th and 5th centuries B.C. from the Mediterranean area. Remnants of first methods of iron smelting, dated to the 6th century B.C., were discovered at the archaeologic site by the east Slovakia village Čečejovce. Two iron blooms dated to the same time, were found in cave Perecs on Slovak – Hungarian borders.

The Celts, responsible for propagation of iron smelting and working methods in LaTéne period in Europe, started to smelt iron in small shaft furnaces. The finds of such free standing small shaft furnaces, dated to the 1st century A.D., were discovered by the holiday resort Slovak Eden, east Slovakia.

Slag pit shaft furnaces were frequently used on the territories of German colonization in first centuries A.D., but Celtic contribution to this invention is very probable. The paper presents facts about finds of the slag pit shaft furnaces in east Slovakia site Kysak.

Iron smelting in cupola furnaces, dated to the 1st century A.D., found in north Slovakia site Varín, is also described in the paper. The sites, where first finds of iron smelting on the territory of Slovakia were discovered, are in Fig.1.

Fig. 1 – The sites with first finds of iron smelting on the territory of Slovakia.

BOWL IRON SMELTING FURNACES AND IRON BLOOMS DATED TO HALLSTAT PERIOD

Rich archaeologic collection from excavations in the site near village Čečejovce, dated to the 6th century B.C., contained unusual amount of finds related to iron smelting: slags, furnace building materials, iron ore, unworked iron bloom. 67 finds were analysed by chemical, microscopic, spectrographic and X-ray diffraction structural methods (1). It was recognized from the form and properties of the furnace building materials remnants, bowl furnaces were used for iron smelting at the site. No intact furnaces were found, but reconstruction with the help of building pieces confirmed assumption. Troughs where blowing pipes were positioned, were found in some pieces, Fig.2. The pieces, that were not suitable for construction of a shaft because of their low strength and low consistency, represented lining of the furnace pit.

Fig. 2 – Piece of bowl furnace lining, site Čečejovce.

Bog iron ore together with charcoal was charged into the furnace. Very rich bog ore with about 58 – 59 wt% of Fe after roasting treatment was used. Its structure is presented in Fig.3. Chemical analysis of 51 slag samples showed very inefficient reduction process in the bowl furnace. Most of them had iron contents more than 50 wt%. Structure of slag from bowl furnace is in Fig.4.

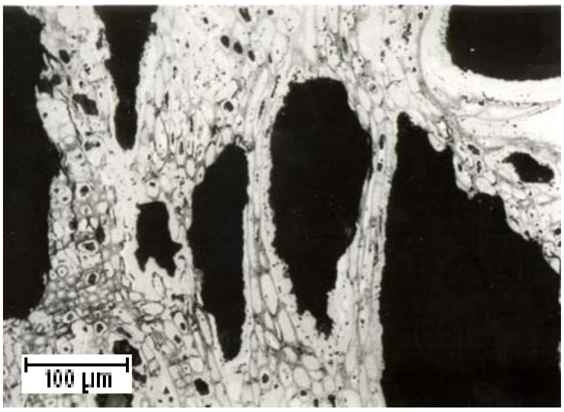

Fig. 3 – Structure of bog ore, site Čečejovce.

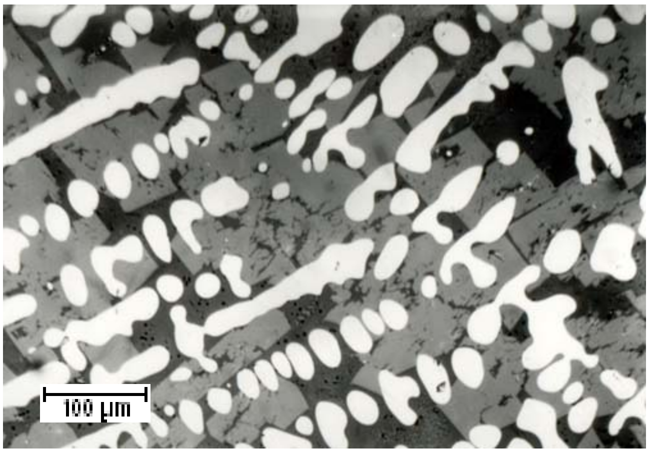

Fig. 4 – Structure of slag from bowl furnace, site Čečejovce

Besides iron bloom from Čečejovce site two iron blooms, dated to 6^{th} – 7^{th} century B.C., were found by the cave Perecs – Nyelö in Hungary near Slovak – Hungarian borders (2). One of the blooms from Perecs is in Fig.5. Weights of the blooms ranged from 0.6 to 2.1 kg. Both blooms from Perecs were treated by hammering. Metallographic analysis of blooms cross – sections revealed the same distribution of macro and microstructures (3). A part of cross – section contained relatively compact iron metal with many inclusions of original furnace slag. The other part was formed by spongy iron with voids filled by furnace slag, Fig.6. Etching of metallographic surfaces revealed iron in the spongy part had only ferritic structure of non – carburized iron. In the solid part structures with different carbon contents were observed, that were distributed by chaotic way. Widmanstätten structure in the solid part is in Fig.7, hypereutectoid structure in the solid part is in Fig.8. From the facts followed non – direct reduction by CO gas prevailed in the primitive smelting furnace that resulted in non – carburized spongy iron. Carburization took place only on contacts with charcoal carbon, i.e. in spots with direct reduction.

Fig. 5 – Iron bloom from site Perecs

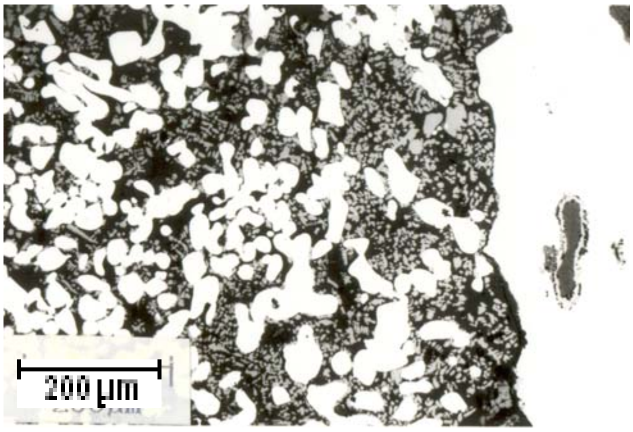

Fig. 6 – Microstructure of iron bloom, site Čečejovce

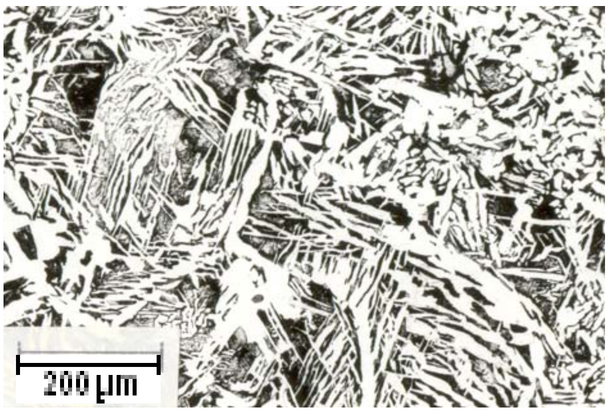

Fig. 7 – Widmanstätten structure in solid part of iron bloom, site Čečejovce

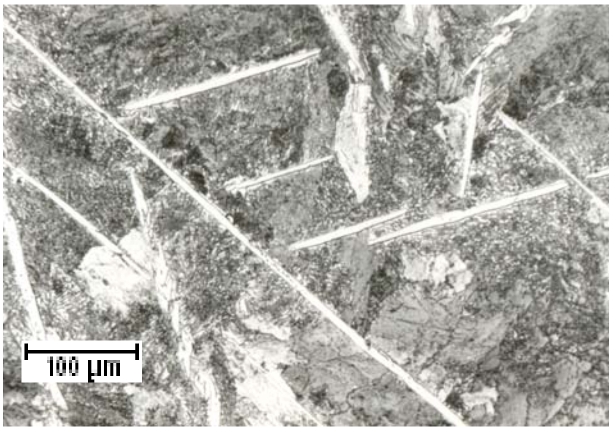

Fig. 8 – Hypereutectoid structure in solid part of iron bloom, site Perecs

LATÉNE SHAFT FURNACES FOR IRON SMELTING

LaTéne shaft furnaces are demonstrated on examples of furnaces excavated in Spiš region, north - east Slovakia. Spiš basin, situated between High Tatra mountains and Slovak Ore mountains created favourable conditions for human inhabitation from neolite. Described furnaces were dated to the 1st century A.D. and related to post – Celtic culture, in Slovakia known as Púchov culture (4, 5).

Iron smelting complex discovered by the village Spišské Tomášovce consisted of ore roasting furnaces, iron smelting furnaces and storage pits for charcoal. Three small shaft iron smelting furnaces were discovered, Fig.9. Iron ore roasting furnaces were in form of shallow pits with dimensions 70 to 100 cm x 100 to 150 cm, inlayed by stones. The roasting was made on a layer of wood and/or charcoal.

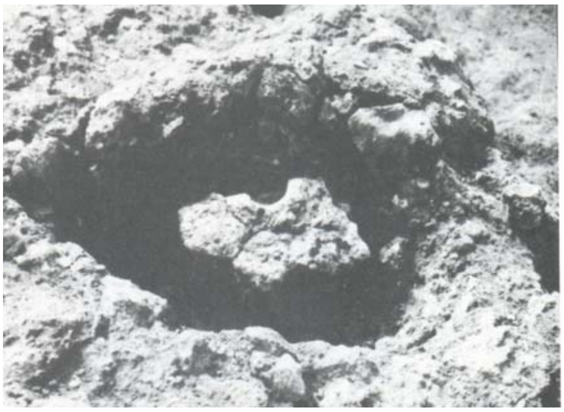

Fig. 9 – Bottom of small shaft furnace, site Spišské Tomášovce

Small shaft furnaces had inner diameter of the hearth about 0.3 m and they were sunken about 0.1 to 0.2 m under the platform level. The furnace walls were built by two – layer way. The inner layer was made of acidic refractory material and had thickness about 3 or 4 cm. The outer layer of the furnace wall with thickness of 6 to 7 cm was made of mixture of clay and small stones. At about 10 cm over the platform level a hole in the wall for inserting the blowing pipe was prepared. Total height of the furnaces was about 0.8 m.

Some pieces of slag, that were spread around the furnaces, were analysed. The analysis revealed typical composition and structure of bloomery slags, Fig.10. Iron contents were very high, from 41.53 wt% to 55.29 wt%, but lower than the ones in Hallstat slags.

Small free standing shaft furnaces can be distinguished as the first step in development of iron smelting methods after bowl furnaces. Iron bloom had weight two or three times higher than the one in bowl furnaces, but reduction efficiency was still very low. Considering the form of the slag pieces, the slag was not tapped, Fig.11.

Specific invention in iron smelting was use of slag pit shaft furnace, Fig.12. The furnaces were found in many parts of post – Celtic world, in Scandinavia, Germany, Bohemia, Poland, Slovakia, Transcarpathian Ukraine. Remnants of slag pit shaft furnaces, slag cakes, were found in east Slovakia, near the confluence of the river Hornád and the river Svinka. They were dated to the 3rd or 4th centuries A.D. (6,7).

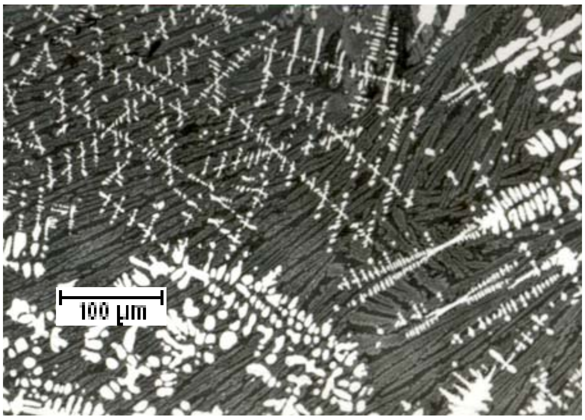

Fig. 10 – Structure of slag from small shaft furnace, site Spišské Tomášovce

Fig. 11 – Slag from small shaft furnace, site Spišské Tomášovce

SLAG PIT SHAFT FURNACES IN SLOVAKIA AND TRANSCARPATHIAN UKRAINE

Slag cakes, slag fragments, fragments of refractory building materials and fragments of pottery were found on the site Kysak. The slag cakes were discovered by chance during yard preparation behind a new built house. Remnants of four furnaces in one row were found. The others, 8 to 10 furnaces, were destroyed during earthwork. Far more extensive iron smelting shop was expected in neighbouring area. One of the slag finds, Fig.13, was in fact the half of a slag cake with dimensions of 45 x 27 cm and weight about 45 kg. From this followed the whole cake had diameter about 45 to 55 cm and weight up to 100 kg.

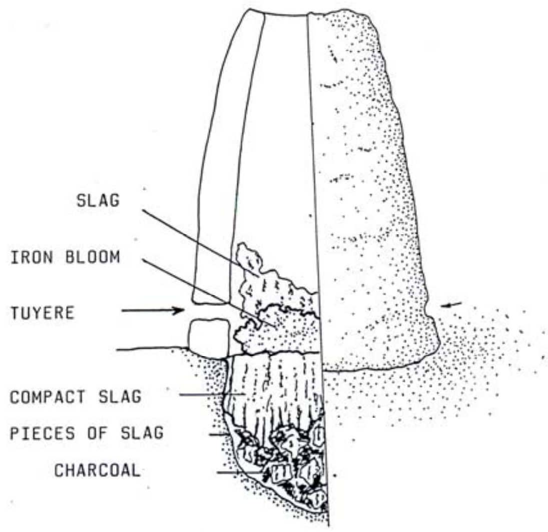

Fig. 12 – Slag pit shaft furnace

Chemical and microscopic analysis of the slag samples showed the slags were typical bloomery slags with high content of iron. The structure was typical for bloomery slags and contained wüstite, fayalite, iron – calcium olivine and ferrous silicate glass, Fig.14. Chemical and X-ray diffraction structural analysis of refractory building pieces showed they were silica based. Layers of contacting slag were found on some refractory pieces. Observation of the contact revealed there was one layer more, positioned between the layer of refractory building material and the layer of slag. This fact changed character of the contacting slag. Only silicate components were found in structure of the contacting slag, the ones with higher Ca and Mg contents prevailed, Fig.15. $MgO.SiO_2$ and $FeO.MgO.SiO_2$ components were found in the intermediate layer. From this followed thin lining made of olivinic sand was prepared on the inner surface of furnace shaft.

Fig. 13 – Slag cake from slag pit, site Kysak

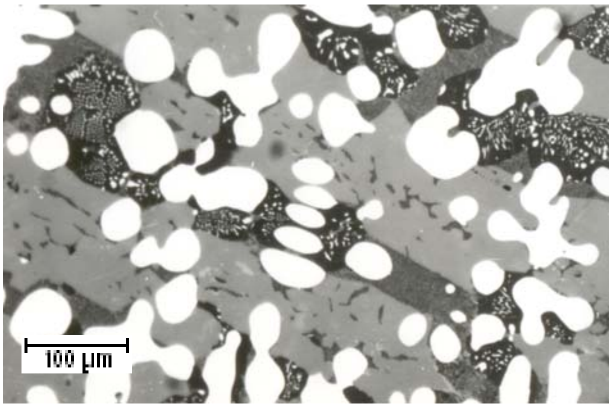

Fig. 14 – Structure of slag from slag pit shaft furnace, site Kysak

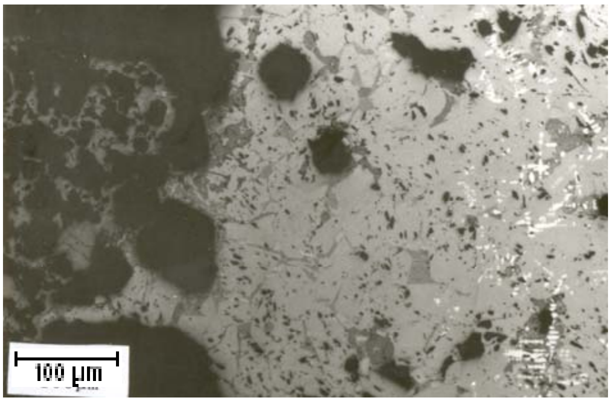

Fig. 15 – Structure of slag on contact with furnace shaft, site Kysak

Concerning the slag cake weight, the iron bloom, yield of smelting, had weight up to 20 kg. The slag, relating its composition, could be highly viscous at temperatures about 1200°C and its free flowing through the bloom pores should be supported by some other conditions. One of them was increased temperature, decreasing the viscosity of the slag. Heat – temperature conditions in the furnace were cosiderably influenced by composition of the furnace building material, that was based mostly on silica with resulting high refractory properties. Its use decreased heat losses through the shaft walls. Temperature increased in interval, where solid structure of iron bloom was kept intact, but viscosity of slag decreased. This fact was also documented by structural homogeneity of the slag. Next factor, that probably influenced mobility of slag, was olivinic layer, lined on silica based refractory. The layer changed character of contacting slag and decreased its viscosity.

Archaeologic sites near villages Novoklinovo and Djakovo, Transcarpathian Ukraine, are characteristic by finds of big slag cakes, remnants of slag pit shaft furnaces (8). High iron contents in slag samples taken from the slag cakes pointed to inefficient reduction process in the furnace, but the iron contents were lower then the ones in slags from Kysak site. The fact was supported by microscopic observations. Most of analysed slags had structure in which silicate matrix, that consisted of fayalite, iron – calcium olivines and ferrous silicate glass, prevailed, Fig.16. No olivinic layer on shaft building materials from Novoklinovo - Djakovo was found.

Both slags from Kysak and slags from Novoklinovo – Djakovo came from slag pit shaft furnaces. Both sets of slags were different in structures. The slags from Kysak had structure, that was common in contemporary LaTéne and Roman slags. Ability of such slag to flow through the iron bloom pores was enhanced by furnace construction improvements. The slags from Novoklinovo – Djakovo had silicate structure with lower contents of wüstite. Fayalitic – olivinic slag had relatively low melting point. This feature enabled the slag to flow through iron sponge pores down to the slag pit.

Slag pit shaft furnaces were repeatedly used. After finishing the heat, a new slag pit was prepared. The furnace structure, after necessary repairs, was moved and positioned over new, empty slag pit.

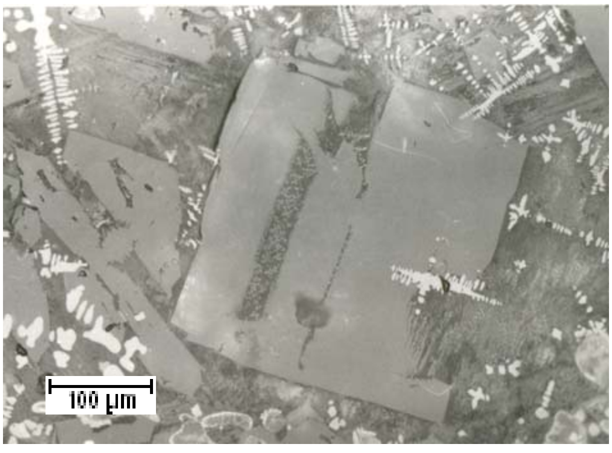

Fig. 16 – Structure of slag from slag pit shaft furnace, site Novoklinovo – Djakovo.

IRON SMELTING IN CUPOLA FURNACES

Remnants of iron smelting activity were discovered in the site Varín – Iron well (9). Archaeologic search resulted in discovery of eight heaps with dimensions about 15 x 23 m and height about 1.5 m each. The heaps consisted of slag, burnt clay, stones, charcoal, fragments of refractories, lumps of iron ore, fragments of pottery. On the basis of pottery type and radiocarbon analysis of charcoal sample the heaps were dated to ±70 A.D.

The smelting furnaces were built from clay bricks, that were repeatedly used. Fragments and segments of furnace walls were used for reconstruction of furnace shape. Free – standing cupola furnaces with hearth diameter about 100 cm and cupola height about 150 cm were probably used for iron smelting at the site.

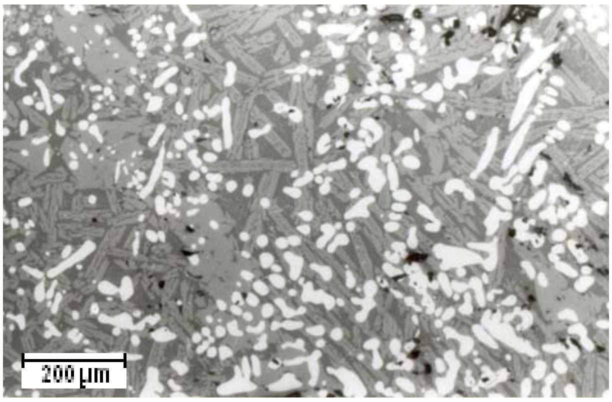

Fig. 17 – Structure of slag from site Varín.

Pieces of slag, lumps of iron ore and fragments of furnace walls were submitted to analysis. Seven samples represented slag from iron smelting process. Evaluation of chemical analysis results showed two characteristic features of the slags, not usual for slags from Roman period in Slovakia. The first one was striking homogeneity of the slags, Tab.I. It was important to note only three of the slag samples were taken from the same heap. Homogeneity of the slags was confirmed also by their structure, Fig.17, showing uniform distribution of wüstite particles in ferrous silicate matrix.

The second one related to high contents of calcium oxide in the slag samples. As CaO content of analysed iron ore was about 3 wt% (sample VA1 in Table I), the high contents of CaO in the slags resulted from intentional additions of lime based materials into the furnace charge. The technology of slag forming lime based additions is known in Slovakia territory from beginnings of the 18th century. Addition of basic materials into the charge resulted in decrease of slag viscosity in the furnace hearth, so the slag was sufficiently liquid to be tapped from the furnace. In fact, all seven analysed slag samples were fragments of bigger slag cakes that solidified outside the furnace.

Table I – Results of chemical analysis of slags and iron ore, wt %.

Sample no.	SiO_2	Fe	CaO	Al_2O_3	MnO	P	FeO
VA1	15.38	55.29	3.36	0	0.08	0.11	0.86
VA5	27.98	44.68	8.40	0.82	0.15	0.14	44.11
VA6	26.98	43.56	14.28	1.63	0.15	0.14	44.26
VA7	31.08	42.45	14.28	1.60	0.13	0.14	41.67
VA8	27.62	44.12	10.08	2.04	0.07	0.12	41.96
VA10	28.56	41.33	10.08	2.24	0.10	0.07	41.41
VA11	29.40	43.00	8.96	1.63	0.15	0.07	45.55
VA13	28.84	40.21	10.64	1.22	0.10	0.11	40.95

MgO 0 to 0.4 wt %; S 0.002 to 0.008 wt%

The smelting process, that was probably similar to the Varín one, was discovered in Spiš, east Slovakia, by the town Spišské Vlachy, where high concentration of slag was found in area of about 8000 sq. meters, situated on the right bank terrace of the river Hornád (10). The site was dated to the Late Roman period.

CONCLUSIONS

The paper presents review of some iron smelting methods used in the Central Carpathians region from the beginning of iron smelting up to the Migration period. Smelting of iron in bowl furnaces from Hallstat period is described. Moreover, structure and character of iron bloom is presented. All next described methods belong to the post – Celtic time, i.e. to the 1^{st} to 4^{th} centuries A.D. Construction and characteristic features of both free standing shaft furnaces and slag pit shaft furnaces are discussed. The specific feature of slag pit shaft furnaces found in site Kysak was the use of thin olivinic lining on furnace inside. This construction detail was not recognized in analysis of slag pit shaft furnaces remnants from Novoklinovo – Djakovo site, Transcarpathian Ukraine. Smelting of iron in cupola furnaces was not regarded as typical for the Central Carpathians. The finds in Varín and probably in Spišské Vlachy can change the opinion on the use of this very effective smelting method.

REFERENCES

[1] Mihok,Ľ.: To the Beginnings of Iron Production. How the First Iron on the Territory of Slovakia was Produced. Slovenská archeológia 1994,1, pp.69-90.

[2] Mihok,Ľ.-Furmánek,V.: Character of Iron Blooms from Protohistoric and Medieval Iron Smelting Furnaces. Materials Science (Medžiagotyra), vol.8, no.4, 2002, pp.355-359.

[3] Mihok,Ľ.-Cengel,P.-Hollý,A.: Metallographic Analysis of Bloomery Iron from Hallstat period Found in Čečejovce near Košice. Archeologické rozhledy 1984,6, pp.670-672.

[4] Mihok,Ľ.-Cengel,P.-Javorský,F.: Analysis of Iron Production in Early Roman Period in Spiš. Nové obzory 1987,29, pp.165-179.

[5] Mihok,Ľ.-Cengel,P.-Hollý,A.-Javorský,F.: The Study of Early Iron Production in Spiš. Historical Metallurgy, vol.21,1987,2, pp.81-85.

[6] Mihok,Ľ.-Miroššayová,E.: Celtic Furnaces for Smelting of Iron in the Vicinity of Košice. Oceľové plechy 1994,4, pp.1-5.

[7] Mihok,Ľ.-Miroššayová,E.-Kotigoroško,V.G.: Slag Pit Shaft Furnaces for Iron Smelting in the Central Carpathians Region. In: Metallgewinnung und – Verarbeitung in der Antike (Schwerpunkt Eisen). Archaeologica Slovaca Monographiae, Tomus III, ed. H.Friesinger, K.Pieta, J.Rajtár, Nitra 2000, pp.73-85.

[8] Mihok,Ľ.-Pribulová,A.-Miroššayová,E.-Kotigoroško,V.G.: Slag Pit Shaft Furnaces in Slovakia and Transcarpathian Ukraine. Carpatica (Uzhgorod), 15,2002, pp.217-230.

[9] Mihok,Ľ.-Pribulová,A.: Metallurgy of Iron at the Beginning of the 1st Millenium A.D. in Slovakia. Prehistoric and Medieval Direct Iron Smelting in Scandinavia and Europe. Acta Jutlandica LXXVI:2, Humanities Series 75, Aarhus University Press, 2003, pp.163-170, 298-302.

[10] Mihok,Ľ.-Pribulová,A.-Javorský,F.: Iron Smelting and Working in Spiš in Roman and Slav Periods. Acta Metallurgica Slovaca 7,2001, Special Issue 2/2001, pp.102-118.