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Slag pit shaft furnaces in Slovakia and Transcarpathian Ukraine

As generally accepted, iron spread into the Central Europe in the 6th and 5th centuries B.C. from the Mediterranean region. First methods of iron smelting, dated to the 6th century B.C., found in the east Slovakia, related to the smelting in bowl furnaces.

Celtic inhabitation that occupied in La Téne time a great part of west, north and central Europe, started to smelt iron in the small shaft furnaces. The change was dependent on exploitation of most of the surface deposits of limonite iron ores.

Slag pit shaft furnaces were frequently used in territories of the Germanic colonization in first centuries A.D., but Celtic contribution to this invention is not excluded. The paper presents facts about finds of slag pit shaft furnaces in the east Slovakia (Kysak, river Svinka region) and in the Transcarpathian Ukraine (Novoklinovo). The finds are not sufficiently dated.

Slag pit shaft furnaces in Kysak site, east Slovakia. Specific invention in development of iron smelting was slag pit shaft furnace. This invention is related by many scholars to Germanic inhabitation. The furnaces were found in many parts of post – Celtic world, in Scandinavia, Germany, Bohemia, Poland, Slovakia, Transcarpathian Ukraine. The furnaces had shaft and hearth constructed over a pit with depth of about 40 cm. Yield of smelting – iron sponge, formed in the hearth on tuyere level. Through the iron sponge slag flew over and collected in the slag pit that was filled with brushwood before smelting. Archaeologic find of such smelting is slag cake, the filling of the slag pit (fig.1) (Mihok, Miroššayová, Kotigoroško, 2000, p.73-85).

Big slag cakes, remnants of smelting in the slag pit shaft furnaces, were discovered in east Slovakia, near the confluence of the river Hornád with the small river Svinka. Four big slag cakes were discovered in the village Kysak by local inhabitants in yard preparation behind the new built house. Based on local reports, more extensive bloomery was expected in the neighbouring area. The furnaces were dated probably to the 3rd or 4th centuries A.D.

Big slag cakes, small slag fragments, fragments of refractory materials and fragments of pottery were found on the site. Some of them were sampled and submitted to chemical, microscopic and X-ray diffraction structure analysis. One of the four big slag cakes is in fig.2, the second one, fig.3, was in fact the half of the 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 its total weight was up to 100 kg.

Chemical analysis of the slag samples showed the slags were bloomery slags with high content of iron. Most of iron contents were between 50 and 60 wt %. Typical structure of slag from Kysak is in fig.4. It consists of wüstite, fayalite, iron – calcium olivine, and ferrous glass.

Refractory fragments that contained also the layer of adjacent slag, were analysed. Chemical and X-ray diffraction structural analysis showed, they were SiO_2 based. The contact between refractory and slag is in fig.5. As can be seen from the figure there is intermediate layer positioned between the refractory layer and the slag layer. The character of contacting slag was changed. Only silicate components were found by the contact, the ones with higher Ca and Mg contents prevailed. The first occurrence of wüstite was observed in distance of about 1 mm from the contact. $MgO.SiO_2$ and $FeO.MgO.SiO_2$ components were found in the intermediate layer. From this follows the intermediate layer in form of thin lining was made of the olivine sand.

Concerning the slag cake weight, the iron bloom, yield of smelting, had weight of about 20 kg or more. The slag in the furnace, concerning its composition, could be highly viscous and its free flowing through the bloom pores should be supported by some other conditions. One of them was temperature inside the furnace, decreasing viscosity of the slag. Heat – temperature conditions in the furnace were considerably influenced by composition of the refractory material that was based on clean silica with high refractory properties. It's use decreased heat losses through the furnace walls. Temperature increased in the interval where solid structure of iron bloom was kept intact, but viscosity of slag decreased. This fact was also documented by structural homogenity of the slag. Next factor, probably influencing the mobility of slag, was olivinic layer lined on silicate refractory. The layer changed the character of contacting slag and decreased its viscosity.

Slag pit shaft furnaces in region of the Svinka river, east Slovakia. The finds of slag from iron production spread along the Svinka river from its estuary to the river Hornád up to the village Radatice (Miroššayová, Mihok, in press). They indicate existence of bigger metallurgical centre with a few production sites. The slag cakes, that were analysed, were found near the village Radatice, site Dubrovjany. They were found in secondary position near field track, where they were dumped after removing from agricultural field. Reduction furnaces were probably situated in the area of present agricultural field between the field track and the left bank of the Svinka river. The slag cakes from Radatice, where compared with the ones from Kysak, were smaller – diameter of about 30 cm, height of about 10 cm and they were different also by shape.

Three samples of slag were taken and submitted for chemical and microscopic analysis; two of them were taken from heavy slag fragments, the third one from the whole slag cake. The sample taken from the whole slag cake had iron content 47,47%, its structure contained tiny wüstite dendrites in two – component silicate matrix (fig.6). The structure was also different from the ones found in Kysak slags and suggested better reducing conditions in the furnace. No refractory materials were found and analysed. This fact did not allow to draw conclusions concerning furnace construction.

The samples taken from the fragments had very high iron contents: 65,9% and 73,16%. They contained dense wüstite structure with parts containing mushy metallic iron (fig.7). They probably represented iron bloom – mushy iron that was removed from the furnace with slag that stuck to it.

Slag pit shaft furnaces in Novoklinovo, Transcarpathian Ukraine. Archaeologic sites near villages Novoklinovo and Djakovo, that belong to Botary region, are characteristic by finds of big slag cakes, remnants of slag pit shaft furnaces. The samples for chemical, X-ray diffraction structural analysis and microscopic analysis were taken from some slag fragments (Mihok, Pribulová, Fröhlichová, Kotigoroško, 1999, p.215-226). Two analysed fragments of slag are in fig.8 and fig.9. Results of chemical analysis are in Tab. I. As can be seen from the Table, analyses are typical for bloomery slag. Low CaO contents exclude intentional additions of slag – forming basic materials into the furnace charge. Results of X-ray diffraction structural analysis are in Table II. Typical structural components of bloomery slag were found. Presence of MgO in composition of the slag no.6 is also reflected in its structural composition.

High iron contents in the slags point to very inefficient reduction process in slag pit shaft furnace. It is very important to note that contents of iron in analysed slags are high, but not so high as the ones in sets of Laténe and Roman slags found on the territory of Slovakia (Mihok, Cengel, Javorský, 1987, p.165-179, Mihok, Longauerová, Cengel, Javorský, 1988, p.415-432). Such finds are supported by microscopic observations. Most of analysed slags had silicate structure that consisted of fayalite, iron – calcium olivines, magnesium – calcium olivines, and ferrous glass. Wüstite was minor constituent in the structure (fig.10).

Conclusions. The slags from sites in Kysak and Radatice in east Slovakia and from Novoklinovo in Transcarpathians Ukraine were studied. All three sets of slags were by –products of smelting in slag pit shaft furnaces. All tree 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 iron bloom pores was enhanced by furnace construction improvements. The slags from Radatice and from Novoklinovo had silicate structure with low contents of wüstite. Fayalitic – olivinic slag had relatively low melting point. This property enabled the slag to flow through iron sponge pores down to the slag pit.

Table I

Results of chemical analysis of Novoklinovo slags, wt.%

Sample no.	SiO_2	Fe_{tot}	CaO	MgO	Al_2O_3	MnO	FeO
2	27.84	49.14	2.24	0	0.40	0.02	34.9
3	29.94	46.35	2.24	0	1.02	0.02	47.7
4	30.28	50.82	1.68	0	0.40	0.07	50.4
5	43.50	41.32	3.36	0	2.65	0.100	29.3
6	28.10	45.79	5.04	2.8	1.23	1.89	55.3
7	23.92	48.59	2.24	3.2	0	3.77	43.7

Table II

Results of X-ray diffraction analysis of Novoklinovo slags

Sample no.	Structural components in sample
2	$2FeO.SiO_2$; SiO_2; Fe_2O; $(Ca,Fe)O.SiO_2$
5	$2FeO.SiO_2$; SiO_2; Fe_2O; $(Ca,Fe)O.SiO_2$
6	$2FeO.SiO_2$; SiO_2; Fe_2O; $(Ca,Mg)O_2$ SiO_2; $(Fe,Mg)O.SiO_2$

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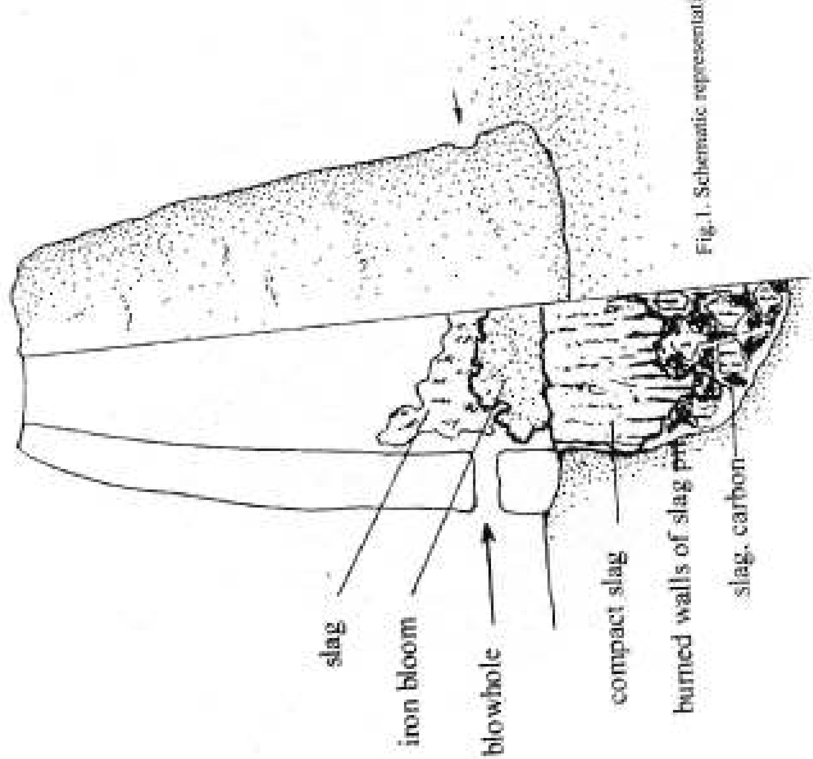

Fig.1. Schematic representation of slag pit shaft furnace.

Fig.2. Big slag cake found in Kysak site.

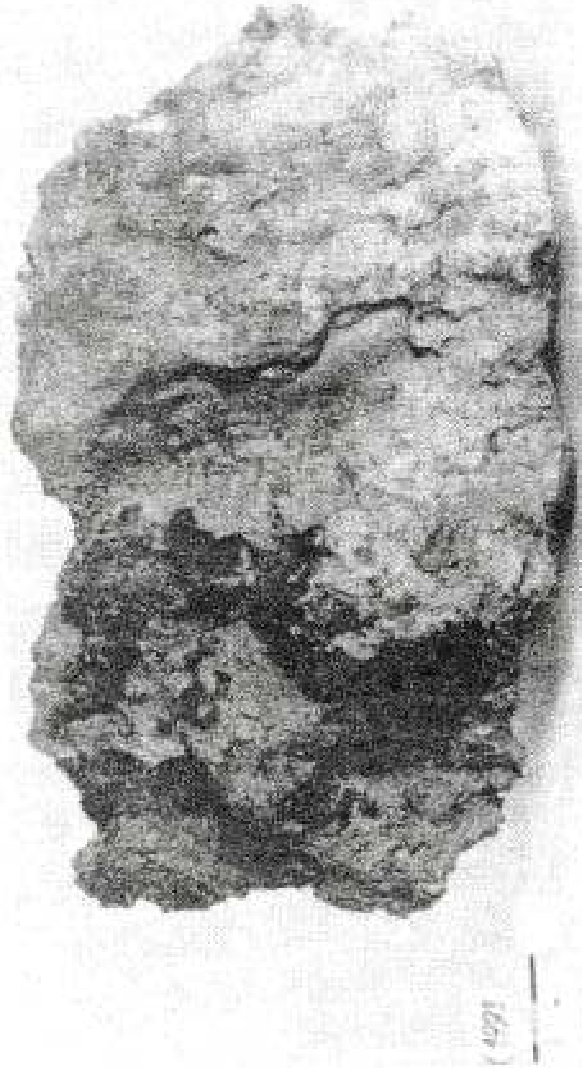

Fig.3. Big slag cake found in Kysak site.

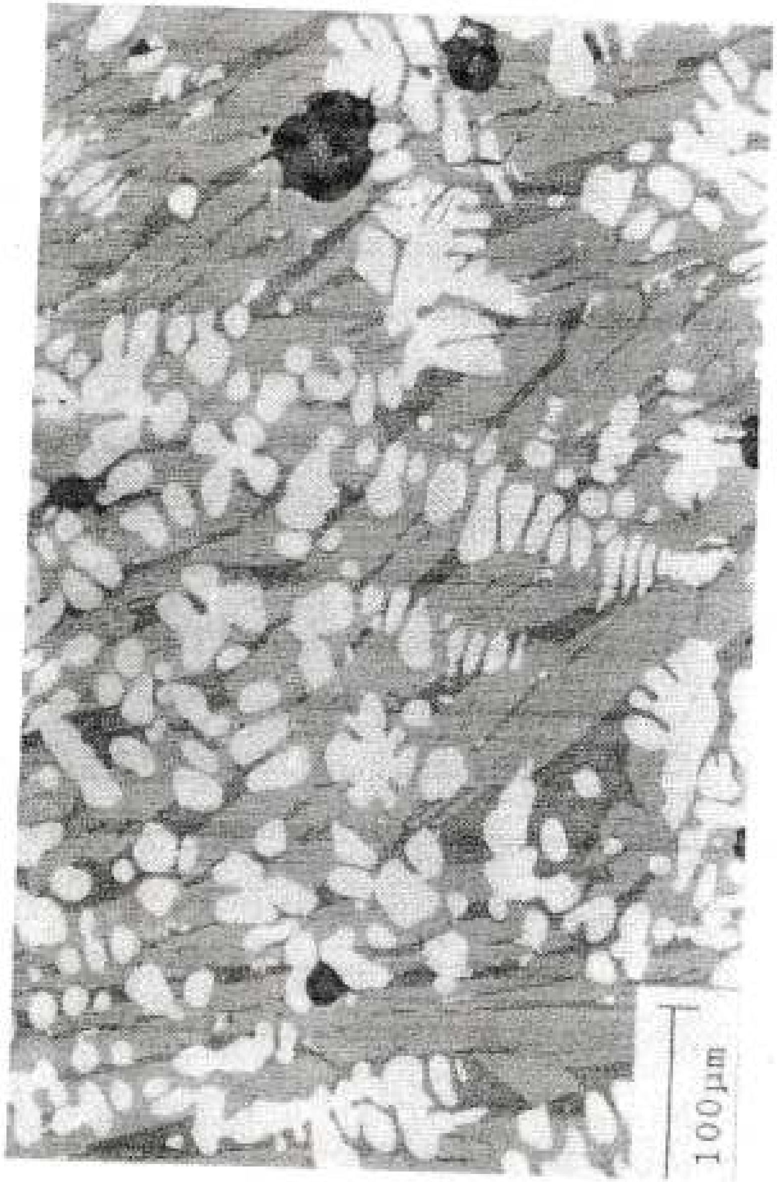

Fig.4. Typical structure of slag from Kysuk site.

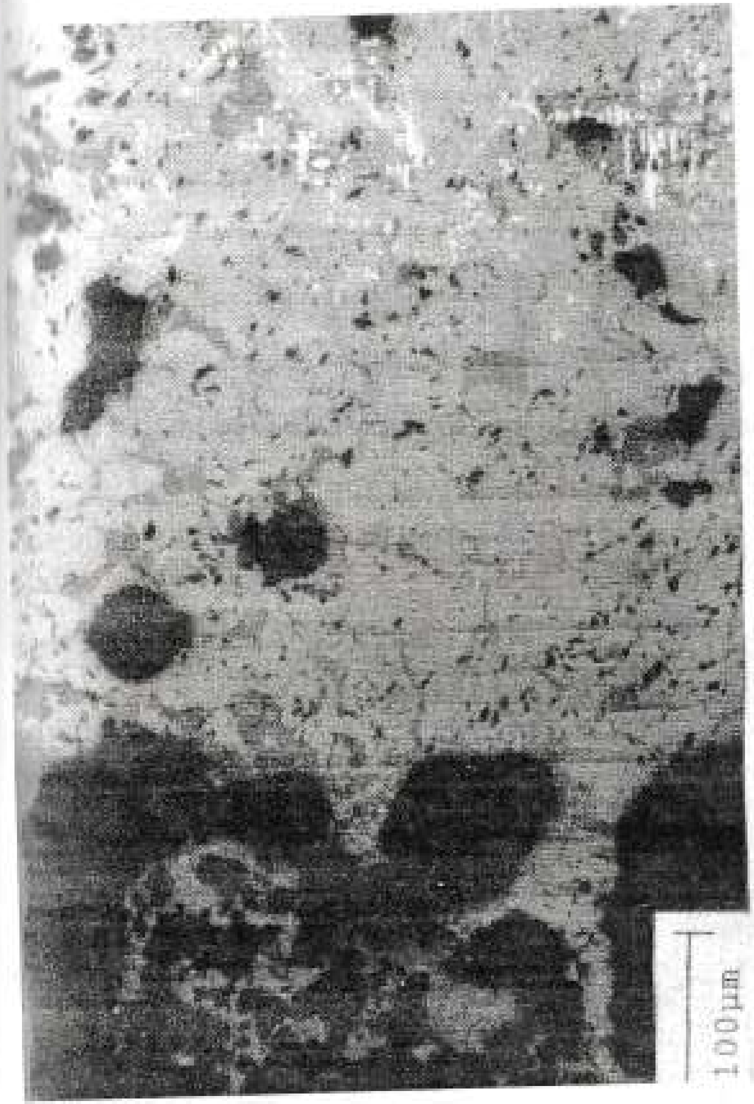

Fig.5. Contact between refractory material and slag in slag sample from Kysuk site.

Fig.6. Structure of slag from Radarice site.

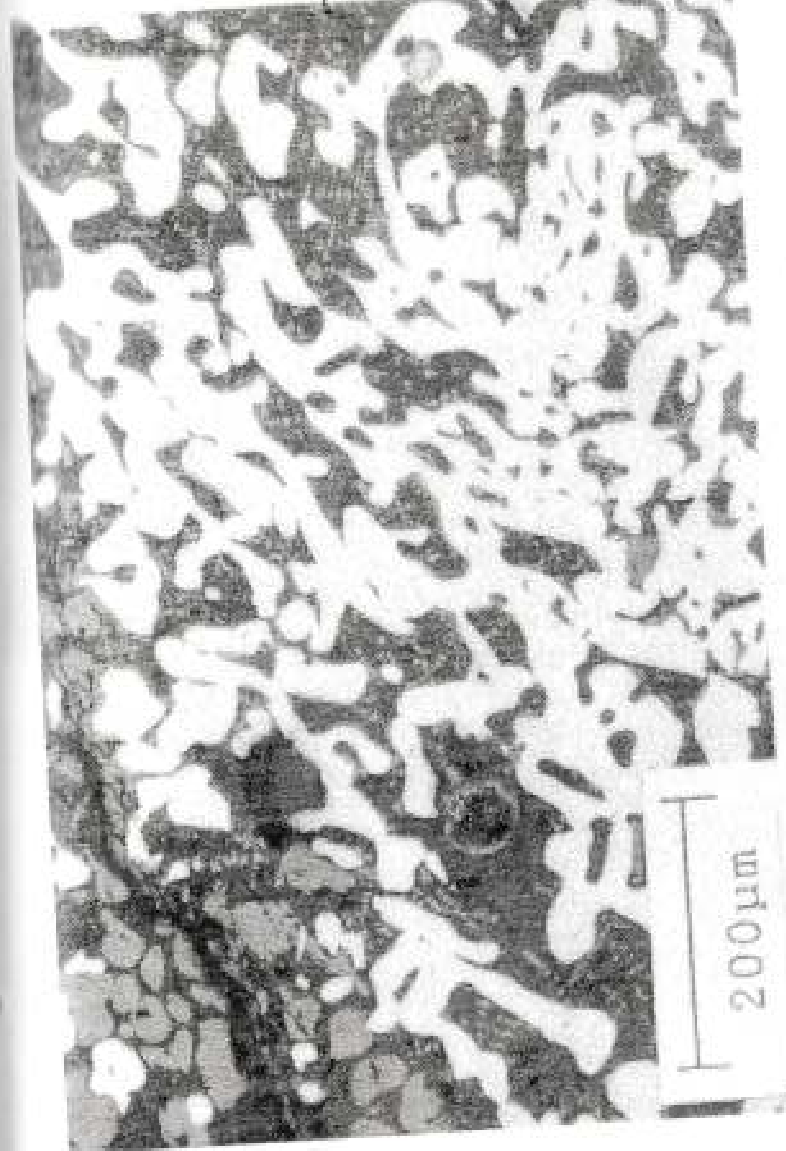

Fig.7. Structure of iron bloom fragment from Radarice site.

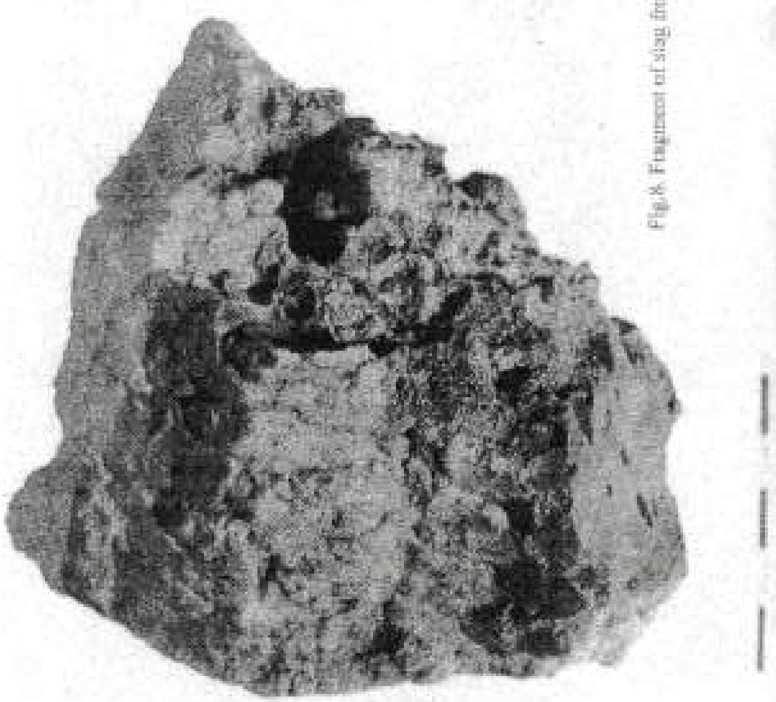

Fig.8. Fragment of slag from Novokhnovo site.

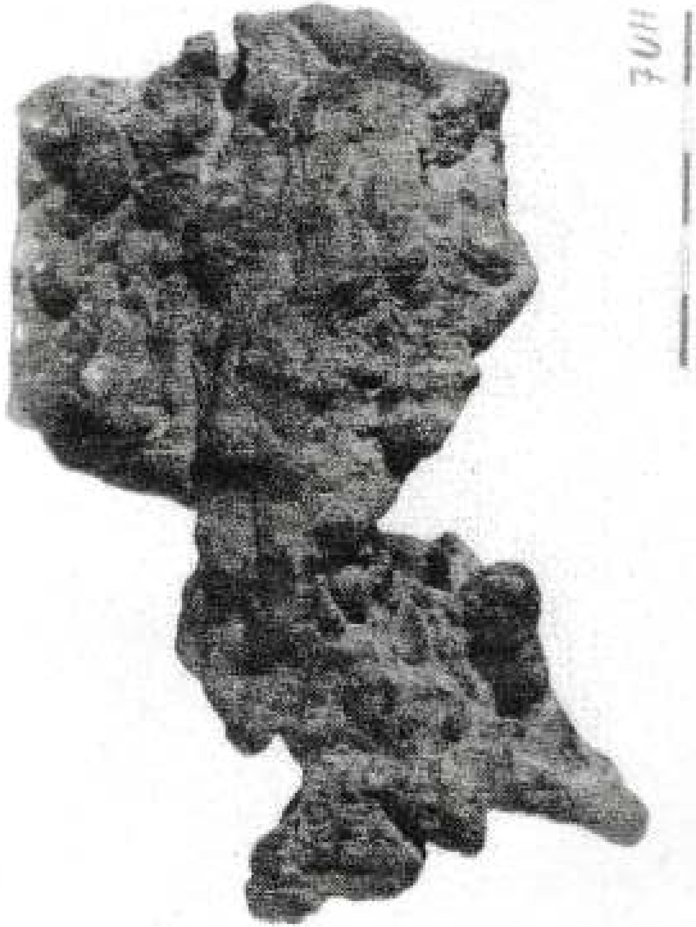

Fig.9. Fragment of slag from Novokhnovo site.

Fig.10. Typical structure of slag from Novokhlinovo site.