Pribulová A., Mihok Ľ., Mácelová M. (Košice)

The research of the production and processing of metal subjects on the slovak settlement of Sliač Horné Zeme.

Medieval metallurgy played a dominant role in the development of the territory of Slovakia, of which the Central Slovak region was an important state. These medieval metallurgy traditions contributed to the existence of many modern metallurgical complexes today, namely in the fields of non – ferrous metals in Banská Štiavnica and iron metallurgy in Horný Hron.

Archaeological evidence strongly suggests that a settlement existed in Central Slovakia, during the early Middle Ages. Along with medieval metallurgy practices, archaeometallurgical evidence would also suggest a much older metallurgy production in the locality of Sitno – Iľja.

These results were obtained by examining iron objects from the Slavic settlement, which occurred in the middle Slovak fold, in the locality of Sliač – Horné Zeme.

The settlement was in the registered town of Sliač, side – Rybáre. The settlement was sub-divided into two sections based on the discovery of pottery artefacts. The first section dates back to between the 7th and 8th century, while the other section dates back to between the 8th and the first half of the 9th century. Systematic archaeological examination of settlement artefacts started in 1979. Besides the discovery of pottery fragments and archaeozoological clay coloured bones, which was a result of being mixed with sludge and coal, iron objects and a large number of slag pieces were also discovered. This can be directly linked to the production and the working of iron, which included pieces of iron ore (Mácelová, 1982, p.117-132; Mácelová, 1990, p.320-344).

It is speculated that various objects discovered by Archaeological research, were used in the domestic environment, while others for economic uses like manufacturing. Because of the discovery of only heterogeneous material near these objects was found, it was not possible to accurately determine their use. Further findings would suggest that the settlement originated from a background of agriculture and craftsmanship.

Archaeological research would indicate that the numerous amount of slags and the few pieces of iron that were found, suggested that the manufacturing and production of iron took place on the settlement. However no trace of productivity could be found, nor could the discovery of any technological implements or structures be found, i.e furnaces for smelting purposes, or the existence of a Smithy workshop. The production of a small quantity of pieces, their scattered remnants and the existence of little integrated metallurgy and smithy places on the large settlement with numerous source of iron ores, were typical for the early Middle Ages, but also for the previous Roman period (Mihok, Pribulová, Frohlichová, Mácelová, in press).

Metallographic analysis of samples. From the research of Slavic agriculture and craftsmen in the settlement of Sliač – Horné Zeme, it was concluded that iron ore production once took place. It was possible to discover the type of technique that was employed in the Smithy workshop for the production of iron ore. This was done with the provision of 13 objects from the settlement's inventory. All objects excavated, showed no military characteristics and therefore it is concluded that they were used for economic purposes.

The Metallographic analysis, following the study of structures, which were found in metal, provides information about the method of production that was used. The pre-condition for Metallographic analysis, is the taking of a metal sample from the object. It is also very important to take a sample from its place of origin, which would characterize the entire object and eventually all it's working sections.

The sample is taken by cutting. Because these samples are very tiny and have irregular shapes, the next step is circumfusion of the sample into a self-solidifying resin. The sample is prepared for analysis by grinding the sample on metallgraphic paper and by polishing with a diamond paste. The surface was viewed under a metallgraphic optical microscope. Cracks, fissures, porous and non-metallic inclusions were registered.

The fissures and cracks can indicate where smithy pressure welding could have taken place. Three sorts of non-metallic inclusions exist in the iron objects from proto-historical and medieval localities (Buchwald, Wivel, 1998, p.73-96; Mihok, La Salvia, Roth, 1998, p.475-477).

1. Inclusions of furnace slag. Furnace slags got into the metal by preparation of a semi product from the iron sponge, when the slag was not eliminated completely. The silicate matrix with wüstite dendrites is typical for them.

2. Smithy inclusions. By heating the semi-product or object, the surface oxidized, forming a scale on the base of the ferrous oxide. Because the oxidized layer could be inhibited by smithy operations, the scales were removed from the heated surface of the object, by adding SiO_2 from silica sand. The by-product of this reaction was ferrous silicate that could be removed from the surface very easily. The remnants of the ferrous silicate, embedded into the metal forming the so-called smithy inclusions.

3. Scales. Not all scales were removed by reacting with silica oxide. Those

not treated came into the metal by the next smithy process.

After the observation and documentation of cracks and inclusions, the metal graphic surface was etched by 2% nital. This allowed one to visualize the metal structures, which were observed under a metallographic optical microscope. It is therefore possible to talk about smithy welding, carburisation, hardening, tempering and normalization of semi-products and objects and also about the intensity of the hammering.

Results of metallographic analysis. The pictures document the results of the metallographic analysis. On each picture there is a sketch of the analysed object and a cross section of the sample. Sometimes the photograph has been enlarged, to show the entire surface of the sample.

Object n.1 – fragment of a currency bar. Metallographic analysis of object n.1 is in fig.1. The sample is cross-section taken from the middle of the object. Only some small inclusions of the furnace slag were found on the non-etched metallographic surface. After etching, only a non-carburized ferritic or mild carburized ferritic-pearlitic structure was found on the entire surface. It can be clearly seen from the photograph, which was enhanced and depicts the entire surface. It is visible from the photograph, that half of the surface had a coarse grained structure. The remaining surface had a milder grained ferrite or ferritic-pearlitic structure, with one area having a deformed grain (fig.1, 1).

From the results of the metallografic analysis, one can determine from the logical properties of the currency bar, that it was made by smithy hammering from the iron sponge (yield of iron smelting in a small reduction furnace) without any further treatment. Carburization of this semi-product was done in a smithy workshop before it was used.

Object n.2 - fragment of knife with edge part. Metallographic analysis of object n. 2 is in fig.2. The sample is a cross-section from the middle of the object. Smithy inclusions were found along with the remnants of scales on the non-etched surface. After etching, it was visible from the surface of the sample that the surface consisted of three sections. A non-carburized structure was found on part of the surface. On the section, which is marked by a deep dashed line, a carburized pearlite structure was found. Also a welded cutting-edge, which was prepared from the deeply carburized iron, was found. The ferritic structure is visible from (fig.2, 1); transformation of ferritic to pearlite structure on fig.2, 2 and carburized tip is on fig.2, 3. The ferritic structure has a mild grain only on the rim, opposite to where the tip coarse grain was. Between the ferritic and pearlitic structure, a boundary is evident, indicating that two semi-products with different carbon contents were welded together. The segregated cementite needles in the pearlite structure gives evidence about the deeply carburized tip.

From the metallographic analysis, one can see that the welding of two semi-products was used in the production of the object (one was non carburized, the other, carburized). A very hard carburized knife-edge was welded at the place where the carburized semi-product meets the border. The describing technology that was used in the production of the knife was excellent. Non-carburized, course-grained iron material was used in the body of the knife, giving it sufficient durability, while a hard carburized iron was used in the knife-edge. Welding of the knife-edge from deeply carburized iron made this.

Object n.3 - round fragment with thorn. The metallographic analysis of object n.3 is in fig.3. The sample is a cross-section from the thicker part of the fragment. The smithy inclusions, which were ordered into bands by welding, were observed on the non-etching surface. After etching, a coarse-grained non-carburised ferritic structure was discovered on the larger part of the surface. In the place marked by a dashed line, the deeply carburized pearlitic structure was observed. Between it and the ferritic coarse-grain structure, was a mild grained pearlitic–ferritic and ferritic–pearlitic structure, crossing suddenly into a coarse-grained ferritic structure. The distribution of structures is shown on the enhanced picture, detail (fig.3, 1).

The sudden change of grain structure suggests that two semi-products were used, in the production of the object. The carburization of the fine-grained part could have been made before the welding of the semi- product. But we cannot exclude the fact that carburisation took place after hammering. Because there is evidence at our disposal, describing the function of this object, it is not possible to determine the serviceability and suitability of the type of production technology used.

Object n.4 – fragment of a nail. The metallographic analysis of fragment of nail is in fig.4. The sample is a cross-section taken from the pointed end of a fragment. Smaller crushed silicate smithy inclusions on the metallographic surface before etching, were found. After etching, there was very homogenous fine-grained pearlitic–ferritic structure, with a very low rate of pearlite on the entire surface. A high homogeneity of structure is clearly visible from the photograph, which was taken by a small enhancement and which covers the entire surface of the cut. A more detail view of the structure is in fig.4, 1. The globularization of ferrite is possible to observe from a bigger enhancement (fig.4, 2); which shows treatment by annealing.

The metallographic analysis shows the exact mode that took place for the production of nails. The iron material was very mild but equally carburized and was also welded equally. Non-carburized or very mild carburized iron material was very suitable for the production of nails. The demanding

preparation of material required for the production of nails was above the required standard.

Object n.5 – pointed fragment. The metallographic analysis of object n.5 is in fig.5. The sample was taken from a cross-section from the middle of the fragment. The small distributed smithy silicate inclusions, were observed on the entire surface. After etching, a fine-grained non-carburized ferritic structure on entire surface was observed. It is clearly visible from the photograph, which represents the entire surface of the cut by a small enhancement. Fig.5, 1 shows the structure in detail.

From the results of the metallographic analysis, one can see that the object was produced from tough non-carburized iron material. Because the kind of object is not specified, it is not possible to determine which type of suitable non-carburized material was used for its production.

Object n.6 – hook (thick-walled fragment). The metallographic analysis of a hook is in fig.6. The sample is a cross section taken from the end of the fragment. By observing the metallographic surface, a high contamination of furnace slag and smithy inclusions were observed too. Only ferritic and structures of non-carburized iron material were observed on the surface, after etching. The coarse-grained structure was found on one part of the surface. It is visible in fig.6, 1. In the middle of the surface, the coarse-grained ferrite with a strong twinning was found, which is indicated in fig.6, 2. The mixed ferritic structure, which consisted of mild and coarse grains, was found on the remaining area of the surface (fig.6, 3).

From the results of metallographic analysis, one can see that the object was produced from non-carburized ferritic iron, at least in the part, which was at the end of the fragment. The use of non-carburized material was not found, but we cannot say that no carburized material was used in the object, because there was missing the tip on the sampled fragment, which could be carburized and eventually annealed. This alternative explanation gives evidence of the occurrence of twinning of the ferritic grains, which could have been caused by the sudden change of temperature, after the quenching. The use of tough non-carburized iron material for the body of the object is regarded as suitable.

Object n.7 – blade of a knife. Metallographic analysis of the blade is on fig.7. The sample was taken from a cross-section of the blade. The fragment used for analysis was very corroded and the razor edge was absent. The smithy inclusions in the form of long bands, which originated during the hammering process, were observed on the non-carburized surface. A small enhancement on two figures, which interlock with one another, depicts the etched specimen. From the figures it is clear that the non-carburized ferritic and mildly carburized pearlitic–ferritic structures were observed on the larger part of the surface.

This could only be seen on the right hand side of the metallographic surface, were the blade is tied up and more carburized pearlitic–ferritic structures are found. On the left side of the surface, on the back of the knife, the coarse-grained ferritic structure was observed (fig.7, 1). On a large part of the surface, the pearlitic–ferritic structure, where the middle coarse-grained and fine grains alternate (fig.7, 2). On the right hand part of the surface, fine-grained pearlitic–ferritic structures are joined on the carburized pearlitic–ferritic structure (fig.7, 3-4).

From the results of the metallographic analysis, one can see that the method of production employed for the manufacture of the knife, was suitable. On the back and in the body of the knife, non-carburized tough iron material was used. In part of the edge, a carburized and harder material was found. It is probably on the edge, which was absent on the fragment, that deeply carburized material was used, the remnants of which indicated deep carburisation on the metallographic surface.

Object n.8 – rim. The metallographic analysis of the rim is on fig.8. A cross section sample was taken of the rim. Only some small smithy inclusions were observed on the non-etched surface. After etching, only carburized ferritic structures with relatively fine grains were found on the entire surface of the cut. On detail fig.8, 1, specific formations of the ferritic structure are visible. These formations were studied on a different sample and they will be explained later. The most suitable material for the rim was both a soft and a tough iron based material.

Object n.9 – nail with the head. The metallographic analysis of sample n.9 is in fig.9. The sample is a cross-section of a nail bolt. Only some small smithy inclusions were found on the non-etched metallographic surface. The whole surface of the sample is visible on the figure by a small enhancement. A very homogenous, soft carburized pearlitic–ferritic structure was found, which is visible on fig.9, 1 and by larger enhancement on the fig.9, 2. It is absolutely the same structure that was found on the nail, sample n.4. The nail with the exception of a slight carburization was treated in the same mode, so that it was annealed and caused the globularisation of ferritic structure. On the basis of the metallographic analysis, we can say that the production technology used was very demanding and over-standard for an object of mass consumption, like a nail.

Object n.10 – the half of horseshoe. The metallographic analysis of sample n.10 is in the fig.10. The sample is a cross-section taken from the end of the fragment of a horseshoe. On the metallographic surface before etching had taken place, some smithy inclusions, but essentially more remnants of scales and smithy wastes were found. The condition of the

metallographic surface after etching is recorded in three photographs, which were taken by small enlargement, covering the entire surface of the cut. A very interested distribution of structures is noticeable in the photographs. The structure shows that the object contains layers of iron with various properties. The formation of this structure is by Piaskowks (1985, p.157-167, 169-178, 265-271) due to the diffusion of phosphorus in high phosphorus irons on the border of the ferritic grains, which followed carburisation. That structure is depicted on figures 10, 1 and 10, 2. The mechanism in question is supported by the presence of iron phosphates in ferritic grains, which is clearly visible in the both figures.

Metallographic analysis shows that the horseshoe was not made from too much carburized iron material. The material was suitable for the production of horseshoes. In another analysis of horseshoes from the medieval era, it was discovered that in many cases, only non-carburized iron was used for the production of horseshoes.

Object n.11 – square punch. Metallographic analysis of a square punch is in fig.11. The sample is a cross-section, not from the peak, but from the opposite end of the square punch. Only small quantities of smithy inclusions were found on the non-etched metallographic surface. The metallographic surface after etching is in the photograph, which was taken by a small enhancer. The photograph covers the entire surface of the cut. From the photograph it is clear that object consisted of two semi-products. One of them contained course-grained ferritic non-carburized structure, while the other, middle carburized fine-grained pearlitic–ferritic structures. The carburized semi-product covered the larger surface of the object. The boundary between both structures and also between the two semi-products is in fig.11, 1. The boundary was very clear and was flanged by smithy inclusions.

The use of middle carburized semi-products in the top part of square punch shows that blacksmiths paid great attention to the production of this type of object. The use of deeply carburization in the portion of the tip cannot be excluded.

Object n.12 – the head of a nail. Metallographic analysis of object n.12 is in fig.12. The sample is a cross-section of the head of a nail. Higher rates of smithy and furnace inclusions were found on the non-etched metallographic specimen. After etching, only the ferritic structure with middle size grains were observed in the entire cross-section. This structure was covered by stick formations, which were in the bands, in some places. The composition of structures by small enhancements is in fig.12, 1 and 12, 2 and in detail in fig.12, 3. Because of the presence of stick formations and the unknown identity and analogy of the authors, the samples were analysed by an energy dispersion electron microscopy. This was done on the premise that there would be plenty of phosphorus. The analysis did not confirm a high content of phosphorus, or the presence of any other elements. It was deduced that the formations are remnants of artefacts after etching had taken place.

The use of non-carburized material for the head of nail was suitable and standard for the production of these objects during the middle Ages. This result does not correspond with the mode of production of the two nails, which were described earlier, but in this case it was neither analogy of shapes.

Object n.13 – key. Metallographic analysis of object n.13 is in fig.13. The sample is a cross-section taken from the end of the key. On the non-etched metallographic specimen, only some smithy inclusions were observed. After etching, divided sections with two different structures, were found. In this sample it is clear that the use of two iron products in the production of the key was used. It was probably the welding of two iron sticks for the production of the key. The boundary-line of these two structures is clearly visible in fig.13, 1, which was taken by a small enhancement. The hammering of two semi-products is indicated by the presence of a rim on the boundary-line. Both structures had a middle size grain. They were pearlitic–ferritic that also had a different content of pearlite. This in turn indicated that they had a different content of carbon in the iron. The detail of the structure of these low carburised semi-products is indicated in fig.13, 2.

The use of iron material with the middle content higher in carbon for key production is regarded as suitable. From the metallographic analysis, it was not possible to determine if the more carburized semi-product lead up to the end of the key arm or was the use of the harder iron material for the more exposed part of key deliberate?

Discussion of analyses results. All analysed objects had economic characteristics. A lot of them were not dedicated to the conditions with extremely high mechanical strain. mithy workers dedicated to the production of objects for military use used the high hard production technologies. Non-carburized iron, which was prepared from the extraction of a small melting reduction furnace, was used very often for objects of economic use and like construction material, just without the next step in modification. This material was used for some objects in the analysed set and its use was validated. Like in the example of the rim, where soft and tough iron had been used, the different material could decrease the properties of this object.

In the cases where it was necessary to treat whole object or its parts, the smithy workers treated the iron semiproducts or finished object. In this way it was increased the hardness of the surface of punch by use the more carburized semiproduct. It is necessary point out production of nails, where very homogenous carburized iron material was used. The use of this technology was not very standard, likewise the use of middle carburized material for the production of the horseshoe is not very standard too. It is true that in the Middle Ages the horseshoes were produced by welding of two layers. It was not found the use of quenching of carburized parts of objects although the character of analyzed objects needed this technology. Some marks point out the use of quenching by the treatment of the tip of hook.

The production of knives documents the high craftsmanship of smithy workers and their knowledge of used material. The results of metallographic analysis of objects from the Slavic settlement Sliač Horné Zeme shows the excellent level of craft in the settlement. By analysis of sets from another settlements the objects with unsuitable properties, which were made by not right technology, were found very often. All objects analyzed in this research had suitable utility properties.

Conclusions. Archaeological finds, which were found on finding place Sliač – Horné Zeme rpoint out to agricultural and craftsmen character of the settlement.

There were found iron objects and pieces of slags, which were connected with production and processing of iron on the settlement. The analysis of iron objects shows the high craftsmanship of smithy workers and their knowledge of used material, what is visible in the used technology, which corresponds with intention of the use of objects.

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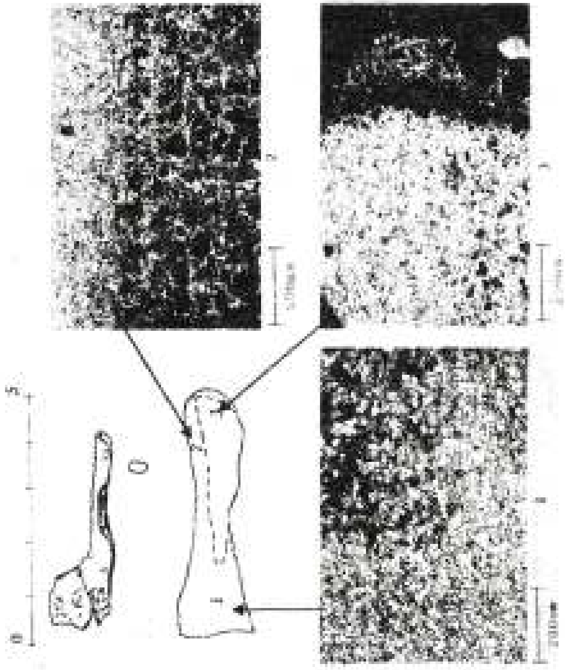

Fig.2. Metallographic analysis of fragment of knife with edge part.

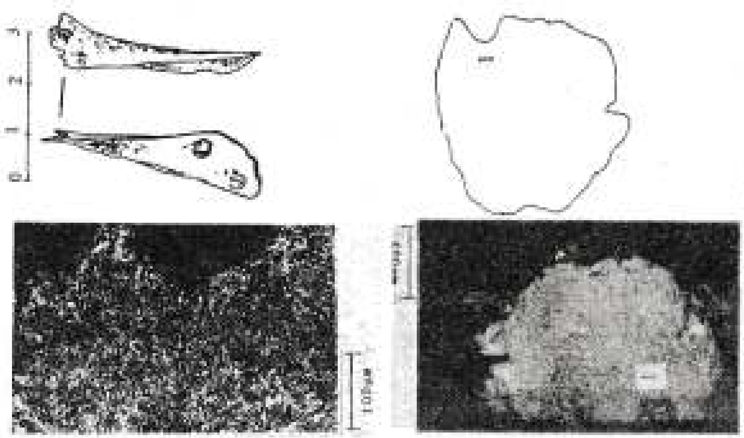

Fig.1. Metallographic analysis of fragment of a currency bar.

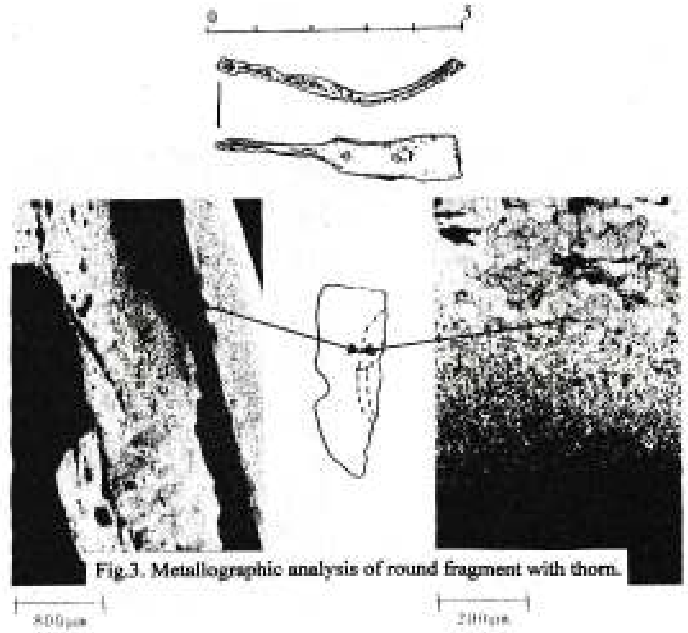

Fig.3. Metallographic analysis of round fragment with thorn.

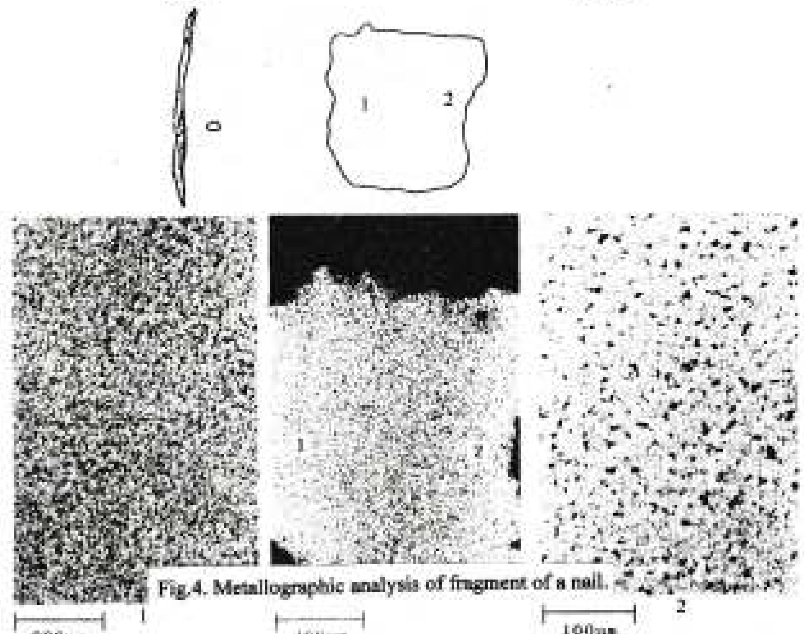

Fig.4. Metallographic analysis of fragment of a nail.

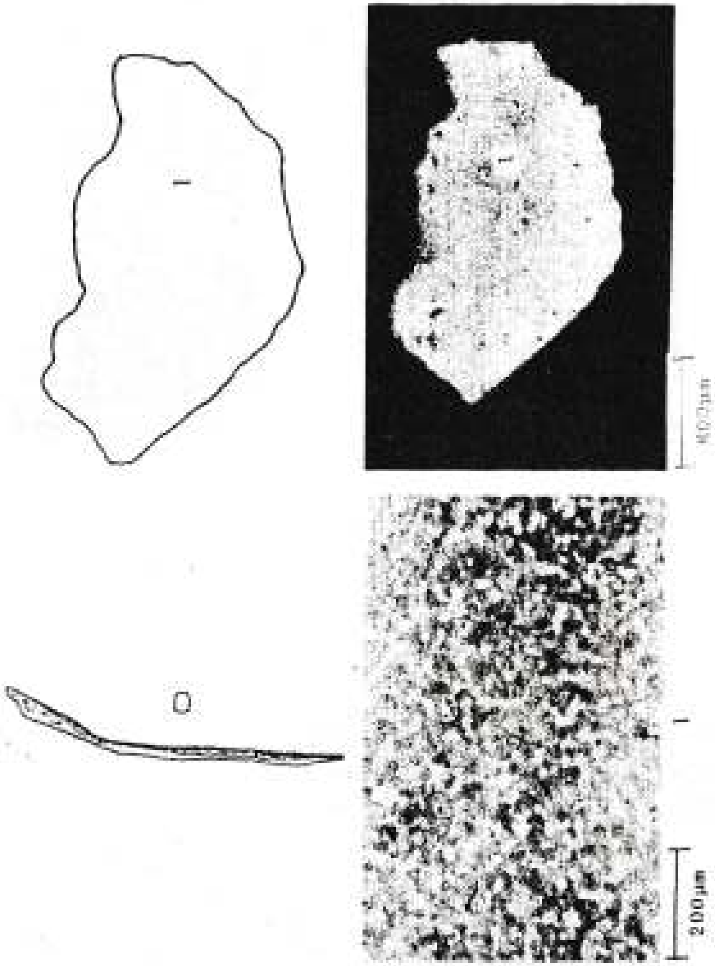

Fig.5. Metallographic analysis of pointed fragment.

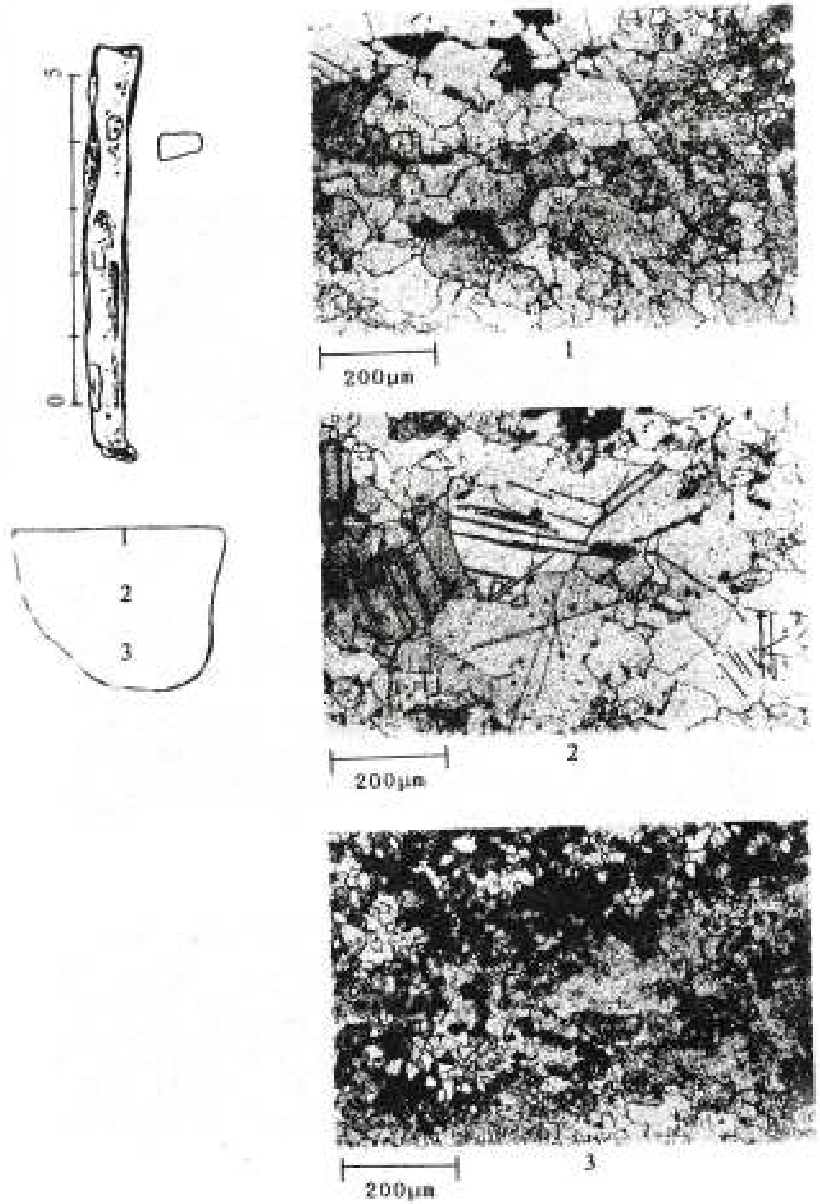

Fig.6. Metallographic analysis of hook (thick-walled fragment).

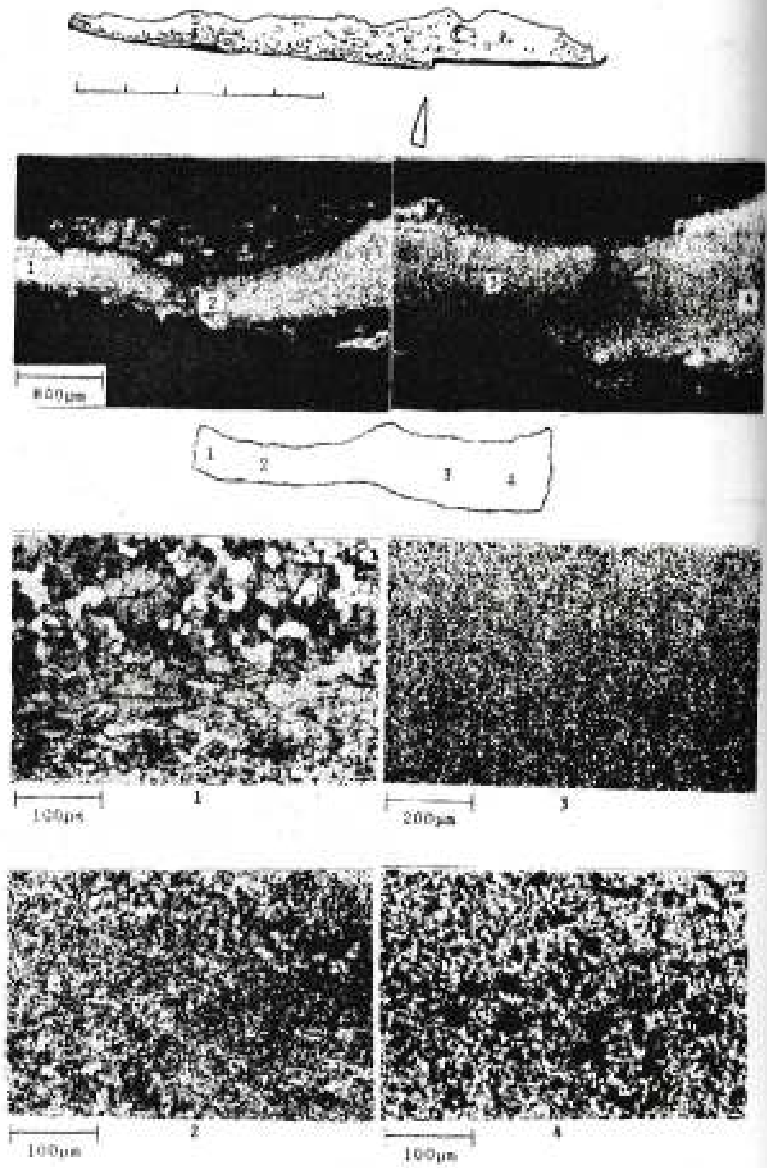

Fig.7. Metallographic analysis of blade of a knife.

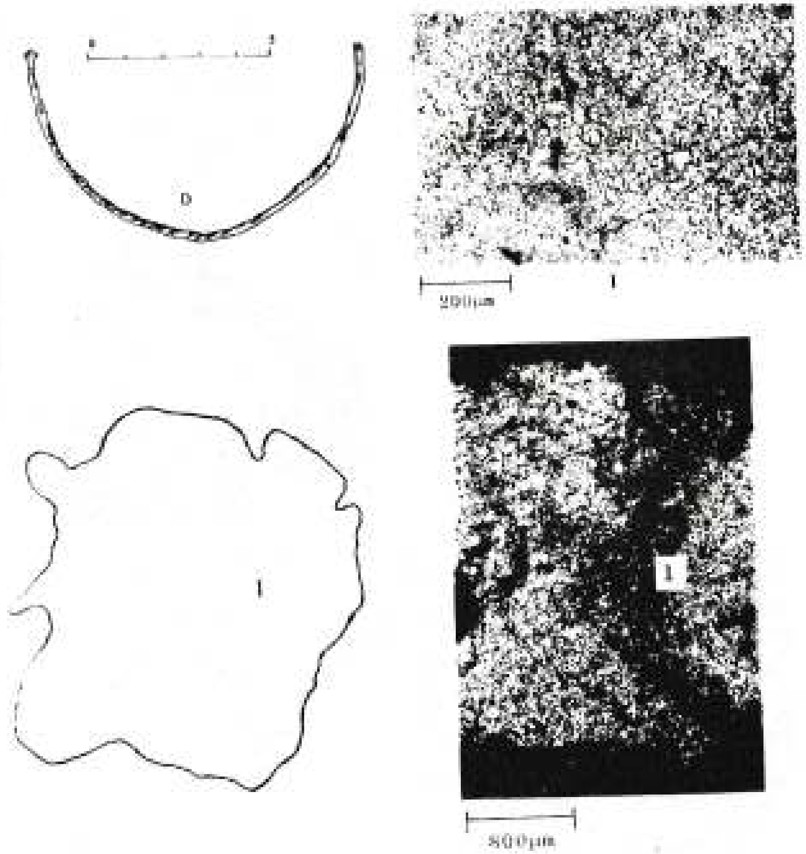

Fig.8. Metallographic analysis of rim.

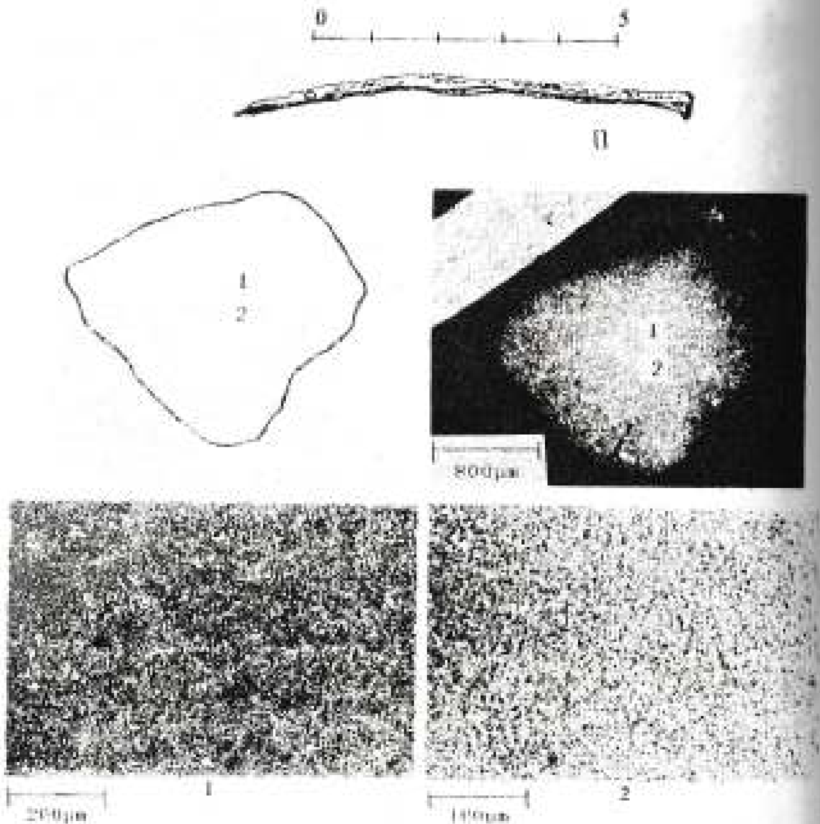

Fig.9. Metallographic analysis of nail with the head.

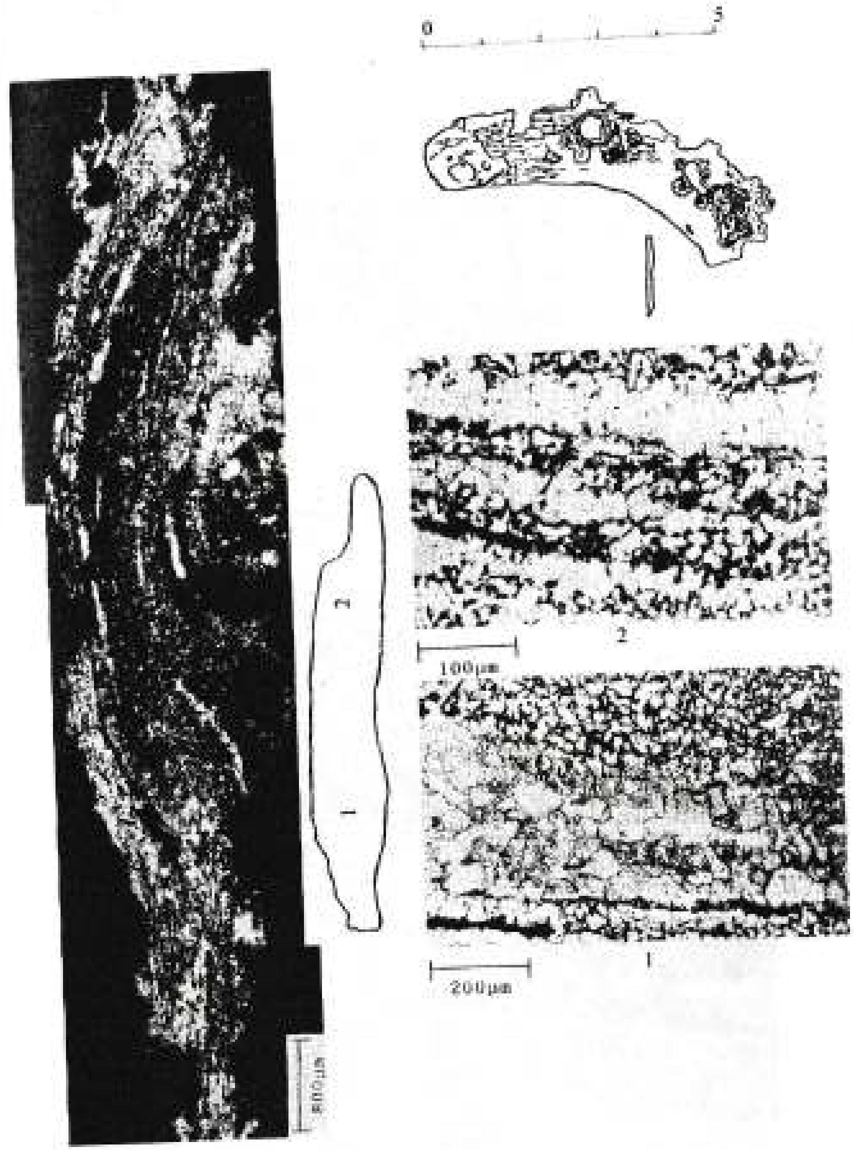

Fig.10. Metallographic analysis of the half of horseshoe.

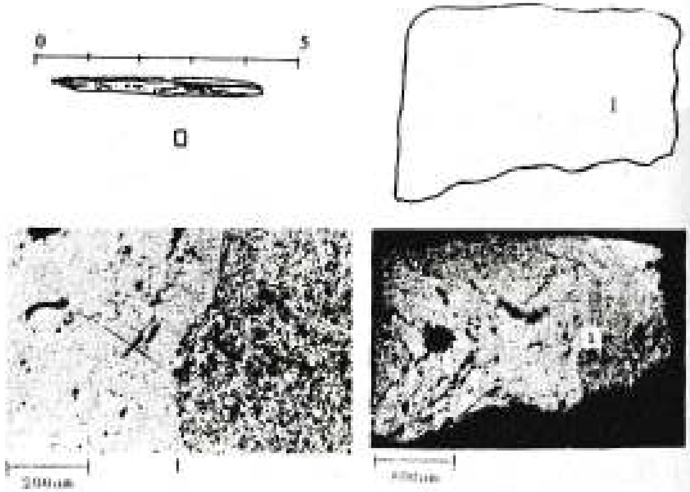

Fig.11. Metallographic analysis of square punch.

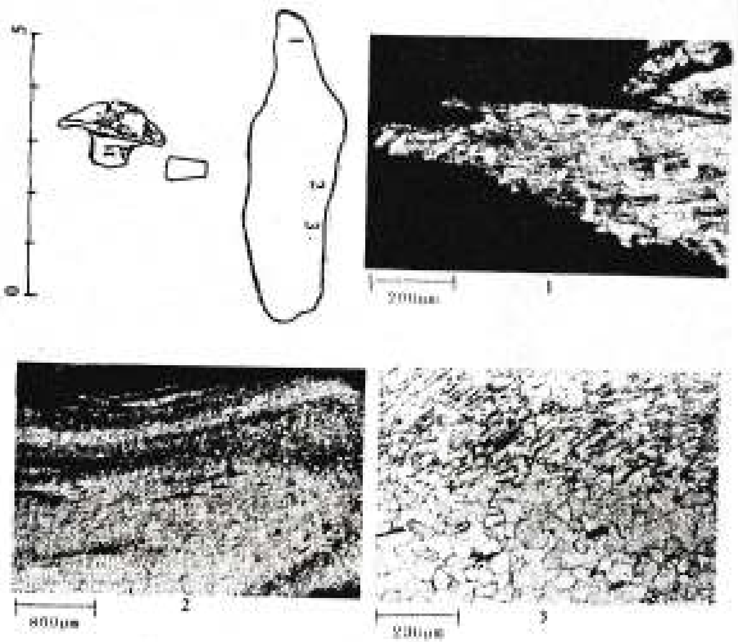

Fig.12. Metallographic analysis of the head of a nail.

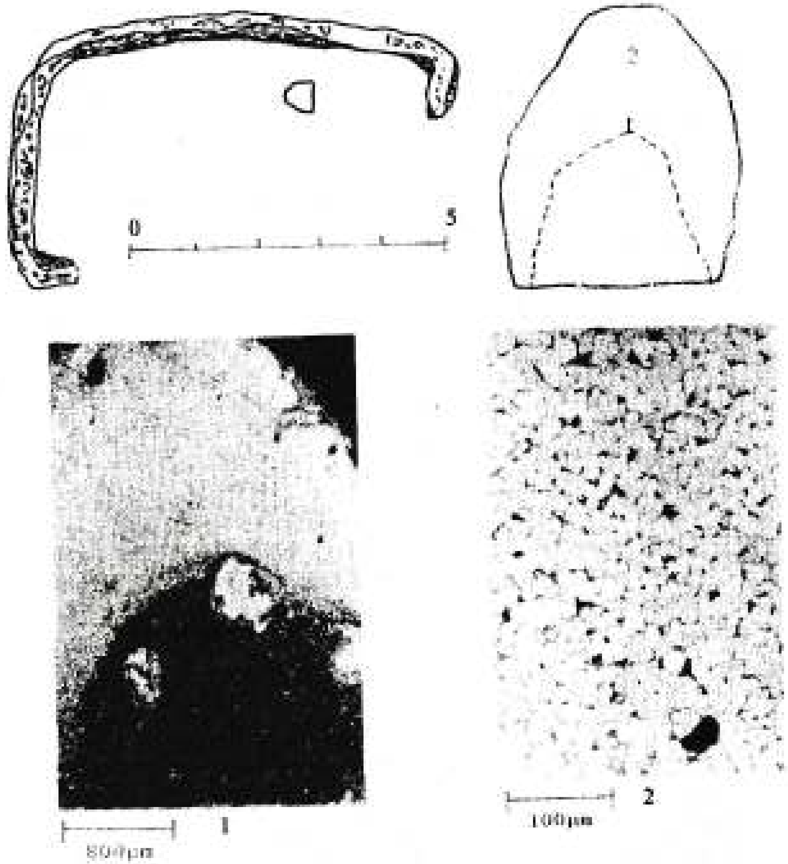

Fig.13. Metallographic analysis of key.