Metallographic examination of four 7th–8th century long-blade weapons from Želovce (Slovakia)

Metalografické rozbory čtyř dlouhých sečných zbraní ze 7.–8. století ze Želovců (Slovensko)

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The article presents the metallographic examination of three sabres and one double-edged sword coming from the 7th–8th century Slavic-Avar site of Želovce (*Slovakia*)*. All four weapons had been subjected to metallography as early as 1975, but the results were not published in sufficient detail. With this article, written in honour of Radomír Pleiner, the authors wish to repay this debt. The blades are compared with other* (*metallographically examined*) *weapons from Želovce, and the manufacturing methods of early medieval production of sabres are discussed.*

Želovce – Avars – sabres – sword – metallography – archaeometallurgy

Článek představuje metalografické rozbory tří šavlí a jednoho dvojbřitého meče, pocházejících ze slovansko-avarské lokality Želovce, datované do 7. až 8. století. Všechny čtyři zbraně byly metalograficky zkoumány již v roce 1975, výsledky rozborů však nebyly nikdy zveřejněny ve všech podrobnostech. Tímto článkem, napsaným k poctě Radomíra Pleinera, by autoři chtěli tento dluh splatit. Dané čepele jsou porovnány s dalšími (*metalograficky zkoumanými*) *zbraněmi ze Želovců a diskutovány jsou i metody výroby šavlí daného období.*

Želovce – Avaři – šavle – meč – metalografie – archeometalurgie

1. Introduction

In 1975, Radomír Pleiner metallographically examined one sword and three sabres from the 7th–8th century Slavic-Avar cemetery of Želovce (south Slovakia). The metallography of the sabres was published in a preliminary fashion in 1979, but no photographs or drawings were included (*Pleiner 1979*). Later, in 1989, R. Pleiner published simplified drawings of the metallographic samples, but no details of the metallography were provided (*Pleiner 1989*). In fact, R. Pleiner never published these weapons and the results of their investigation in full detail. In 1991, Ľ. Mihok published the results of the metallographic examination of several long-blade weapons from Želovce (*Mihok et al. 1991*), including the same 'Carolingian' sword that had been previously investigated by R. Pleiner. The opportunity was taken to check the metallographic samples stored in the Institute of Archaeology in Prague and to present details of the metallographic examinations.

2. Avar-Age long-blade edged weapons

Long-blade weapons coming from the Avaric environment form a specific group of weapons used in contemporary Europe. The most comprehensive study dealing with this topic

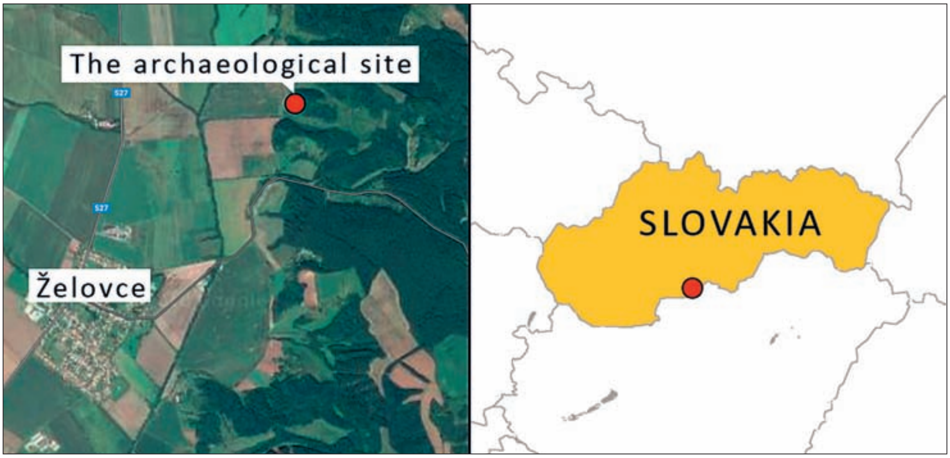

Fig. 1. Location of the site of Želovce.
Obr. 1. Poloha lokality Želovce.

was recently published by *G. Csiky* (*2015*), who also introduced a specific classification system for these objects. Following Csiky's classification, edged weapons (corresponding to category of artefacts 'E') coming from Avaric sites are categorized according to both the form and cross-section of blades: double-edged swords (E.I), single-edged swords (E.II), sabres (E.III) and seaxes (E.IV; *Csiky 2015*, 152). Observed through this grouping, the main trend in 7th–8th century Avar weaponry is the gradual decrease of sabre blade curvature, the relatively permanent presence of single-edged swords and the increasing appearance of crossguards. Weapons with a single-edged and curved blade, suitable for cutting, can be considered sabres. Sabre blades could also be provided with a false edge (or 'elman') running some distance (up to 260 mm) from the point upward (i.e. the lower third or quarter of the blade was double-edged). There are several theories on the function of the double-edged parts; they offered more options to cut and facilitate thrusting, 'since a lenticular cross-section has several advantages over a triangular cross-section' (*Csiky 2015*, 195). This particular feature is seen on Želovce sabres as well; the length of their false edges lies in a very wide range going from 0 to 205 mm.

Some sabres (such as those from the Želovce-cemetery graves nos. 167, 335, 442, 818) have a cross- or star-shaped crossguard, formed by two arms and two langets in the middle. The function of the langets was to fit the crossguard tightly to both the wooden grip and the scabbard's throat, thus protecting the blade from atmospheric factors and preventing accidental unsheathing when riding a horse.

Although the morphological features compose the main basis of classification, technological investigations play an increasingly important role in grouping the artefacts. Therefore, Csiky also drew attention to the metallographic results of Avar weapons (roughly 30 items in total).[1] He discussed the metallographic examinations of Avar sabres and single-edged

[1] The examined weapons are: one sabre from Hoilare (grave No. 102), one sword from Hohenberg, two sabres (grave nos. B-23 and D-338) and one single-edged sword (grave No. D-3) from Zillingtal, one sword

swords published by *R. Pleiner* (*1967*, 90), *J. Piaskowski* (*1974*), Ľ. Mihok (*Mihok et al. 1991*; *Mihok – Pribulová – Mačala 1995*), and *M. Mehofer* (*2006*), who examined finds from Holiare (Slovakia), Környe[2] (Hungary), Želovce and Košice-Šebastovce (both in Slovakia), Zillingtal and Gnadendorf (both in Austria), respectively.

3. The archaeological background of the Želovce blades

The archaeological site of Želovce (excavated between 1963 and 1968 under the direction of *Z. Čilinská 1973*) was situated on the Slavic-Avar border, and today lies roughly 2.5 km northeast of the village of Želovce (Veľký Krtíš district, south Slovakia). It was a large burial ground (with 870 graves) and represents one of the most important Slovak sites of the 7th and 8th centuries. It consisted of two parts (as a structural analysis revealed) most likely belonging to two individual settlements (*Čilinská – Wolska 1979*, 154). A total of 628 graves were excavated in the first (earlier) part of the burial ground; burials were made there from the 630s. In the second (later) part of the burial ground, 242 graves were excavated, and it was in use from the second half of the 7th century. The latest burials at the Želovce site date to the second half of the 8th century (*Čilinská 1992*, 30–36). The Želovce burial ground features an unusually high number of weapons (17 sabres, one 'Carolingian' sword, one single-edged sword-palash, and one seax), which is unmatched by other contemporary burial grounds in the Carpathian Basin.

4. Weapons from Želovce examined metallographically

Radomír Pleiner examined the following long-blade weapons: sabres from grave nos. 27, 30 and 44, and a 'Carolingian' sword (undoubtedly from grave no. 124).

The metallography of the sabres was preliminarily published (*Pleiner 1979*; *1989*). Here, all the details gathered from Pleiners report (*Pleiner 1975*) are finally presented.

1) Sabre from grave 27 (specimen no. 301; *fig. 2*)

The presence of welding seams indicates that the blade was welded from three strips. One side was more carburised than the other. Before welding, the strips were somewhat homogenised by extensive forging at rather low temperatures. Even the most carburised places barely reach the quality of medium-hard steel, hence the material was not suitable for quenching, which was not applied. This weapon is of mediocre quality.

Metallographic description:

Two samples ('A' and 'B') were collected for metallography from the middle part of the blade. Part of sample 'B' was also used for chemical analysis.

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from Dabas/Gyón-Paphegy, one from Csolnok, three swords (grave nos. 78, 97, 149) 2 other swords (as stray finds) and 2 spearheads (grave no. 129 and stray find) from Környe, 3 spearheads (grave nos. 221, 238, 321) and one sabre from Košice-Šebastovce, eight edged weapons (grave Nos. 78, 124, 126, 235, 311, 335, 442, 818) from Želovce, and other spearheads and swords from Budakalász and Szegvár-Oromdűlő (*Csiky 2015*, 293–294: nos. 7–11).

[2] However, the Környe burial belongs to the Early Avar period and thus does not chronologically correspond to the Želovce cemetery.

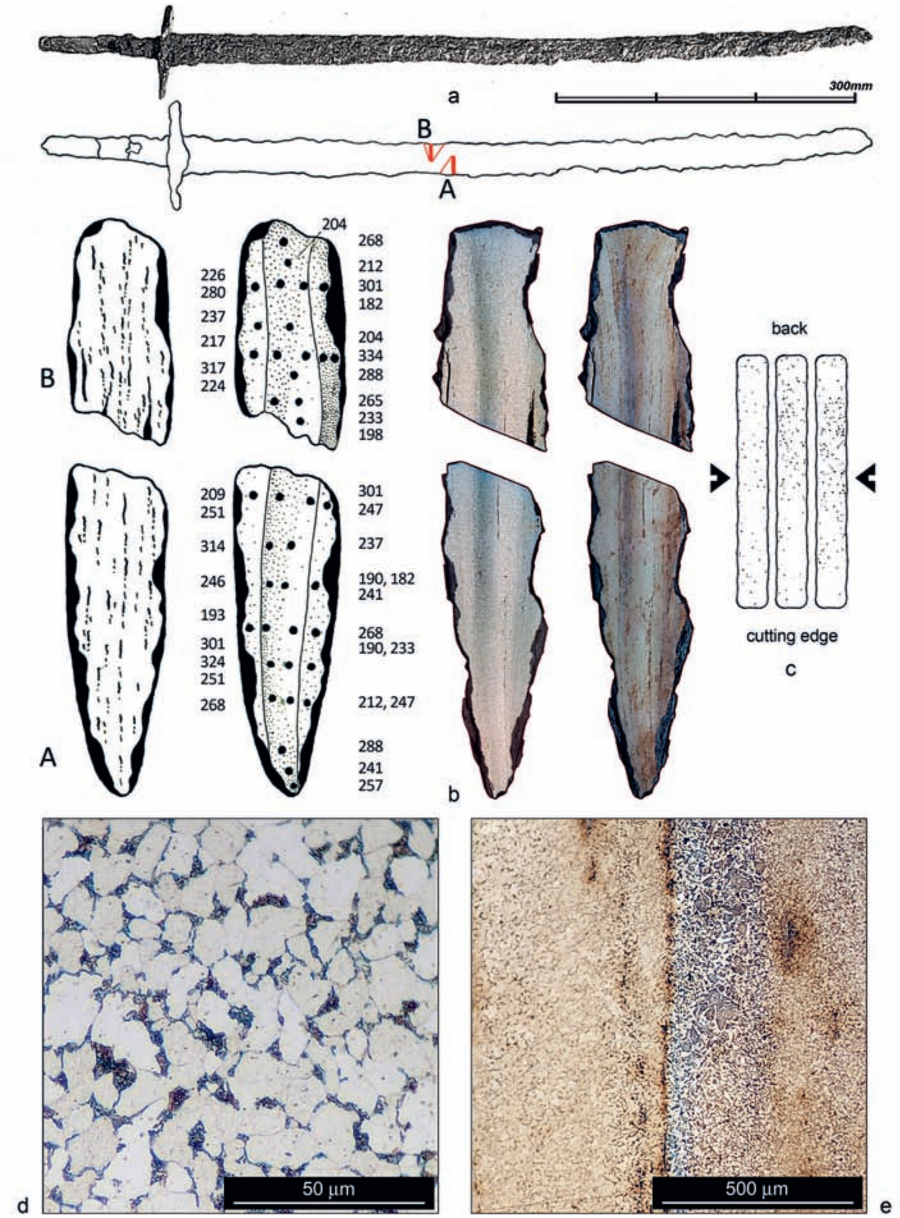

Fig. 2. Sabre, Želovce (Slovakia), grave 27: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of assembling individual rods to make the blade (edge to back layering); d – ferritic-pearlitic structure of the cutting edge (specimen A); e – one of the welding lines observed (specimen A). Etched with Nital (c) and Oberhoffer (d). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–e).
Obr. 2. Šavle, Želovce, hrob 27: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (vrstvení od břitu ke hřbetu); d – feriticko-perlitická struktura v břitu (vzorek A); e – jedna ze svarových linií (vzorek A); leptáno nitalem (d) a Oberhofferovým roztokem (e).

The surface layers of the metallographic samples are corroded. In sample 'B', the slag inclusions are chained in roughly three bands running lengthwise from the edge towards the back. Considering their number, corresponding to level 3–2 on the Jernkontoret scale, the metal is of mediocre purity. Sample 'A' also contains slag inclusions chained into several bands, but inclusions individually scattered throughout the sample prevail. The number of inclusions corresponds to levels 3 and 4 on the Jernkontoret scale.

Macroscopic etching with Oberhoffer's and Heyn's reagents revealed that the blade profile consists of several strips. In sample 'B' a strip (separated from one side by the weld) of fine-grained (ASTM 12) ferritic-pearlitic spheroidised structure runs through the centre of the sample. This structure slowly changes into ferrite (ASTM 11–12) with traces of pearlite and is separated by a weld from another strip of ferritic-pearlitic structure with a grain size of ASTM 12. Specimen 'A' shows a striped microstructure similar to that of specimen 'B', i.e. a continuity of the strips and two distinct welds. A strip of ferritic structure with traces of pearlite (grain size ASTM 11–12) is observed on the left side of the sample. This structure is beyond a weld changed into a fine-grained ferritic-pearlitic structure. Pearlite with a ferritic network and needles appears in places. This structure slowly changes into ferrite with traces of pearlite and tertiary cementite on the boundaries of grains of ASTM 8–9 size. This structure is separated by a weld from a strip of ferritic and ferritic-pearlitic structure. The blade has a very fine ferritic-pearlitic structure – globules of cementite can be seen within ferritic grains.

2) Sabre from grave 30 (specimen no. 302; *fig. 3*)

The blade was forge-welded from two, or (more likely) from three strips of material, of which each (mainly the central one) was unilaterally strongly carburised in advance. A significant diffusion of carbon to the adjacent ferritic areas occurred in the course of subsequent forging. The cutting edge was slightly hardened, perhaps by cooling it down in a stream of cold air or in warm oil, etc.

Metallographic description:

A specimen for both metallographic and chemical analysis was cut off crosswise from the middle part of the blade. The sample is covered by a thin corrosion layer. Non-metallic inclusions are chained in several bands running lengthwise from the edge towards the back. The number of inclusions corresponds on average to levels 2 and 3 on the Jernkontoret scale.

Etching revealed a highly heterogeneous structure. There is a narrow strip of ferrite with traces of pearlite at the back of the blade. The cutting edge shows a fine-grained sorbitic structure, which, towards the centre of the blade, changes in places to pearlite with a ferritic network, and further into a strip located in the lengthwise axis of the sample with a structure of ferrite with some pearlite (grain size corresponds to ASTM 9–10). At the right side of the sample there is a fine-grained ferritic-pearlitic structure that changes into ferrite (of ASTM–8 grain size) with traces of pearlite.

3) Sabre from grave 44 (specimen no. 396; *fig. 4*)

The blade was made of soft carbon steel. Considering the distribution of slag inclusions, it is likely that the billet was welded from at least two strips of such steel, of which one contained irregularly distributed zones richer in carbon. The cutting edge remained relatively soft and was not (and could not be) quench hardened; on the contrary, it seems that intensive final forging took place at rather low temperatures. The blade was a simple product.

Metallographic description:

Two samples ('A' and 'B') were collected for metallography from both the cutting edge and back of the blade. Part of sample B was also used for chemical analysis.

The surface layers of the metallographic samples are corroded, and the cracks filled with corrosion products are in places propagating into the metallic core. Slag inclusions are chained into several lines running lengthwise from the edge towards the back. In addition, numerous individually scattered inclusions occur in the whole sample. The total number of inclusions corresponds to levels 4 and 5 on the Jernkontoret scale, i.e. it is metal of very low purity.

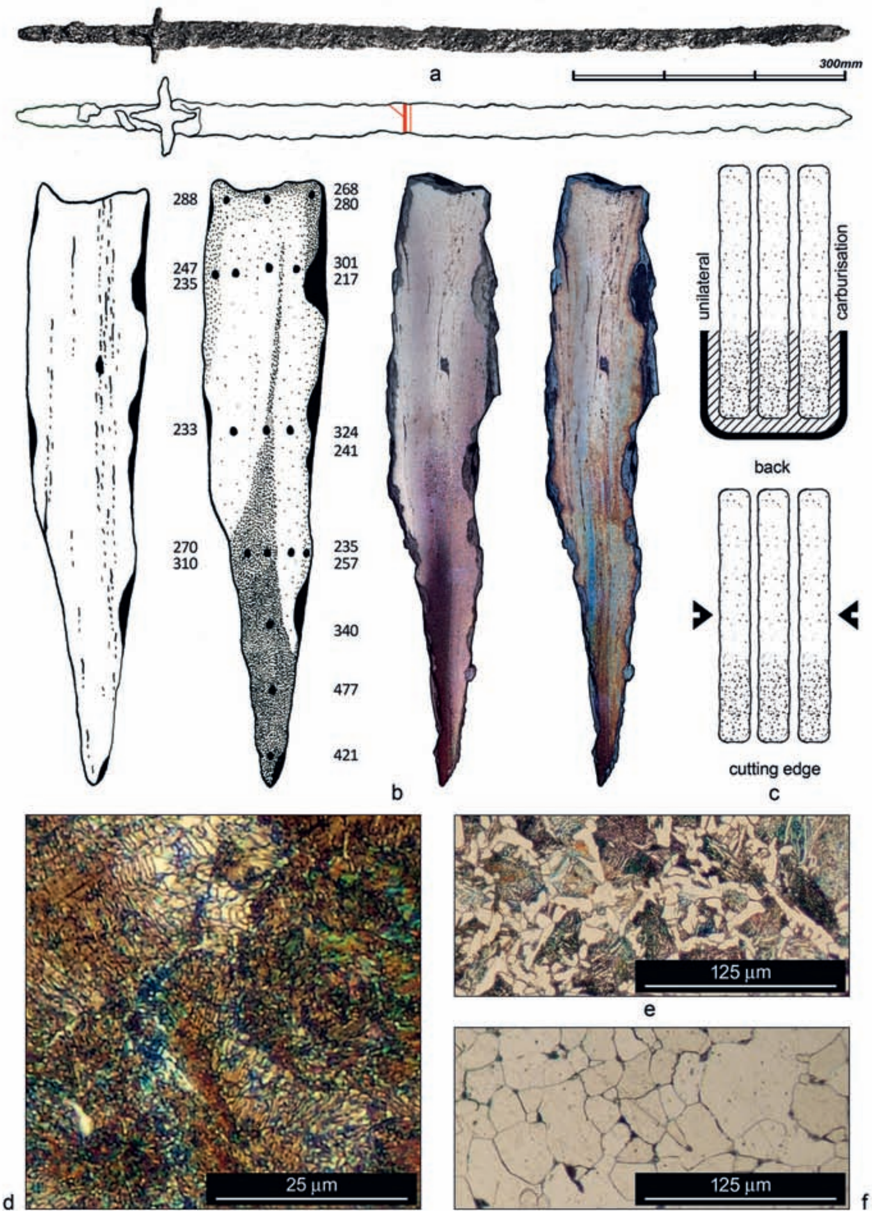

Fig. 3. Sabre, Želovce (Slovakia), grave 30: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of preparing and assembling individual rods to make the blade (unilateral carburisation followed by edge to back layering); d – pearlite in the cutting edge; e – pearlitic-ferritic structure in the middle portion of the sample; f – ferritic structure in the back of the blade. Etched with Nital (c–e). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–f).

Obr. 3. Šavle, Želovce, hrob 30: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (nerovnoměrné nauhličení polotovarů vrstvených od břitu ke hřbetu); d – perlitická struktura v břitu; e – perliticko-feritická struktura ve střední části vzorku; f – feritická struktura ve hřbetu čepele; leptáno nitalem (d–f).

Half of the sample 'B' has ferritic structure with traces of pearlite; the grain size corresponds to the ASTM 8–10. A narrow strip of ferritic-pearlitic structure is on the right side of the sample. The left side of the sample shows a very fine-grained (ASTM 10–11) ferritic-pearlitic structure that includes zones of pearlite with ferritic network and needles. A pearlitic structure appears on one side at the back of the sample. A predominant part of sample 'A' contains a ferritic structure (of ASTM 9–1 grain size) permeated entirely by spheroidised cementite. The middle portion of the blade shows an oblique strip of pearlite structure with ferritic network and needles, which gradually changes over to the structure of ferrite and pearlite (traces of pearlite in places). The cutting edge contains ferrite with a small amount of pearlite.

While the metallography of the sabres was published at least in a fragmentary manner, an examination of the 'Carolingian' sword (undoubtedly from grave no. 124) was never published. One of the possible explanations is that Pleiner lacked information he needed for the proper description and identification of the weapon.[3] His original interpretation of the sword production describes a blade made of a single piece of iron subjected to secondary carburisation (either the edges of the iron semi-product were carburised prior to the final forming to the shape of the blade, or the cutting-edge(s) of the nearly finished blade were carburised). However, this interpretation appeared slightly inaccurate when the sample was checked. Therefore, a re-assessment and re-examination recently conducted by the authors is presented here.

4) 'Carolingian' sword (grave 124; specimen no. 299; *fig. 5*)

The blade consists of steel cutting edges welded onto a middle portion consisting of surface panels and a core of iron. The overall character of the revealed part of the surface panel corresponds to a layered-and-twisted composite, which, however, cannot be considered a standard pattern-welded composite. The reason lies in the very low differences in the local contents of phosphorus. The blade was not quench hardened (at least not in the whole volume) in the place of sampling. The very low visibility of the welding lines, along with the extensive carbon diffusion beyond the welds, indicate that during the forging cycles the blade was exposed to high temperatures for a long time. The find seems to be a failed attempt to produce a more glamorous pattern-welded weapon.

Metallographic description:

Two samples were cut out roughly halfway down the blade, each from one side. While one sample had a well-preserved metallic core, the other was entirely corroded.

Metal purity varies considerably in both the central and cutting-edge portions of the blade (from level 2 to level 5 on the Jernkontoret scale).

When etched with Nital, the metallographic structure revealed three basic areas. Area I shows a pearlitic structure with a hardness of 220±27 HV0.2 (maximum hardness was 251 HV0.2 on the cutting edge, decreasing to HV0.2 towards the central portion). Area II is a mixture of pearlite and ferrite; the carbon content gradually decreases from circa 0.7 to 0.25 percent towards the central portion of the blade; the hardness reaches 133±8 HV0.2. Ferrite is present in the form of polyhedral grains network as well as lamellas penetrating the pearlitic grains. Area III is ferrite with some pearlite in places (max. c. 0.2% C). Hardness is 116±19 HV0.2, grain size c. ASTM 7–8.

Etching with Oberhoffer's reagent gradually revealed traces of welding lines separating the cutting edge (A), the core (B) and one surface panel (C). Sharply bounded areas appeared (C*) within this panel (C). Their hardness (133±6 HV0.2) is somewhat higher than the hardness (121±7 HV0.2) and apparently also the phosphorus content of the surrounding matrix.

[3] The metallographic report lacks the number of the grave in which the sword was found, and there is no description, photograph or drawing of the weapon itself.

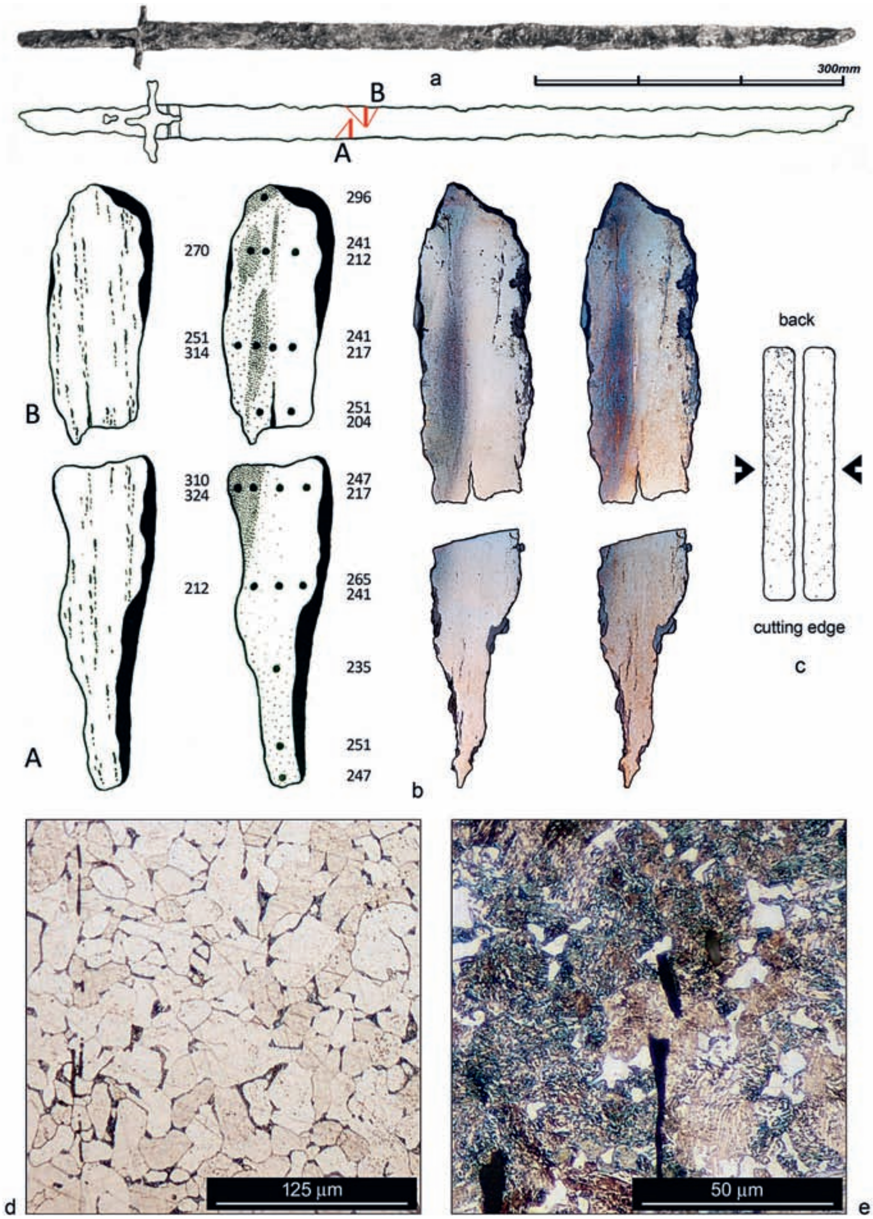

Fig. 4. Sabre, Želovce (Slovakia), grave 44: a – the examined weapon; b – schematic drawings and photos of the samples (from the left: unetched state; distribution of the microstructures and of the main welds across the sample with values of hardness (HV0.03); after etching with Nital; after etching with Oberhoffer's reagent); c – the expected method of assembling individual rods together to make the blade (edge to back layering); d – ferritic structure with traces of pearlite in the cutting edge (sample A); e – pearlitic-ferritic structure in the back (sample B). Etched with Nital (c, d). Photo and drawings by R. Pleiner (a, b) and J. Hošek (b–e).
Obr. 4. Šavle, Želovce, hrob 44: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku (zleva: neleptaný stav, rozložení strukturních oblastí a vyznačení hlavních svarů s údaji o naměřené tvrdosti (HV0,03), po naleptání nitalem, po naleptání Oberhofferovým roztokem); c – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele (vrstvení od břitu ke hřbetu); d – feritická struktura se stopami perlitu v břitu (vzorek A); e – perliticko-feritická struktura v hřbetu čepele (vzorek B); leptáno nitalem (d, e).

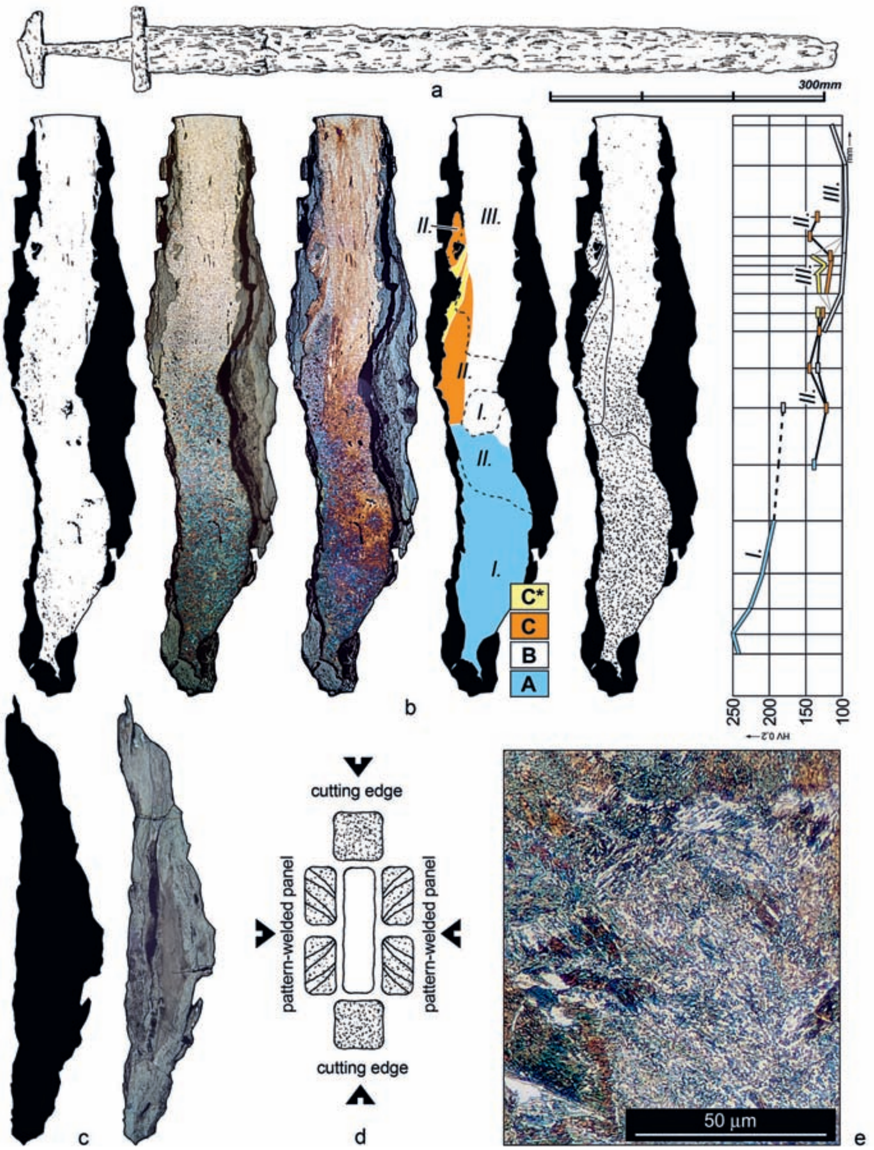

Fig. 5. Sword, Želovce (Slovakia), grave 124: a – the examined weapon; b – schematic drawings and photos of the blade samples (from the left: unetched state; after etching with Nital; after etching with Oberhoffer's reagent; layout of areas described; distribution of the microstructures and of the main welds across the sample; hardness distribution chart); c – the other sample, which was entirely corroded; d – the expected method of assembling individual rods to make the blade, if double-edged (cutting-edge welding onto a middle portion with pattern-welded surface panels); e – pearlitic structure in the Area I (etched with Nital). Photo and drawings after *Z. Čilinská* (*1973*, 199, Taf. XXII: 16) (a) and by J. Hošek (b–e).
Obr. 5. Meč, Želovce, hrob 124: a – analyzovaná zbraň; b – schematické nákresy a fotografie vzorku čepele (zleva: neleptaný stav, po naleptání nitalem, po naleptání Oberhofferovým roztokem, rozložení popisovaných strukturních oblastí, vyznačení hlavních svarů a zachycených strukturních oblastí, graf průběhu tvrdosti); c – druhý odebraný vzorek, který byl zcela prokorodován; d – předpokládaný způsob sestavení jednotlivých prutů při výrobě čepele, je-li dvoubřitá (břity navařeny na střední část nesoucí povrchové damaskové panely); e – perlitická struktura v oblasti I (leptáno nitalem). Foto a kresby podle *Z. Čilinské* (*1973*, 199, Taf. XXII: 16) (a) a J. Hoška (b–e).

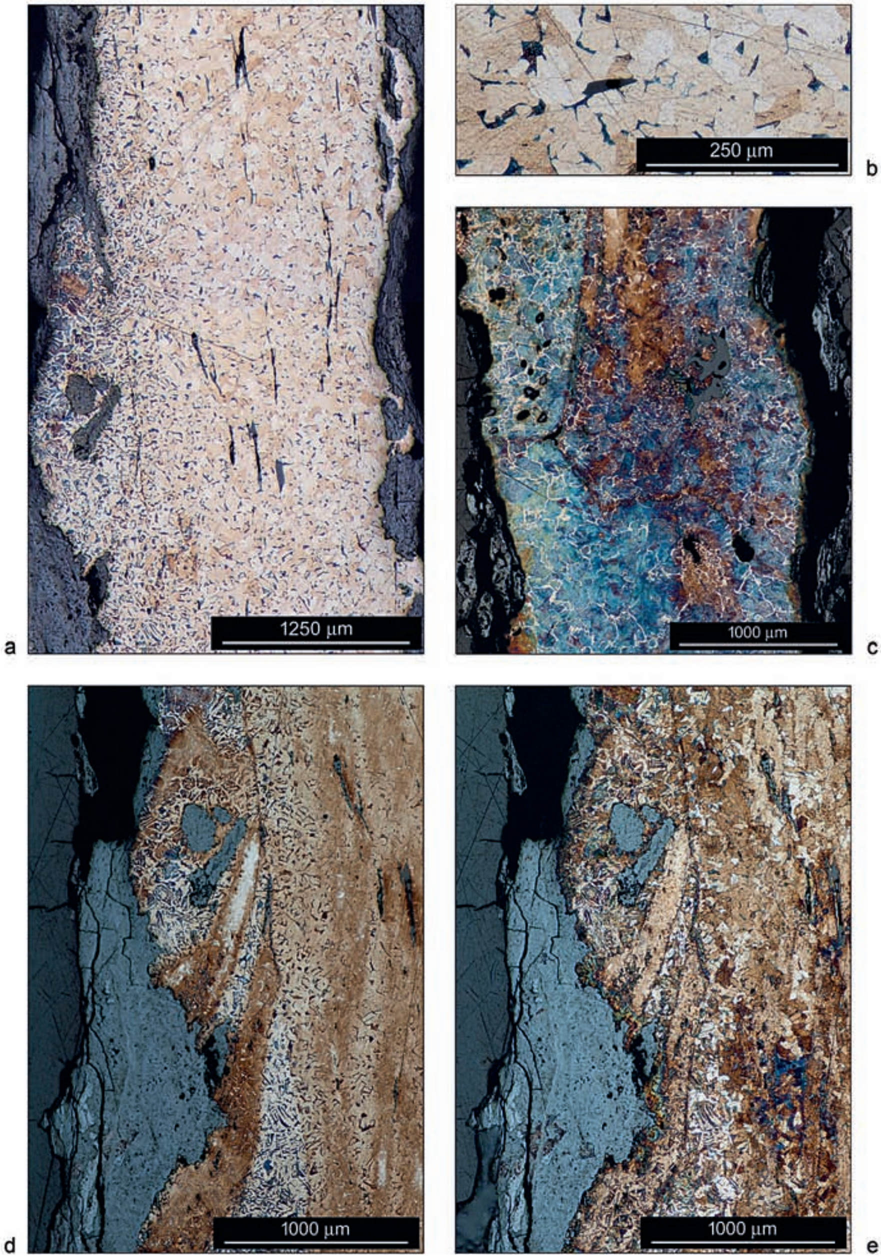

Fig. 6. Sword, Želovce (Slovakia), grave 124: a – macrophotograph of the changeover between the Areas II and III; b – ferrite with some pearlite in Area III; c – slightly visible welds in the place where the cutting edge, the core and the surface panel were attached to each other (when slightly etched); d – the surface panel (when slightly etched); e – well visible Areas (C*) within the surface panel (after strong etching). Etched with Nital (a, b) and Oberhoffer (c–e). Photo by J. Hošek.

Obr. 6. Meč, Želovce (Slovensko), hrob 124: a – celkový pohled na přechod oblasti II do oblasti III; b – ferit s trochou perlitu, oblast III; c – slabě viditelné svary v místě napojení břitu, jádra a povrchového panelu (při slabém naleptání); d – povrchový panel (při slabém naleptání); e – dobře viditelné oblasti (C*) v povrchovém panelu (po silném naleptání); leptáno nitalem (a, b) a Oberhofferovým roztokem (c–e).

The archive of metallographic specimens also contains sample nos. 684–687, which were detached from the Želovce weapons, but we do not know from which weapons in particular these samples were taken. Although R. Pleiner and his assistant Mrs. B. Novotná started with the metallographic examinations, they never completed them. The folders with semi-finished metallographic reports (each of which is labelled only as 'sword – Želovce') also contained a letter from Ľ. Mihok. The letter (now preserved in fragments)[4] explains that Ľ. Mihok sent photographs of metallographic specimens to R. Pleiner in 1990, which he himself examined and also published a year later (see *Mihok et al. 1991*). Therefore, we can only assume that the samples, which R. Pleiner had at his disposal, were provided by Ľ. Mihok. In that case, the samples should come from sabre nos. 78, 335, 442 and 818. Because these samples are of low importance for the research of the production techniques of Avar sabres, their description is not included.

Ľ. Mihok and his colleagues also examined several weapons from the Želovce cemetery (*Mihok et al. 1991*): four sabres (from grave nos. 78, 335, 442 and 818), one single-edged sword-palash (from grave no. 167), one seax (grave no. 311), one 'Carolingian' sword (grave no. 124), and one dagger (no. 235). The obtained results (except for the 'Carolingian' sword) are summarised in *fig. 7*. The blades of sabre nos. 78, 335, 442, 818 and the blade of dagger no. 235 were made by edge-to-back layering. Blade 818 is a steel-iron-steel sandwich, while blades 335 and 442 are a steel-and-iron sandwich. The blade of sabre no. 78 was welded from two plates of steel, and it seems that the cutting edge was also subjected to secondary carburisation. Sword-palash no. 167 was most likely made of a single piece of heterogeneous iron. Mihok himself believed that the palash has a side-to-side banded blade, but he did not provide any acceptable evidence for this hypothesis. The same situation concerns seax no. 311, the blade of which consists of heterogeneous iron and which is described as a side-to-side banded item. Sword no. 124 has, according to Ľ. Mihok, a single-edged blade made from an iron back and welded-on cutting edge of steel. No traces of quenching were detected in the examined weapons.

Another sabre examined metallographically by Ľ. Mihok and his colleagues (*Mihok – Pribulová – Mačala 1995*) came from the 7th–8th century Slavic-Avar cemetery of Košice-Šebastovce (Slovakia). The sabre is presumably the one from grave no. 161 dating to the first half of the 7th century (for more details see *Krivák 2017*, 69). According to Mihok, the blade of this weapon was made as a sandwich (a variant of the edge-to-back layering) consisting of a mildly carburised central plate to which a somewhat less carburised plate was laterally welded from each side. In addition, it seems that the cutting edge of the blade was secondarily carburised (but no more than 0.3% of carbon was observed). Two samples were taken from the blade crosswise, one near the hilt, the other near the point, but none shows traces of quenching.

R. Pleiner (*1967*, 90, 120) published a metallographic examination of the sabre coming from the 7th–8th century cemetery of Holiare (Slovakia). The weapon was found in grave no. 484, dated to the 7th century. The blade has a welded-in cutting edge of nearly eutectoid steel, and the back is iron. The blade was quenched and tempered (or slack-quenched).[5]

[4] The archive, including the metallographic reports in question, was heavily damaged by flood in 2002.

[5] However, it is not clear from which part of the blade the sample for metallography was detached.

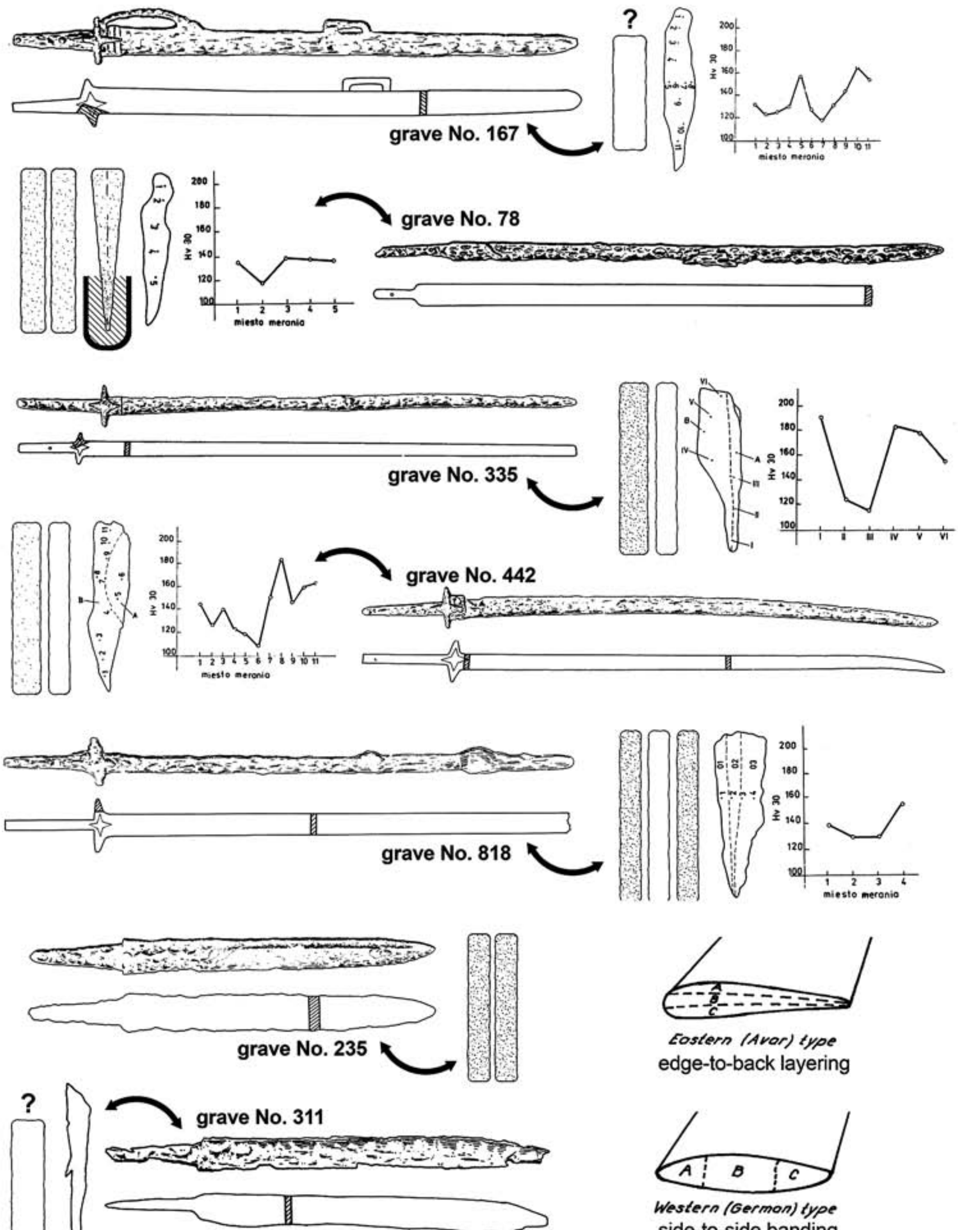

Fig. 7. Single-edged weapons from Želovce (Slovakia) examined metallographically by Ľ. Mihok: Sabres from grave nos. 167, 78, 335, 442 and 818, dagger from grave no. 335, and seax from grave no. 311. Drawings (not in scale) after *Ľ. Mihok et al.* (*1991*), adapted and amended by J. Hošek.
Obr. 7. Jednosečné zbraně z Želovců (Slovensko) prozkoumané metalograficky Ľ. Mihokem: Šavle z hrobů 167, 78, 335, 442 a 818, dýka z hrobu č. 335 a sax z hrobu č. 311. Nákresy (v různém měřítku) podle Ľ. Mihoka (*Mihok et al. 1991*), upravené a doplněné J. Hoškem.

Three single-edged long-blade weapons dating from the 7th to 8th century were also examined by *M. Mehofer* (*2006*); all three pieces (two sabres and one single-edge sword) come from the Avar burial ground of Zillingtal (Austria). Possible manufacturing techniques used to produce the weapons are described as follows (*Mehofer 2006*). The 8th century sabre from grave B 23 was made from a single piece of iron (with some steel in places), and no traces of hardening were observed (samples were taken half-way down the blade). The sabre from grave D 338, dating to the second half of the 7th century, was apparently made from a single piece of metal irregularly varying between iron and steel. While samples taken half-way down the blade show no traces of hardening, samples taken close to the point indicate rapid cooling or even quenching (although the carbon content was insufficient for the formation of typical quenched microstructures). The blade of the single-edged sword from grave D 3, dating to the second quarter of the 7th century, was made of at least two lamellas, as suggested by a corroded weld running from the back downwards. The carbon content of the blade is presumably low and its distribution uneven.

Certain comparisons can also be made with 7th to 9th-century sabres from Volga-Bulgarian cemeteries, which were examined and recently published by *Yu. Semykin* (*2015*). Two sabres come from the Novinkovskij kurgan burial ground /Новинковский курганный могильник/ (Russia) dating from the late 7th to the mid-8th century. The blade of the first one (no. 45) was made of heterogeneous material, mostly iron, but in places also steel. The other (no. 29) was presumably made of a similar material, but it seems that cutting edges were also secondarily carburized and subjected to quenching. While samples from sabre no. 29 were taken approximately half-way down the blade, the sample from sabre no. 45 was taken close to the hilt and just from the cutting edge. One sabre (no. 35) comes from Boľshe-Tiganskij I burial ground /Больше-Тиганский I грунтовый могильник/ (Russia) dating from the mid-8th to the mid-9th century. The blade of this weapon was forged from a piled billet (combining iron and steel). The sample was taken approximately half-way down the blade and just from the cutting edge. Five sabres come from the Boľshe-Tiganskij burial ground /Больше-Тиганский грунтовый могильник/ (Russia) dating from the mid-8th to the 9th century. The blade of sabre No. 21 was presumably made from a layer of steel welded to one side on a piece of iron (*Semykin 2015*, 139).[6] A sample for metallography was taken from a cutting edge in the upper part of the blade (closer to the hilt), and no traces of quenching were detected. The four other sabres (nos. 22 to 25) were made of steel with visible welding lines running from cutting-edge to back. Sabre nos. 22, 23 and 24 were sampled near the point, the hilt, and half-way down the blade, respectively. All three blades were subjected to quenching limited to the cutting edges. Three samples detached from blade no. 25 indicate that the blade was quenched along the entire length and in the whole volume. One sabre (no. 1), dating from the mid-8th to the mid-9th century, comes from the 'burial ground at the 116th kilometre' /могильник у 116 километра/ (Russia). The blade shows a layer of quench-hardened steel welded to one side of a piece of heterogeneous material varying between iron and steel. The sample for metallography was taken from a cutting edge in the upper part of the blade (closer to the hilt).

[6] The same sabre is also described in the monograph as a piece made of a rather heterogeneous material, mostly iron with some steel in places (e.g. *Semykin 2015*, 56).

Considering the small number of the 7th–8th century sabres metallographically examined, it seems pointless to strive for a detailed comparison of the sabres from Želovce with those from other contemporary sites. We can just conclude that they did not differ significantly in any technological aspect. However, we can clarify the current knowledge of the techniques used in the manufacture of sabres. Their blades were in general forged from billets prepared by edge-to-back layering;[7] some of them consist entirely of steel, others entirely of iron or heterogeneous material varying between iron and steel. Various forms of sandwiching or cutting-edge welding-in seem to be a standard for making blades, deliberately combining iron and steel. Perhaps carburising cutting edges could also be practiced (as suggested by some of the examinations). No blades with cutting-edges of steel welded onto an iron back (corresponding to side-to-side banding) were encountered. No pattern-welding appears on sabres. In fact, the constructions of the sabre-blades correspond well to the constructions used in manufacturing knives in the given cultures (see e.g. *Semykin 2015*, 110; *Mihok – Pribulová – Mačala 1995*). The blades of 7th–8th century sabres were seldom quench-hardened in their whole volume (i.e. across the whole cross section and along their whole length).

Comparing the 'Carolingian' sword from Želovce (grave 124) with other contemporary swords is rather difficult. First, it is not clear whether the blade is single- or double-edged. *Čilinská* (*1973,* 57) described the sword as a single-edged sword, and Mihok was convinced that the results of his examination confirmed this (*Mihok – Pribulová – Mačala 1995*; *Mihok – Holý – Čilinská 1993*). However, in 1975 the weapon was already heavily corroded and 'preserved in poor condition'. Pleiner cut out two samples from the blade, one from each side, but only one sample contained a metallic core (see *fig. 6*). In addition, newly obtained metallographic results suggest instead that it was a double-edged pattern-welded blade (or rather an attempt to produce a pattern-welded blade). If so, the sword would be a common 7th–8th century 'spatha' in terms of the construction used, but an unusually poor piece in terms of the low quality of the pattern-welded composites.

5. Conclusion

The sabres from Želovce, examined in 1975 by Radomír Pleiner, show features similar to those of other contemporary sabres in terms of the manufacturing techniques employed. Deliberate combinations of iron and steel, encountered in 7th to 9th century sabre-blades, were typically based on edge-to-back layering, and most of the examined blades show no traces of quenching. The 'Carolingian' sword from Želovce (grave 124) has a welded and most likely double-edged blade deliberately combining iron and steel. The cutting edges were welded-on and the middle portion was provided with surface panels of layered and apparently twisted material resembling pattern-welded composites. If the sword is indeed a 'pattern-welded' specimen, like the majority of the 7th–8th century swords, the pattern-welding was virtually invisible.

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[7] Ľ. Mihok even considered edge-to-back layering of blades an eastern-type technique. In contrast, he believed that side-to-side banding was a western type technique (*Mihok – Holý – Čilinská 1993*).

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