PÁZMÁNY PÉTER CATHOLIC UNIVERSITY

FACULTY OF HUMANITIES AND SOCIAL SCIENCES

DOCTORAL SCHOOL OF HISTORY

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TÓTH BOGLÁRKA

THE TECHNICAL BACKGROUND OF THE PRODUCTION OF TENTH-CENTURY DOUBLE-EDGED SWORD BLADES FROM THE CARPATHIAN BASIN (ARCHAEOMETRIC AND ARCHAEOMETALLURGICAL INVESTIGATIONS)

DOCTORAL (PHD) DISSERTATION

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SUPERVISORS: DR. PÉTER LANGÓ, DR. BÉLA TÖRÖK

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INTRODUCTION

One of the most interesting and, in recent years, most intensively researched groups within the archaeological material of the Hungarian Conquest period is represented by the so-called tenth-century Western-type double-edged swords. These weapons are prominent examples of early medieval European weaponry, which functioned not only as combat implements but also carried significant symbolic value. Their possession and display were important means of expressing social status, the representation of power, and cultural connections.

As a result of several decades of research in Hungary and internationally, a detailed picture can now be formed of the distribution, chronology, and social significance of these weapons. Hungarian research has been dominated primarily by typological, chronological, and archaeological approaches, while international scholarship has increasingly focused, alongside the examination of the weapons' external attributes, on their historical and cultural context. In recent decades, however, scholarly attention has increasingly turned towards the technological aspects of sword production. Technological analyses provide insight not only into the methods by which individual swords were produced, but also into the level of knowledge possessed by contemporary smiths, their technological connections, and the processes employed in sword manufacture.

The study of tenth-century double-edged swords from Hungary gained new impetus within a large-scale interdisciplinary project launched in

2020. The aim of the programme was the comprehensive study of double-edged swords recovered from the Carpathian Basin, based on two main pillars: firstly, the archaeological analysis of the weapons, and secondly, archaeometric and archaeometallurgical research employing scientific methods. The present dissertation is connected to the latter line of research. Although this weapon type has long been a focus of interest among Hungarian archaeologists, its interdisciplinary study had remained incomplete. The aforementioned project was established to address this gap, bringing together archaeologists and doctoral students from Pázmány Péter Catholic University and researchers from the Archaeometallurgical Research Group of the University of Miskolc.

The research focused on the examination of the material structure of tenth-century double-edged sword blades, the identification of different manufacturing characteristics, and the experimental reconstruction of certain forging techniques. Combining metallographic analysis with experimental forging made it possible to investigate the manufacturing processes of this weapon type in greater detail and to interpret the finds from the Carpathian Basin within a broader European technological context.

The aim of the dissertation was, on the one hand, to determine in detail the manufacturing characteristics of the examined sword blades and, on the other, to develop a technical classification suitable for facilitating the technological comparison and interpretation of the weapons. The central question of the research was the extent to which

the examined specimens display similarities and differences in the application of forging techniques, and to what extent the methodology of archaeometry and archaeometallurgy makes it possible to interpret tenth-century double-edged swords from the Carpathian Basin from a technological perspective.

The research can be regarded as fundamental research, as there had previously been few comparable comprehensive scientific investigation programmes in Hungary concerning this type of archaeological material. The application of metallography made it possible to investigate the raw materials used, forging techniques, and heat-treatment procedures, while experimental forging enabled the practical verification and interpretation of the laboratory results. At the same time, the research did not attempt to provide a comprehensive archaeological analysis of the weapons: it focused specifically on the blades, while the detailed examination of the guards, hilt fittings, and their decoration did not form part of the dissertation.

The aim of the dissertation, therefore, was not solely to present new data, but also to demonstrate how different scientific and archaeological methods, when combined, can contribute to revealing the manufacturing and material-structural characteristics of tenth-century double-edged sword blades. The results obtained also provide an opportunity to place the sword material from the Carpathian Basin within broader European technological traditions, as well as to

establish a technical classification that may serve as a basis for future comparative studies of similar weapon finds.

THE EXAMINED SWORDS AND THE RESEARCH METHODOLOGY

A total of 23 swords and sword fragments were examined within the framework of the research. Of the examined objects, 7 are stored in the Jósa András Museum in Nyíregyháza, 5 in the King Saint Stephen Museum in Székesfehérvár, 4 in the Móra Ferenc Museum in Szeged, 2 in the Migration Period Collection of the Aquincum Museum, and one each in the Hungarian National Museum, the Laczkó Dezső Museum in Veszprém, the Rippl-Rónai Museum in Kaposvár, the Dobó István Castle Museum in Eger, and the Janus Pannonius Museum in Pécs.

Certain sword fragments are not presented separately in the dissertation, as the fragments were unsuitable for metallographic examination. The sword recovered from Grave 1 at Szeged, Csongrádi út, is likewise not presented, as no suitable area for examination could be found in the poorly preserved and heavily corroded blade. Therefore, only a piece was cut from the tang of the sword; however, no conclusions relevant to the research could be drawn from its examination. Thus, successful metallographic examinations were carried out on a total of twenty swords.

The blades included in the research underwent archaeometric and archaeometallurgical examinations, one of which was metallographic

examination. Since this is a destructive examination method, one or more samples had to be cut from the sword for this purpose. Photographic documentation of the objects was made before and after cutting. The samples were examined by members of the Archaeometallurgical Research Group (ARGUM) at the University of Miskolc.

Sampling was carried out with a high-speed multifunctional tool with the utmost care. The sampling locations varied: if a blade was already broken, for example, the sample was cut from one of the broken edges. In every case, however, the location of the cut was agreed upon in advance with the museum holding the object. Particular attention was paid throughout the process to ensuring that the artefact could be restored as easily as possible after sampling.

Following sampling, the samples were embedded in cold-curing resin and then ground and polished in several stages. The properly prepared surface was etched with a nital solution, making it possible to examine the microstructure. The prepared samples were then examined using optical microscopy and electron microscopy, the latter supplemented by analysis with an energy-dispersive microprobe. The examination process was completed with microhardness measurements. The results of the microscopic examinations were evaluated according to a predefined set of criteria. The evaluation was based on the microstructural characteristics observed in the samples, from which conclusions could be drawn concerning the techniques used in forging

the blades. The examination results were presented in the form of case studies. The criteria of evaluation were as follows:

1. Most common forging techniques

Based on the microscopic examinations, folded, forge-welded, and homogeneous blades could be distinguished, as well as specimens in which several techniques were used in their production.

2. The structural composition of the blade – forged from one or more pieces

On the basis of microstructural transitions, diffusion zones, and differences in material properties, blades made from a single piece of material could be distinguished from those assembled from several separate elements.

3. Carbon distribution within the blade

The examination of carbon distribution made it possible to determine the different structural and functional zones of the blade, with particular regard to the formation of a higher-carbon edge and a lower-carbon core.

4. Heat treatment

On the basis of the microstructural phenomena, I examined whether deliberate heat treatment could be detected and whether signs of quenching-like cooling could be identified at the blade edge.

5. Inclusion analysis – morphology and chemical composition

The morphological and chemical examination of slag inclusions contributed to the characterisation of the raw material and manufacturing processes, as well as to the reconstruction of individual technological processes.

6. Theory and practice

I supplemented the metallographic observations with experimental forging, during which I examined the microstructural effects of folding and bulk forging and compared the results with the phenomena observed in the archaeological blades.

NEW SCIENTIFIC RESULTS AND THESES

Based on the metallographic examinations, the tenth-century double-edged sword blades examined display considerable variation in terms of their manufacturing techniques. Folding and forge welding played a decisive role in determining the properties of the blades, while deliberate heat treatment could only be identified in exceptional cases within the examined material. Folding was primarily associated with the formation of the blade core; at the same time, forge welding occurred not only in the course of folding but also as an independent structural technique, particularly in the production of blades composed of several pieces. Thus, different forging techniques also occur in combination within the examined sword material.

One of the important results of the examinations is that the presence of folding cannot be reliably established solely on the basis of banded phenomena appearing during etching. In identifying folding, the distribution of carbon, together with the possible arrangement and deformation of slag inclusions, may provide more reliable evidence. The results of the experimental forging also supported this approach. The microstructural phenomena observed during the reconstruction experiments could be compared with those observed in the archaeological blades, and the experimental results thus also served to verify the interpretation of the metallographic observations.

Based on the metallographic observations, a technical classification of tenth-century Hungarian double-edged sword blades could be developed. The system is based on the structural composition of the blades and the method of material preparation, distinguishing between blades forged from a single piece of material and constructions assembled from several elements by forge welding. The classification does not establish a chronological or morphological developmental model, but rather provides a technical framework that allows different manufacturing solutions to be interpreted comparatively. The examined material includes both carefully prepared, low-inclusion-content blades with more complex structures and simpler specimens with ferritic microstructures, indicating differences in the technical quality of sword production without allowing the functional value of the weapons to be ranked unequivocally.

Overall, the examinations demonstrate that the structural solutions of the examined Hungarian sword blades were not isolated local phenomena, but formed part of the broader technological tradition of early medieval European sword production. This is particularly supported by the predominance of soft-core–hard-edge constructions, the presence of Košta's blade-structure types I–IV, as well as the Central European parallels of the more complex structural solutions observed in the Kiskundorozsma and Eger swords. On this basis, the technological characteristics of the sword material from the Carpathian Basin can be interpreted within a broader European context.

The Theses of the Research

1. Metallographic analysis of the twenty tenth-century sword blades examined demonstrates that the properties of the blades were primarily achieved through structural solutions based on folding and forge welding, while deliberate heat treatment could be identified with greater certainty in only two cases. Folding could be identified in more than half of the swords, primarily in connection with the blade core; in technological terms, it invariably involves forge welding, since the material is elongated, folded back, and joined by forge welding. Forge welding, however, does not occur solely as part of folding, but also as an independent structural technique, particularly in the production of blades composed of several pieces.

2. The presence of folding cannot be reliably identified solely on the basis of etching bands (*white lines*); its detection is fundamentally possible through the determination or estimation of the carbon content characteristic of individual areas, together with the possible arrangement of inclusion chains. The experience gained from experimental forging demonstrated the necessity of this methodological approach, which reduces the risk of incorrectly identifying folding in archaeological sword material.

3. Based on the results of the metallographic examinations, a technical classification of tenth-century Hungarian double-edged sword blades could be developed. On the basis of their structural composition, two main groups can be distinguished: I. Main group – Blades forged from one piece and II. Main group – Sword blades forged from several pieces. Within the first main group, I/A: Bulk-forged blades and I/B: Folded blades can be distinguished, while within the second main group, II/A: The core of sword blades forged from several pieces and II/B: The edge of swords forged from several pieces can be distinguished. Within subgroup II/A, two further groups can be identified: II/A/1 – Swords with a bulk-forged blade core and II/A/2 – Swords with a folded blade core; within subgroup II/B, II/B/1 – Swords with a bulk-forged edge and II/B/2 – Swords with a folded edge can be distinguished. The results indicate that, from a technological perspective, the swords from the Carpathian Basin form part of the broader tradition of contemporary European sword production.

4. The structural solutions of the examined sword blades correspond to technical types widely distributed in early medieval Europe; at the same time, significant differences can be identified in the quality of manufacture and the purity of the raw material. The examined samples include both carefully prepared, low-inclusion-content, more complex constructions and simpler blades with ferritic microstructures.

5. The structural solutions of the examined Hungarian sword blades were not isolated local phenomena, but formed part of the broader technological tradition of early medieval European sword production. This is particularly supported by the predominance of soft-core–hard-edge constructions, the presence of Košta's blade-structure types I–IV, and the Central European parallels of the more complex structural solutions observed in the Kiskundorozsma and Eger swords.

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