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Iron Metallurgy and Working in the Ciuc Basin, from the Arpadian Period to the First Decades of the Eighteenth Century

PhD Thesis Abstract

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Abstract

Iron production has always served as a fundamental cornerstone of socio-economic development and military power. In the Ciuc Basin, this industry transformed a peripheral mountainous region into one of the key metallurgical centers of the Principality of Transylvania. Despite the civilizational significance of iron, Romanian historiography and specialized research have long suffered from fragmented data, ideological distortions, and the lack of a systematic synthesis. This research addresses a critical void by analyzing the long-term dynamics of iron processing in the Ciuc Basin from the Arpadian era to the beginning of the eighteenth century. However, the study also investigates earlier periods preceding this chronological framework, provided they left a significant imprint on iron metallurgy. By examining technological continuity, the socio-political factors of production, and the structural causes of industrial decline, we demonstrate how this vital material shaped the region's life until the late eighteenth century.

Utilizing an interdisciplinary framework, this study synthesizes the analysis of 375 archaeological artifacts with extensive archival research, methods from the natural sciences, and GIS-based digital elevation modeling (DEM). A key finding reveals an unexpectedly high volume of production during the Sântana de Mureș-Chernyakhov culture period (third to fourth centuries AD), which utilized "belt-type" direct reduction furnaces (bloomery type). This peak was followed by a significant hiatus in iron use. The study also presents the craft of medieval ironworking, both known and novel, delving into the history and environmental context of the princely iron reduction and processing center (vashámor) at Csíkmadaras (Mădăraș-Ciuc). Geospatial analysis, correlated with archival data, demonstrates that this site was strategically selected for its superior hydraulic potential, despite being located 7.2 km

away from the mines. In addition, the study reveals that the collapse of the workshop in the eighteenth century was caused by a socio-administrative bottleneck—characterized by mass evasion of compulsory labor (robotă)—and not by the depletion of ore.

These results challenge established narratives that depicted Transylvanian metallurgy as technologically stagnant. Instead, they suggest that the industry's limited output was primarily caused by a lack of cutting-edge technologies and the persistence of archaic, medieval modes of labor organization. Facing these constraints, Transylvanian metallurgy and the iron workshops of the Ciuc Basin demonstrated a complex adaptation to environmental and political pressures. By positioning material culture at the intersection of hydraulic energy, landscape dynamics, and archival records, this research provides a transformative compendium for both archaeologists and historians. Ultimately, the study enriches the disquisition on early industrialization and resource management within the broader Carpathian region, as well as in the Ciuc micro-basin.

Keywords: Ciuc Basin, direct reduction furnace, ironworking, iron metallurgy, Middle Ages, Early Modern Period, princely forge and blast furnace of Mădăraș-Ciuc, interdisciplinary research, material culture, princely authority, landscape use.

Research Objectives and Hypotheses

Our fundamental objective was to integrate fragmented data and results into a coherent system. Within this general framework, we structured our research based on several specific targets and their closely associated hypotheses.

A first major objective was the comprehensive analysis of the relevant archaeological material related to iron metallurgy in the collection of the Szekler Museum of Ciuc. According to our hypothesis, a systematic examination of these objects can reconstruct the level of technological development in the basin and the character of its material culture, from the Early Middle Ages to the late Early Modern Period.

Regarding the chronological span, we aimed to delineate more precisely the spatial and temporal peaks and declines of ironworking activity. We assumed that, based on data provided by find assemblages from Dealul Vasfúvó in Miercurea Ciuc, Grădina Fodor in Șumuleu Ciuc, and Karimósarka, a qualitatively new, system-wide metallurgical boom emerged during the Arpadian era. However, in the field of iron smelting, this remained inferior to the activity carried out by the population of the third to fourth centuries AD. To overcome the lack of Late Medieval sources, we considered the typological analysis of ironwork elements preserved *in situ* on buildings as a priority task, with particular attention paid to the iron grilles in the tabernacle niches of Gothic churches.

One of the most important objectives of our dissertation was the comprehensive historical and economic investigation of the second golden age of iron metallurgy in Ciuc, and, within this context, of the princely forge at Mădăraș-Ciuc in the period following the Szekler revolt of 1562. At this point, we proceeded from the hypothesis that the founding and operation of the forge were not based solely on a profit-oriented economic rationality, as formulated by József Pataki. In

our view, its operation was organically integrated into the centralization trends of princely power and the ruthless application of *ius regium* (princely right) in the Szekler Land, a fact that fundamentally transformed the socio-administrative relations of the region.

Finally, we aimed to critically revise the dominant hypothesis regarding the level of development of Transylvanian forges, and, implicitly, that of Mădăraș-Ciuc, according to which these workshops produced exclusively through an archaic direct process. Furthermore, our goal was to better understand how the forge's site was chosen and the role of its administrators (intendants). We revised previous narratives in the specialized literature regarding the decommissioning of the forge at the beginning of the eighteenth century, which focused primarily on the shortage of raw material. According to our hypothesis, its collapse, datable to around 1720, was not caused by the exhaustion of ore reserves, but by the cumulative effect of the socio-administrative crisis in the region, the migration of the workforce due to unbearable fiscal and labor burdens, and the changing political-economic context. Overall, we strived to demonstrate that the historical iron metallurgy of the Ciuc Basin adapted flexibly to the challenges of different historical eras and, over the centuries, represented one of the most important pillars of local subsistence, with major significance at a regional level as well.

Reseach history

The earliest data regarding iron metallurgy in the Carpathian region date back to the period of humanist geographical writings and papal diplomatic missions of the fifteenth and sixteenth centuries. Works such as the notes of Nicolaus Olahus—which do not yet possess specialized scholarly value but hold exceptional value as documentary sources—are of particular interest. Even more relevant is the world atlas of Mercator and Hondius from 1606, popular in the Early Modern Period, which explicitly mentions steel production in Ciuc (*"Chalybs ad Cyk"*), as well as iron production in Rimetea (Torockó) and Hunedoara (Vajdahunyad).

During the Enlightenment, István Csiba's 1714 manual manifested a certain scientific interest in this subject. This type of interest expanded in the second half of the nineteenth century alongside the industrial boom of the Dualist Era, when engineers, and later historians, began publishing in the pages of the *Journal of Mining and Metallurgy* (*Bányászati és Kohászati Lapok*, starting in 1868).

It was during this period that János Jankó's 1893 monograph on Rimetea took shape, which remains an irreplaceable work to this day due to its ethnographic description and technical history of archaic forges that preserved the technological level of the Early Modern Period. The pioneer of the archaeological approach was Gábor Téglás, who analyzed mining and metallurgy in Roman Dacia[1].

The true paradigm shift in iron metallurgy research was brought about by archaeometallurgy, which developed after the Second World War. Through the intersection of history, archaeology, and engineering sciences (such as metallography and materials testing), an international network of Czech, Polish, English, and German scientists was formed during the 1950s and 1960s. Ronald F. Tylecote,

1 MERCATOR ET HONDIUS 1606, p. 99.
JANKÓ 1893, p. 178-202.
TÉGLÁS 1895, p. 354— 357.

owing to his engineering background, was the first to integrate the examination of polished sections (*finomcsiszolat*) into archaeology and laid the methodological foundations for distinguishing between direct and indirect processes, which he published in his synthesis works of 1962 and 1975. Following the work of the Czech researcher Radomír Pleiner, the CPSA (*Comité Pour la Sidérurgie Ancienne*) was established, elevating the flow of data to a European level. Pleiner's two-volume monograph, *Iron in Archaeology*, published in 2000 and 2006, represents a monumental synthesis of iron production and forging. However, it also clearly illustrates the lagging state of research in Romania: while Hungarian data is abundantly presented, archaeological material from Romania is almost completely absent or restricted exclusively to the La Tène period.[2]

In parallel with these international trends, research into iron metallurgy in Hungary began to yield significant results starting in the mid-1950s. Under the leadership of Gyula Nováki, Gábor Vastagh, and subsequently János Gömöri, field surveys and systematic excavations were initiated—focusing primarily on western Hungary and Borsod County—leading to the creation of a cadastre encompassing hundreds of sites. Experimental archaeology and experimental iron smelting processes, carried out by Endre Zoltay and later by representatives of the new generation, Ádám Thiele and Béla Török, enabled an empirical understanding of furnace operation. The pinnacle of this historiographical synthesis is represented by Gusztáv Heckenast's comprehensive 1991 monograph, *The History of Iron Metallurgy in Hungary during the Feudal Era* (*A magyarországi vaskohászat története a feudalizmus korában*). Utilizing an unparalleled documentary apparatus, Heckenast reconstructed the history of iron production in historical Hungary—

2 TYLECOTE 1962, p. 10.
PLEINER 2000, p. 41.
PLEINER 2006, p.153-156.
CLEERE, HOŠEK, LANG *ET AL.* 2015, p. 10.

including Transylvania—from the thirteenth to the eighteenth century, clarifying, among other aspects, the fourteenth-century introduction of water-powered forges by French monastic orders. Furthermore, regarding the typology of iron objects, we utilized numerous publications from Hungary, such as excavation reports from the castles of Ozora and Nagyvázsony, which provide indispensable analogies.[3]

The state of research in Romania stands in stark contrast to this mature scholarly context in Hungary and Europe. A modern archaeometallurgical perspective, alongside the systematic examination of slag and iron objects, has been almost entirely absent here, with the metallographic analyses of Emil Ioan Emandi from 1976 being among the very few exceptions. Archaeological excavation publications, such as the works of Expectatus Bujor, Lucian Roşu, or Nina Neagu, frequently suffered from documentation deficiencies. The smelting furnaces discovered at Doboşeni (*Székelyszáldobos*) and Herculian (*Magyarhermány*), published by Zoltán Székely in 1959 and 1981, prove to be sources of irreplaceable value by their very existence, although, particularly in the case of the Herculian finds, their dating to the La Tène period cannot be established beyond a doubt. The presentation of metallurgical sites is characterized by a significant ideological distortion (Dacian-centric) in Ioan Glodariu and Eugen Iaroslavschi's 1979 monograph, *The Iron Civilization of the Dacians* (*Civilizaţia fierului la daci*), which groundlessly interpreted even sporadic mentions in data collections compiled by the staff of the

3 HECKENAST, NOVÁKI, VASTAGH *ET AL.* 1968.
HECKENAST 1980, p. 1-21.
HECKENAST 1991.
ÖMÖRI 1980, p. 317-342.
GÖMÖRI 1981, p. 110-121.
GÖMÖRI 1982, p. 93-144.
GÖMÖRI, KISZELY ET VERŐ 1983, p. 537-540.
GÖMÖRI ET KISHÁZI 1985, p. 325-354.
GÖMÖRI 2000.
THIELE ET TÖRÖK 2011, 345-350.
THIELE ET A. 2014, p. 127-137.

Ciuc Museum as belonging to the Dacian era. Despite this, the work addresses the activity of Dacian blacksmiths at a high level and also includes archaeometallurgical analyses.[4]

Nevertheless, the achievements of Romanian historiography have significantly compensated for the shortcomings of archaeological research. David Prodan published a fundamentally important study on the seventeenth-century iron forges of the Hunedoara estate, the antecedents of which had been uncovered by József Pataki. For our research, the most decisive work also belongs to Pataki. In 1971, he published a monograph of exceptional documentary value detailing the seventeenth-century operation of the Mădăraș-Ciuc iron forge, largely drawing upon the documentary base made available by Gusztáv Heckenast, which relied predominantly on records from the princely fiscal archives.[5]

Regarding specialized literature in the Romanian language, a welcome novelty is represented by a recent publication by Gheorghe Postică from the Republic of Moldova, which has filled an information gap by presenting medieval smelting furnaces contemporary with the Arpadian era.[6]

The exploration of iron metallurgy in the Ciuc Basin was completely absent until the second half of the twentieth century, just as archaeology in the Ciuc region itself was non-existent. Local knowledge was represented by Mózes Vitos, who wrote as early as 1894 about the Vasfúvó Hill (Hill of the Iron Blowers) in Toplița Ciuc. Although rescue excavations and field surveys led by Pál János and Dénes Kovács in

4 SZÉKELY 1959, P. 131-133.
BUJOR ET ROȘU 1968, P. 307-309.
EMANDI 1976, p. 163-184.
GLODARIU ET IAROSLAVSCHI 1979, p. 20-21.
SZÉKELY 1981, p. 31
NEAGU 1985, p. 39-44.

5 PRODAN 1959, p. 29-124.
PATAKI 1971.
PATAKI 1973.

6 POSTICĂ 2021, p. 59-61, 71-72, 138-140.
POSTICĂ 2023. p. 43-44

the 1960s signaled the presence of metallurgy in Ciuc, unprofessional documentation and the repeated disturbance of the archaeological repository at Mikó Castle led, in countless cases, to the accumulation of contextless mounds of artifacts. A partially similar fate befell the extremely rich seventeenth-century iron archaeological material from the village of Cibrefalva (destroyed in 1694), discovered in the 1980s by János Szőcs, which remains unpublished to this day.

A qualitative leap occurred after the 2000s, with professional excavations conducted by Lóránt Darvas and István Botár. Alongside the extensive rescue excavations of Lóránt Darvas, the archaeological fieldwork and publications of István Botár laid the foundation for modern research in the Ciuc region. These two researchers correctly identified the remains of third-to-fourth-century AD iron reduction furnaces associated with the Sântana de Mureș–Chernyakhov culture. István Botár's name is linked to the identification of the Arpadian-era blacksmith workshop (twelfth to thirteenth centuries) at Șumuleu Ciuc (Fodor Garden), as well as the radiocarbon (14C) dating confirmation of early medieval production at Vasfúvó Hill in Miercurea Ciuc.[7]

The scientific milestones and paradigms outlined above clearly highlight significant research gaps, justifying the legitimacy of this dissertation. While European and Hungarian archaeometallurgy have developed a high-level, interdisciplinary methodology for the study of historical ironworking, this paradigm has not yet been systematically applied in Transylvania, specifically in the Ciuc Basin. The theoretical distortions and methodological shortcomings of Romanian

7 BOTÁR 2001, p. 165-174.
BOTÁR 2010, p. 19-20.
DARVAS 2012, p. 59-104.
BOTÁR 2013, p. 79-80.
BOTÁR 2021, p. 30-31.
BOTÁR 2019, p. 79, 410.
BOTÁR 2024a.
DARVAS 2023a, p. 75-95.
DARVAS 2023b, p. 191-204.

research in previous decades, alongside the interpretation of local, partially unexploited material discoveries, promised numerous opportunities.

Although József Pataki's historical synthesis and István Botár's recent excavations provide vital starting points, there is a lack of a comprehensive, monograph-length study that coherently analyzes the technological and economic evolution of iron use in the region from the Arpadian era to the beginning of the eighteenth century by synthesizing archaeological and written sources. A significant unexplored gap remains between early medieval iron production, late medieval metal trade and utilization, and the interdisciplinary (archaeological and historical) contextualization of the Mădăraș-Ciuc forge's operation. My dissertation is designed to address this complex research niche.

Methodology

The study of iron metallurgy in the Ciuc Basin required a complex methodological framework integrating multiple disciplines due to the fragmentation of sources and the lack of previous systematic processing. The fundamental methodological paradigm of this thesis rests on source analysis and a mosaic-style synthesis. The primary driver of this approach was the recognition that neither archaeological nor historical sources are sufficient on their own to reconstruct the region's thousand-year history of metallurgy and blacksmithing. Drawing from the perspective of the French Annales School, and in particular Fernand Braudel’s concept of the *longue durée* (long term), this research analyzes iron metallurgy not as a series of isolated events, but as an organic part of deep-seated economic, technological, and social structures characterized by a slow dynamic of change. From this theoretical foundation, material (archaeological) sources and written historical sources are treated with equal

weight, validated and complemented by data from the natural sciences and experimental archaeology.

Sources

The foundation of the research is a material corpus of approximately 375 artifacts related to iron metallurgy. The vast majority of the archaeological material originates from the collections of the Szekler Museum of Ciuc, with a small portion from the Museum of the Eastern Carpathians; consequently, the first methodological step was compiling a comprehensive archaeological catalog, which forms a separate appendix of the thesis.

The research integrated the results of classical archaeological methods, as well as data derived mainly from unsystematic field surveys (*periegheses*) and rescue excavations. Locating early "field surveys" conducted under unclear conditions was greatly facilitated by the inclusion of toponymic data: the nineteenth-century toponymic collections of Frigyes Pesty and the modern ones of Magdolna Csomortáni. Starting from these collections, mapping field and stream names associated with metallurgy—such as *Vasfúvó* (Iron Blower), *Bányaoldal* (Mine Slope), and *Szénégető* (Charcoal Burner)—highlighted several phenomena that proved to be highly useful.

To overcome the gaps in the archaeological material and written data predating the Early Modern Period, this thesis also relies on extensive archival research. Reconstructing the history of the princely forge of Mădăraș-Ciuc in the sixteenth and seventeenth centuries, alongside its political and administrative context (for instance, the *homo regius* status of the administrators), would have been impossible solely through archaeological means; likewise, the broader context of the forge itself or the

centers of metallurgical production in the Principality of Transylvania could not have been mapped without archival documents.

In the course of the research, several physical collections available at the National Archives of Hungary (MNL OL) served as primary sources, including the Transylvanian Chamber Archives (especially the Apafi family records), as well as documents from the *Lymbus*, *Cista Comitatuum*, and *Centenaria* collections of the Alba Iulia Chapter. Furthermore, online research of diplomas in the Transylvanian Royal Books (*Libri Regii*) yielded highly interesting data. These were complemented by princely accounts and mining treasury documents preserved at the Cluj branch of the National Archives of Romania. Moreover, the analysis of mining inventories, urbarial registers, forge regulations, and seventeenth-century litigation documents—both published and unpublished—allowed us to demonstrate that the cessation of production at the beginning of the eighteenth century was not caused by the exhaustion of ore resources, but by the mass evasion of feudal compulsory labor and administrative collapse. The transparency of these major sources is ensured by the documentary archive appended to the thesis, which contains the literal transcription of six critical sources from the seventeenth and early eighteenth centuries, including forge instructions.

Alongside documents, contemporary prints and iconographic sources were included to reconstruct the history of technology. The world atlas of Mercator and Hondius (1606), Antonio Possevino's *Transilvania* (1584), the *Approbatae Constitutiones* of 1653, and the classical treatises of Agricola and Biringuccio provided a foundation for addressing the region's level of technological development (direct versus indirect processes).

The innovative aspect of this research lies in the application of archaeometric methods and spatial analysis (GIS), the use of which was prompted by the physical

and legal limitations of traditional approaches. During the technological analysis of the metal artifacts, the research encountered a major obstacle: the legal and institutional regulations in Romania, combined with financial constraints, did not permit traditional destructive metallographic analyses (such as preparing polished sections) on museum heritage pieces. Due to this constraint, the research turned to a non-invasive alternative, applying compositional analysis using a portable X-ray fluorescence spectrometer (pXRF). Although the pXRF method primarily analyzes heavier elements in the object and provides a picture strictly of surface composition (such as the proportion of impurities and alloying elements) without revealing the microstructural metallic tissue, it can still provide significant data regarding the type of iron ore used and the degree of refinement in purification procedures when combined with future statistical analysis.

To establish chronological frameworks and refine temporal boundaries, the typological dating of pottery was, in some cases, reinforced by scientific dating methods. Radiocarbon (14C) analyses, initiated by Lóránt Darvas on material from the Karimósarka site and by István Botár on materials from Vasfúvó-domb and Fodor-kert, provided objective reference points.

The exact location of the princely forge at Mădăraș-Ciuc cannot be pinpointed at present due to the large number of sawmills that once operated along the Mădăraș Stream, leaving behind highly similar topographic anomalies. The probable site of the forge is assumed to be at the toponymic point known as *Fejedelem-kertje* (The Prince's Garden). This location revealed a major logistical anomaly: the facility was established at an extremely great distance from the mines, namely 7.2 kilometers. Traditional historical sources were insufficient to causally explain this seemingly irrational decision.

To elucidate the reasons for this distance from the mines, the research formulated an answer by employing spatial analysis (GIS) methods, which were cross-referenced with data regarding serf population in Upper Ciuc at the time of the forge's founding (during the reign of John Sigismund). Computerized analysis of the hydrological basin and the flow accumulation slope of the streams definitively demonstrated that the energy potential of the upper course of the Mădăraș Stream (indispensable for driving the bellows and heavy tilt hammers of the forge), supplemented by the concentration of available labor in the valley, economically outweighed the additional costs incurred by transporting raw materials to the site.

Archaeological remains, such as fired clay walls and slag residues, have only a limited capacity to answer questions regarding the operational dynamics of these installations on their own. To understand the remarkable volume of iron production during the Sântana de Mureș–Chernyakhov culture (third to fourth centuries) and its uniquely structured ore reduction furnaces with arched walls, the research turned to the methods of experimental archaeology. Following a theoretical reconstruction, the author built a physical reduction furnace of the type used in the early Migration Period and modeled the entire iron ore reduction process. Recording the thermal and thermodynamic data obtained during ore roasting, the addition of charcoal, and artificial air blast pumping provided empirical proof of the efficiency of this furnace typology. This experimental phase not only confirmed the viability of the technology but also highlighted the high level of empirical knowledge possessed by ancient craftsmen regarding airflow control and reduction processes, thereby providing an explanation for the production peak of that era.

Synthesis of Main Ideas

We divided the history of iron metallurgy in the Ciuc Basin into five defining periods, of which two were examined only as historical antecedents (the Iron Age and the period of Visigoth settlement), addressing exclusively those eras for which relevant data are available. For this reason, the period of Slavic settlement—in the absence of iron objects—was excluded from the research.

We began the analysis, with a preliminary historical character, by presenting the Iron Age. The number of reliable data from the Hallstatt period is limited, and based on the discovered materials, it can currently be assumed that in Lower Ciuc (Alcsík), there was local production and processing of iron as early as the La Tène period. This seems to have been followed by a brief hiatus, after which, during the early migration period in the third to fourth centuries AD, iron metallurgy experienced a revival. The collected traces of a "Gothic" character belonging to the Sântana de Mureș–Chernyakhov culture outline a picture of metallurgical activity of significant proportions.

Following a major demographic and industrial history hiatus that succeeded the early migration era, the review continues with the Arpadian period. During this period, the presence of both smelting and forging can be demonstrated once again, although the intensity of the latter remained inferior to the phenomena of the preceding migration period.

We treated the Late Middle Ages as a distinct unit, at the end of which written sources concerning iron metallurgy in Transylvania also appear in the research horizon. For the time being, however, it appears that there was no smelting activity—meaning the extraction of iron from ore—in the Ciuc Basin at that moment, with only forging being assumed as a metal-processing activity.

Finally, we analyzed the context of the Early Modern Period in detail. During this period, iron production in the Ciuc Basin reached such proportions that seventeenth-century European atlases mentioned the area as one of the most important metallurgical centers of the region, alongside Hunedoara and Rimetea.

Determining the beginnings of Iron Age metallurgy in the Ciuc Basin poses a serious methodological challenge. Regarding the Hallstatt period, we do not yet possess archaeological material whose context conclusively confirms the existence of a local metallurgy; the only object worthy of mention is a winged axe from Lower Ciuc, which in itself does not prove local production. In contrast, in the case of the La Tène period, the extraction of iron can already be documented with certainty. The key point for research is represented by the phenomena discovered by Zoltán Székely at Vârghiș. From Lower Ciuc, we know of at least three pieces that are typologically analogous to the "furnace doors" from Doboșeni. It can be observed that these discoveries came to light, almost without exception, along the edge of the former floodplain of the Olt River. Behind this conscious choice of location may lie the proximity of raw material sources: on the terraces along the Olt, mineral water springs rich in iron oxide created significant deposits of limonite (bog-like iron ore), which, together with the extensive forests providing charcoal supply, created ideal conditions for smelting.[8]

Iron smelting during the Migration Period in Ciuc, driven by the population belonging to the Sântana de Mureș–Chernyakhov culture, manifested as a mature and well-defined activity during the third to fourth centuries AD. Judging by the abundance of archaeological finds, this period far exceeded in intensity the volume of

8 SZÉKELY 1981, p. 31-35.

production of the preceding Iron Age, as well as the subsequent Arpadian era, a fact also supported by the density of the sites identified in the region.

Based on the research of István Botár and Lóránt Darvas, the specific construction type of the furnaces used for ore reduction at various points in the basin can currently be outlined with precision, such as in Sânsimion, Sâncrăieni, Bancu, the Mikó Castle area (Miercurea Ciuc), Șumuleu Ciuc, Delnița, Mihăileni, as well as in Cârța and Ineu. The furnaces used here to obtain the iron bloom fall, in their fundamental character, within the technological traditions of the Central European Barbaricum. Their construction consists of a slag pit dug into the ground, over which a relatively thin-walled conical shaft was built. However, in two essential aspects, the furnaces of the Ciuc Basin exhibit local specificities that distinguish them significantly from the aforementioned analogies.[9]

One of these characteristics is the belted construction—the technique of raising walls from superimposed clay rings—whose functional advantages we confirmed during our own experimental archaeological reconstruction. According to our observations, this solution significantly increased the thermal stability and resistance of the furnace. The other peculiarity lies in the management of slag: while in other known European metallurgical centers of this era, the content of the slag collection pit was usually left intact, leaving behind fields of slag blocks, the discoveries at Șumuleu Ciuc suggest that the slag was removed from the pit.

After the fourth century, a very significant hiatus in iron metallurgy occurs in the basin, which is interrupted only by the identification of the first phenomena from the Arpadian period. The slag layer discovered by István Botár on Vasfúvó Hill in Miercurea Ciuc is currently our only certainly attested metallurgical site from the

9 BOTÁR 2001, p. 165-174.
MÁRTON, BOTÁR, DARVAS *ET AL.* 2019, p. 92.
BOTÁR 2024a, p. 4-5.

Arpadian era. Its formation, based on radiocarbon dating (14C), can be placed between 1150 and 1250, an interval that largely coincides with most of the examined archaeological finds dated to the Arpadian era, specifically the twelfth to thirteenth centuries.

Based on the research of István Botár, we can conclude that iron smelting could have emerged in the region even before the traditionally accepted Szekler colonization, in which case we consider that this activity was carried out by a Hungarian-speaking population belonging to royal counties or ecclesiastical structures. Of particular importance for this period is the blacksmith workshop at Șumuleu Ciuc, which we have read about on several occasions thanks to István Botár's publications. This is the only blacksmith workshop in the Ciuc Basin archaeologically investigated to date.[10]

The few metallurgical phenomena of the era are compensated for by the discoveries of iron objects. In our view, the most valuable of these is the analysis of the assemblage of artifacts from the ritual grave archaeologically investigated by Lóránt Darvas at the Karimósarka site in Sâncrăieni.

The subsequent medieval period, following the cessation of smelting activity, was treated as a new era. This is because, concurrently with it, we noticed a certain change in material culture. These modifications were most visible regarding spurs and knives. A unique element in the history of iron processing in the basin is that, from this period, the iron grilles of the tabernacle niches have been preserved *in situ* in four locations. The scientific processing of these iron pieces has been carried out for the first time in the present research. The objects are found in the churches of Armășeni, Misentea, Leliceni, and Ciceu.

10 BOTÁR 2024a, p. 6-7.

Delineating our next epoch proved to be somewhat of a challenge because, in the field of material culture, it is very difficult to draw a sharp line of demarcation in the middle of the sixteenth century, whereas from a political history perspective, this is much easier to achieve. Thus, major changes took place in the life of the Kingdom of Hungary and, by extension, in the Ciuc Basin during the Early Modern Period. From the perspective of our theme, of course, the most important are those social and political changes that made the establishment of the Mădăraș iron forge possible. Furthermore, during our research, we questioned claims in local history literature that multiple forges operated in the Ciuc region. At least, we believe this was not true in the Early Modern Period, with only the princely forge of Mădăraș-Ciuc existing.

To contextualize the forge at Mădăraș-Ciuc, it was indispensable to review iron production and the macroregional iron trade in Early Modern Transylvania. In order not to interpret the plant at Mădăraș-Ciuc as an isolated phenomenon, but rather as an organic part of the principality's iron industry, alongside Hunedoara and Rimetea—which are prioritized in the specialized literature—we included in the analysis locations such as the Beiuș domain, the sporadically mentioned forges of the Apuseni Mountains, the Gutâi area, Ștei, and Lueta. The comparison was somewhat hindered by the inequality of documentary sources: while we could rely on a rich documentary corpus for Hunedoara and Cernabanya (which was in the hands of the prince), far fewer data were available to us regarding the smaller forges of Rimetea, the Apuseni Mountains, and Stejvaspatak.

This broader perspective also confirmed that although the forge at Mădăraș-Ciuc was not among the most productive Transylvanian plants, its operation of approximately 150 years—unlike the forges of the Beiuș domain or the Lueta forge, which operated very briefly in that era—was rarely disrupted by external factors. Thanks to this stability, the forge remained a reliable economic unit of the princely

court, continuously securing a significant portion of its needs. In addition, the macroregional perspective proved that, similar to the plants at Hunedoara, there are certain data indicating that Transylvanian iron from Mădăraș-Ciuc reached the markets of the Romanian Principalities.

For a comprehensive understanding of iron metallurgy in Early Modern Transylvania, and specifically within the Ciuc Basin, it is indispensable to analyze the social groups practicing this craft, as well as their products. The society of Transylvanian blacksmiths in the sixteenth and seventeenth centuries was fundamentally structured into three main classes: village and market town blacksmiths who served rural needs (complemented by Roma blacksmiths with a marginal status, who fulfilled a special role), guild masters in cities, who produced high-quality weapons and tools with a greater degree of specialization, and forge employees who ensured mass production on an industrial scale, such as iron semi-finished products, cannonballs, and mining equipment.

Since we cannot speak of urban craftsmen operating within guilds in the Ciuc Basin during the analyzed period, the supply of iron tools to the region's population was ensured by a complex system fed by multiple sources. The main conclusion of the research in this field is that daily local and agricultural needs were fundamentally met by village masters and the production of the princely forge in Ciuc, while special craft products with a more refined finish penetrated the area—as documented—through markets and trade, brought from the guilds of major Transylvanian cities by their merchants. The complex analysis of this interdependent production and distribution system, which functioned on multiple levels, is indispensable for the authentic reconstruction of the material culture and economic daily life of the studied region and period.

József Pataki achieved invaluable results in the research of the Mădăraş forge. We strived to complement his work with recently uncovered documentary sources. We were particularly interested in the motive for establishing the forge and the exact timing of this event. We were also concerned with whether or not it was a phenomenon preceding the era of the principality. In our view, the establishment of the forge was not due exclusively to economic reasons and can only be placed in the period following the Szekler revolt of 1562. We believe that the prince created it as an instrument of control over the Szeklers and to obtain economic profits. Regarding the decline and decommissioning of the forge, we aim to identify a new cause. More precisely, it was not the exhaustion of ore resources that became problematic, but the lack of labor and the collapse of the princely administration that caused the decommissioning of the forge.

The continuous decline is well reflected by the report from 1704: although it does not present an exact nominal table, it notes with bitterness that the workforce had drastically decreased. Especially lacking at that time were those laborers (serfs) who had previously ensured the maintenance of the plant through free labor, reducing the total number of workers to 50 individuals.[11]

The extraordinary size of the workforce of the Ciuc iron forge observed in the second half of the seventeenth century (138 people in 1673), followed by its subsequent significant decrease (about 50 people in 1703), can be attributed to several interconnected factors. One of the fundamental conditions for this initial "oversizing" was created by the fact that the forge operated for a long time as a princely domain, and thus belonged to the fiscal (chamber) administration. The princely court possessed an extensive land fund to which a significant number of

11 Archival appendix, document nr. 6.

serfs belonged, who, however, did not necessarily perform labor within the forge. Although the volume of these serfs' labor depended on the land policy of the moment, particularly on land donations, it fundamentally provided the possibility to allocate a large number of people, even through coercion, for the multiple tasks required for the forge's operation—including auxiliary tasks outside direct production. This fact can explain the remarkably high workforce recorded in the 1673 census compared to other plants.

One of the main causes of the subsequent drastic reduction in the workforce—this "decline"—was the mass evasion of service at the forge, which became a widespread phenomenon. This was because labor at the forge was extremely exhausting.

Another factor that may have hindered the operation of the forge in its final years was that, in its last decades of existence, the Ciuc Basin was hit by highly significant calamities. Thus, at the end of the seventeenth century, during the Kuruc incursions, iron was plundered from the forge. A much more serious event was that in 1694, after thirty-three years of peace, a new Tatar invasion took place in the Ciuc Basin. The blow caused by the Tatar invasion was felt even in 1704, as it was explicitly formulated that due to the *"impedicionem Tartarorum"* (hindrance of the Tatars), it was not possible to return many to the operation of the forge, because they had been taken prisoner or had died.

To remedy this situation, contract workers (*țidulă – "schédás"*) should have been hired, but this was probably very difficult to achieve in a context where, between 1717 and 1719, drought followed by famine and a devastating epidemic drastically reduced the population and workforce in Ciuc.[12]

12 SZILÁGYI 1894, p. 724-726.
Uo., p. 188-200.
SzOkl. VII., p. 229.
SZŐCS 1995, p. 150.
PÁL-ANTAL 2012, p. 8-9.

In the course of analyzing the ownership history of the Mădăraș-Ciuc iron forge, we confirmed that it remained, for the most part, in the ownership of the treasury, even though it was periodically leased out, partially mortgaged, or came into the possession of various individuals. We strived to complement the ownership history with new early data, thereby demonstrating the court's consistent effort to maintain or regain control over the forge—an effort that remained evident throughout the entire era of the Principality. Particularly interesting is the late fate of the forge, when its decline occurred precisely due to the loss of its chamber (fiscal) character.

The dissolution of the Principality of Transylvania at the end of the seventeenth century and its transition under Habsburg rule caused significant structural changes that profoundly affected the operation of the Ciuc iron forge. After passing under the authority of the Habsburg Empire, the forge did not fall under the control of the central treasury (Chamber) but remained under the jurisdiction of the widow of Prince Michael Apafi II, Kata (Catherine) Bethlen. Following the change in political regime, the princess's prerogatives and influence became limited, which apparently made the efficient administration of the forge impossible.[13]

Based on the integration of written sources and high-resolution DEM (Digital Elevation Model) topographic surveys, we consider it certain that in the sixteenth and seventeenth centuries, iron ore extraction involved not only surface collecting but also the implementation of systematic underground mining extending over an area of more than 31 hectares, traces of which can still be observed today on the borders of Cârța and Tomești.[14]

Irattár, 6. irat.

13 SÁNDOR 1914, p. 150-151.
Uo., p 189-190.
Uo., p 205-208.1

14 SZILÁGYI 1894, p. 725.
PATAKI 1971, p. 23.
Irattár, 6. irat.
BOTÁR 2024, p.10-12.

One of the main methodological novelties of our research consists in the fact that, by applying spatial analysis (GIS), we succeeded in finding an explanation for the dilemma of choosing the site of the Mădăraș forge. Topographic modeling of the least-cost path (LCP analysis) highlighted that, due to the steep slopes of the valleys, the transport of raw materials between the mines and the processing unit took place along an obligatory and extremely demanding route at least 7.2 kilometers in length. This major transport disadvantage was, however, counterbalanced by the hydropower potential: hydrological modeling (Flow Accumulation, Stream Power Index) confirmed that the Mădăraș Stream, located at a greater distance, has a catchment basin approximately 26% more extensive, which guaranteed a much higher and more stable water flow compared to the watercourses in the proximity of the mines, thereby ensuring a more reliable driving force for the bellows and hammers.

During the examination of the technological development level of the Mădăraș forge, we also addressed the issue of direct and indirect processes. In contrast to the view formulated by Gusztáv Heckenast, our opinion is that after 1585, in addition to the direct process (obtaining the iron bloom), the emergence and use of the indirect process can be assumed in Transylvania, as well as in the Ciuc Basin. However, for the indubitable confirmation and demonstration of this fact, targeted archaeological excavations and archaeometallurgical investigations on the territory of the former Mădăraș forge would be indispensable in the future.[15]

We strived to analyze in detail the origin of the iron vestiges discovered in Ciuc, but, in the vast majority of cases, in the absence of an in-depth analysis of the entire archaeological material, we could not make this attempt with precision. Only in the case of mass-produced products specific to Lower Austria from the Late Middle Ages and the Early Modern Period (such as Styrian knives and scythes) could we assume with relative certainty that they were imported items.

15 HECKENAST 1985, p. 937-938.

The final chapter of our work consists of an "Archaeological Archive" (Archaeological Repertory). Its role is to serve as a reference base and to facilitate the verification of our data, but it also contains information that, in the absence of a complete context, cannot yet be fully integrated into the body of current knowledge. An example of this is several metallurgical phenomena whose dating cannot yet be established.

It can be stated that the wide range of iron vestiges discovered in the Ciuc Basin, datable between the fourteenth and seventeenth centuries—ranging from military and equestrian equipment, to personal items, agricultural and household tools, and architectural hardware—offers a valuable perspective on the material culture of the era. Although many of the object types used in the Late Middle Ages are continuously present, certain transformations can also be observed, for example, through the appearance of bullet molds associated with firearms or in the evolution of knife morphology. Among the most characteristic and frequent types of discoveries from the Early Modern Period in the studied area are fire steels and jew's harps. Overall, the archaeological material does not indicate a sharp break (caesura) between the Late Middle Ages and the Early Modern Period; rather, the inventory of everyday iron objects in Ciuc is characterized by a gradual transition and continuity.

Conclusions and Future Directions

In concluding my research and thesis, I summarize below the main results of the work, with a particular focus on their practical applicability, as well as the identified gaps and future directions of research. Overall, the primary goal of the thesis is to stimulate further research into Transylvanian iron metallurgy—a field unfairly treated with superficiality until now—thereby creating a bridge between archaeology, historical sciences, and the natural sciences.

The results of this work can be directly utilized by multiple disciplines and professional communities, laying the foundation for comprehensive interdisciplinary research. For the domestic archaeological community, the work—especially through its extensive appendices and detailed catalog of finds—can be used as a practical manual or compendium. It provides assistance in the precise identification and dating of iron tools and metallurgical phenomena from different eras, thereby also contributing to a more accurate understanding of the early phase of the Iron Age. For historians, as well as those interested in the economic and technical history of Transylvania or the social history of the Szekler Land, the thesis offers a documentary body and analysis that fills a major gap. Particularly valuable is the complex presentation of iron processing and trade in sixteenth- and seventeenth-century Transylvania, which casts the economic network of the region in a new light. Moreover, since this work represents the first monograph-length treatment of iron metallurgy in the Ciuc Basin, it serves as a fundamental, unavoidable reference for local historians and specialists studying the region's past.

Scientific objectivity also requires mentioning the methodological and practical limitations that represent shortcomings of the current research, the resolution of which will require a closer future involvement of other disciplines (materials science, chemistry, and geology). Among the methodological and material study limitations,

the absence of destructive metallographic analyses must be highlighted. Due to strict legal and financial regulations, it was not possible to perform metallographic analyses on museum objects, although their inclusion would have been indispensable to reveal the exact manufacturing technology, carbon content, and steel properties of the artifacts. Although we applied non-destructive portable X-ray fluorescence (pXRF) analysis during the research, due to the technological limitations of the device used, it did not detect elements lighter than manganese. For this reason, it was not possible to analyze the amount of carbon, silicon, phosphorus, and sulfur—elements of crucial importance from a metallurgical perspective that fundamentally influence iron quality; therefore, deeper chemical investigations are required in this area. In addition, the research was hampered by museological and administrative difficulties. Due to the repeated relocations of the Szekler Museum of Ciuc repository and the unprofessional documentation practices of the period prior to the year 2000, a significant loss of information occurred in the old collections, with the archaeological context of many valuable vestiges being lost. Reconstructing these data in the future will require painstaking and much better-coordinated work between museology and archival research.

The thesis also serves as a guide for future research, mapping those "white spots" where systematic and in-depth investigation is indispensable. To address these archaeological gaps, there is a great need for collecting precise data on iron processing in the early phase of the Iron Age, as well as for the professional discovery and research of intact ore reduction furnaces (bloomery furnaces) from the Arpadian era, which have not yet been discovered on Transylvanian territory. It is also indispensable to systematically excavate an early Transylvanian forge—most notably the forge at Mădăraș-Ciuc—since, despite the abundance of written sources, no targeted excavations have taken place here yet. For a more precise dating of

features exposed to thermal shock, such as furnaces and ore roasting hearths, the introduction of archaeomagnetic dating is recommended, which will require *in situ* sampling during future excavations. Furthermore, the precise geological and mineralogical determination of iron ore types in the region is imperative to clarify unequivocally the origin and exact extent of the raw material base of the Early Modern forges. Ultimately, one of the most important benefits of this work is that it can substantiate and justify the initiation of a vast and modern series of archaeometallurgical investigations on Transylvanian archaeological material.

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