Metallurgists of the Wetlands:
The Role of Intensification of Metallurgy in Transforming Societies and the Environment of the Tisza-Maros Region between 4500 and 1500 BCE

by

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Dedication

"I made it."

To Alojzija Tomažič (1928-2020), the strongest woman I have ever known.

I dedicate this dissertation to those who abandoned their dream because someone convinced them they were not good enough. The greatest favor you can do to yourself is refusing to believe them and proving them wrong.

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Abstract

Metallurgy was one of the earliest technologies to generate a lasting impact on people, animals, and landscapes. In European archaeology, metallurgy has long been framed as a technology that transformed social systems and organization, along with the distribution of wealth. Nevertheless, its most enduring impact — from mining to smelting to manufacturing— was on the environment, on soil, on plants, and on the animals and humans who were exposed to it.

When metallurgical activities such as mining, smelting, and manufacturing shifted from occasional to intensified practices, they produced unintended consequences, many of them deleterious, including air and soil pollution and contamination.

The case study for this dissertation is situated in the Southeastern Carpathian Basin and spans the period from the Early Copper Age (4500–2800 BC) to the end of the Middle Bronze Age (ca. 2000–1500 BC). Over the span of 3000 years, social, environmental, and technological changes reshaped communities and their surroundings, producing multiple episodes and different degrees of intensification. This dissertation documents the impact of metallurgical production on individual communities and each community's responses to its intensification.

To address the impact of metallurgical intensification on the environment, I analyzed metallurgical debris, the teeth of domestic and wild animals, and soils from six sites: Klárafalva Hajdova, Kiszombor Új Élet, Rabe Anka Siget, Majdan 28, Crna Bara–Prkos, and Pecica Şanţul Mare. Using a suite of analytical techniques—including ICP-MS and LA-ICP-MS— I was able to detect contamination patterns and signatures in those datasets.

The results show that metallurgical intensification varied through space and time. Both regional episodes and community-specific cycles of intensification are evident, each shaped by local environmental conditions. The study also identifies shifting relationships between husbandry

practices and metallurgical activity, demonstrating that the impacts of intensification were neither uniformly perceived.

This dissertation contributes to anthropology and archaeology in several ways. First, this work contributes to the understanding of intensification by documenting specific trajectories of metallurgical intensification over a span of three millennia. Second, through the development of a methodology that combined archaeological evidence with interdisciplinary methods, I was able to create framework for detecting contamination from metallurgical production, this work demonstrates that it is possible to trace metallurgical impacts even where direct archaeological evidence is sparse or elusive. Third, by identifying contamination at local scales, examining its effects on animals and humans, and analyzing how communities responded to heightened metallurgical activity, this study positions archaeology as a vital contributor to broader discussions of anthropogenic pollution.

Ultimately, the findings highlight the interpretive power of archaeology when multiple lines of evidence and multidisciplinary approaches are combined. They show how archaeological research can illuminate long-term human–environment interactions, the dynamics of intensification, and the enduring consequences of human activity.

Chapter 1 Introduction

Metallurgy has long been regarded as a technology that has reshaped human societies. Yet evidence for the impact of metallurgical production on many prehistoric contexts remains to be documented and analyzed. On the European continent, in particular, metallurgical activity becomes archaeologically visible primarily during periods of heightened production, when large quantities of metal objects were widely circulated across the region.

With the explosive intensification of metallurgical production during the Early and Middle Bronze Age (ca. 2700–1500 BCE) (Muhly 1969; Chernykh 1992; Pernicka et al. 2003; Radivojević et al. 2019; Găvan 2019), evidence for local production began to spread and appeared even in areas far removed from ore sources. It is also during this period that, for the first time in human history, anthropogenic contamination is detected on a global scale in environmental datasets, such as Greenland ice cores (Longman et al. 2018; Pompeani 2019; McConnell et al. 2018; Grattan et al. 2004; Grattan et al. 2013).

However, although visible in both the archaeological and environmental records, the impact of heightened metallurgical production was likely far from uniform. The archaeological evidence indicates that between 4500 and 1500 BCE there were several distinct phases of intensified metallurgical activity across the European continent (Jovanović 1996; Pernicka et al. 2003; Radivojević and Roberts 2021). This suggests that metallurgical technology were highly variable and shaped by temporal trends and local community circumstances. As a result of a changing metallurgical technology and the intensity of production, the amount of contamination released would have similarly varied not only through time, but also across regions and in individual communities. However, how and how much did the process vary remains poorly understood.

How did metallurgical intensification change over time, particularly during the Bronze Age? To address this question, I draw on both direct archaeological evidence of metallurgical production and indirect indicators of environmental contamination preserved in animal teeth and

soils from sites dating to the Early Copper Age (4500 BCE) and end of the Middle Bronze Age (ca. 1500 BCE).

The focus of this case study is the Tisza–Maros region. Currently divided between Hungary, Romania, and Serbia, this area provides a prime example of how changes in metallurgical technology reshaped societies. Because the region lies far from ore sources, communities had to procure ores, ingots, and metal objects and bring them to settlements, thereby organizing community practices to their communities to the craft.

In contrast to ore-rich regions where metallurgical production evidence appears as early as 5000 BCE (Radivojević et al. 2021), the southeastern Carpathian Basin shows clear archaeological evidence for local metallurgical production only around 2700 BCE, when stages such as ore transformation (smelting or roasting, refining, alloying) and object manufacture (casting, smithing, repairing) first appear in settlements from the region.

In this dissertation, I examine the evidence for these processes at six archaeological sites: Pecica Şanţul Mare, Crna Bara–Prkos, Klárafalva Hajdova, Kiszombor Új Élet, Rabe Anka Siget, and Majdan 28.

During the Bronze Age, all of these sites—except Crna Bara–Prkos—were occupied by communities belonging to the Maros/Maros/Mureș cultural complex (ca. 2700–1500 BCE). Although all Maros settlements show evidence of metallurgical production, the archaeological record shows a varying intensity of metallurgical activity from site to site.

This variation raises two related questions that oriented this work: *How did metallurgical activity impact these societies, and how did different Bronze Age communities within the Tisza–Maros region express the intensification of metallurgical production?*

While in this work I am focused on a specific region, questions addressed in this work can be applied to any region or community. Given that elements released during metallurgical processes, such as lead, arsenic, copper, and cadmium, have measurable effects on biological systems (West 2006), they have primarily attracted substantial attention within public health and medical research. From this research, it is possible to deduce that contaminants generated through metallurgical production affected not only humans (West 2006) and animals (Hejna et al. 2018)

but also the broader environment (Flyn 2021), including alterations in soil chemical composition (Sposito 2008).

In this work, evidence of contamination was obtained by analyzing domestic animals (pigs, sheep/goats), wild fauna (deer), and soils from the six mentioned archaeological sites. Samples were collected both through excavation and from museum collections. All materials were examined using a suite of analytical methods. Enamel from animal teeth was separated, dissolved, and analyzed using ICP-MS. Teeth exhibiting higher concentrations of contaminants were further examined with LA-ICP-MS to produce trace-element distribution maps. A small subset of soils was analyzed for mineralogical composition to better understand soil structure and its implications for trace-element behavior, while all soils were then processed using a leaching protocol adapted from Blum et al. (2002).

The contamination results were then compared with the archaeological evidence for metallurgical production. Each site was divided into phases corresponding broadly to the Early, Middle (Siklósi and Szilágyi 2021), and Late Copper Age (Bondár 2008), and the Early and Middle Bronze Age (Kiss et al. 2019). The sites were examined both within their individual occupational histories and at the regional scale, allowing the identification of local and regional episodes of metallurgical intensification and the assessment of their associated impacts.

This dissertation contributes to scientific research in several meaningful ways. First, the multidisciplinary model presented in this work can be applied across a wide range of archaeological contexts and time periods, offering a flexible framework for investigating technological intensification and its social and environmental impacts, even in cases of ephemeral metallurgical production. Second, it brings much-needed attention to anthropogenic contamination resulting from metallurgical processing—an issue long examined in other scientific fields but rarely discussed in archaeology. In contrast to other sciences, archaeology offers a multidimensional perspective on contamination and pollution by providing evidence and responses at the societal, regional, and temporal levels of technology's impacts, which are increasingly more relevant to contemporary discussions of pollution and sustainability.

1.1 Dissertation structure and organization

This dissertation is organized into twelve chapters. It comprises a theoretical chapter (Chapter 2); background chapters (Chapters 3–6); methodological chapters (Chapters 7–9); a chapter on results (Chapter 10); and chapters on discussion and conclusion (Chapters 11 and 12).

Chapter 2 presents the theoretical foundations of this dissertation. The chapter begins by defining intensification. I emphasize how intensification was studied, depending on how it was initially understood and that it unfolds differently, depending on pre-existing societal conditions. The chapter then turns to anthropological perspectives on intensification in terms of subsistence and craft production. I then move on to place intensification within a technological cycle; here intensification is typically short-lived, unsustainable process and often gives rise to new cycles following its collapse, along with a set of unwanted consequences. The chapter concludes by examining pollution and contamination as examples of production consequences and the feedback loops, they generate.

Chapter 3 presents the first of four background chapters. Drawing on interdisciplinary literature, it examines the real-world impacts of intensification using pollution and contamination as examples. Before addressing these issues in detail, the chapter begins by distinguishing between contamination and pollution. I explain that, in this work, I will use the word "contamination" to avoid modern-day connotations associated with pollution. In this study I focus on heavy-metal contamination. The chapter proceeds to describe the elements analyzed in this dissertation. Here I distinguish between essential and hazardous elements, and discuss their effects by element type, exposure pathway, dose, and individual biological profiles. I then examine how heavy metals affect environments, animals, and the human body. Drawing on public health and medical research, I explain the contamination process: how heavy metals enter organisms, where they accumulate, and how their accumulation appears in humans and animals. The chapter continues by reviewing interdisciplinary studies of contamination and by noting the limited attention archaeology has given to these issues. I conclude by discussing the reasons for this lack of focus by emphasizing diagenesis as the primary concern that has historically constrained archaeological engagement with contamination studies.

Chapter 4 examines the background of metallurgical intensification in Europe. I begin by considering the social role of metallurgy, highlighting long-standing issues surrounding the 'social

image' of the metallurgist. I argue that understanding metallurgy in the archaeological record requires avoiding broad generalizations and recognizing that the social role of metallurgists, like the process itself, varied across societies and across different stages of the metallurgical sequence. The chapter then reviews how metallurgy and its material traces have been studied to date, emphasizing the importance of the *chaîne opératoire* as a foundational analytical framework. I proceed by outlining the metallurgical technological cycle, distinguishing between developments over time and the dynamics that unfold within individual metallurgical cycles. The chapter concludes by situating metallurgy within its archaeological context, discussing its often elusive and incomplete nature, and setting the stage for the case study that follows.

Chapter 5 examines metallurgical activity within the natural and cultural environment of the Tisza–Maros region between 4500 and 1500 BCE. I begin by outlining the location and historical background of the study area, emphasizing that all sites are situated within or along the margins of a (now drained) wetland zone. I then discuss the general climatic conditions over this 3000-year period, noting the absence of a local climate reconstruction and the resulting reliance on proxy records located roughly 200 km away. In the second half of the chapter, I focus on the cultural history of the region from the Copper Age (4500–2800 BCE) to the Bronze Age (ca. 2700–1500 BCE), by describing archaeological evidence from the wider and Tisza–Maros region. A particular focus is placed on the evidence for metallurgical activity.

Chapter 6, presenting the last background chapter, focuses on the excavation history of each site and the recovered evidence for prehistoric land use; this includes subsistence practices (fauna and flora) and metallurgical activity. While I present both the Early (4500–4000 BCE) and Middle Copper Age (4000-3600 BCE), the evidence of local metallurgical activity appears only during the Bronze Age and occurs in varying degrees across most Maros sites (ca. 2700–1500 BCE).

Chapter 7 is one of the first methodological chapters of this research, in which I present the models and research design of this dissertation. I begin with the initial assumption (grounded in archaeological data), that metallurgy and its intensification occurred in the study region; what remains unclear is how this intensification *changed over time*, how it was *expressed at individual settlements*, and how it *affected* the societies involved. I then outline the analytical approaches used to address these questions, drawing on both evidence of metallurgical production and indicators of environmental contamination. Particular attention is given to technological and

spatial organizational changes, focusing on shifts in animal husbandry strategies, in response to heightened metallurgical activity. Building on these themes, I develop a series of hypotheses and expectations. The first set explores potential pathways of intensification, which may have steadily or stepwise increased, or were characterized by non-monotonic fluctuations. The second hypothesis examines whether the expression of metallurgical intensification across communities was homogeneous or heterogeneous. Together, these models establish the framework for the analyses that lead into the next chapter, where I describe the methods and analytical approaches in greater detail.

Chapter 8 continues the methodological discussion by focusing on materials used in this study — animal teeth and settlement soils. Before going into details about the materials, I start the chapter by outlining the importance of sampling strategy, including the development of a sampling model. I then focus on details about the teeth and soils, which together present complementary datasets that provide both spatial and material resolution for interpreting metallurgical activity and its environmental impacts, as well as tracking potential shifts in their spatial distribution. I conclude each section by detailing the sampling protocols used for each type of material.

Chapter 9 presents the analytical methods used in this study. I begin by outlining the elements targeted in the analysis, with particular emphasis on the lead–calcium relationship in teeth and on copper and tin concentrations in soils. I then describe the application of inductively coupled plasma mass spectrometry (ICP-MS), inductively coupled plasma–optical emission spectrometry (ICP-OES), and laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), explaining the rationale for employing these techniques and how their complementary strengths help address diagenetic concerns. Together, these methods form the core of the geochemical framework used throughout this dissertation. The chapter concludes by detailing the standard operating procedures for both faunal and sediment samples and by introducing two additional analytical approaches: X-ray diffraction (XRD) and radiocarbon dating. XRD is used to determine the mineralogical structure of soils, while radiocarbon dating provides the chronological framework necessary to situate metallurgical activity and contamination within a precise temporal sequence.

Chapter 10 presents the results of this study. I begin by establishing a comparative baseline through the material while focusing on elemental relationships. For teeth, I focused on lead–calcium ratios as indicators of metallurgical contamination. To explore potential avenues of

diagenesis, alongside pasturing locations and animal age, I also examined barium–calcium ratios and phosphorus–calcium ratios. The latter, in particular, aids in evaluating the extent of diagenetic overprinting. Outliers identified in these datasets are then presented in greater detail. I then turn to the soil results. This section begins with the XRD analyses, followed by a principal component analysis (PCA) to identify the major dimensions of variation within the dataset. Because both primary components show strong correlations with elements showing anthropogenic activity, including heavy metals, I conducted an ecological assessment to evaluate the magnitude of anthropogenic. The chapter continues with a site-by-site discussion of results and emerging patterns, for teeth and soils alike. Here, I also discuss the identified outliers for teeth and soils. The outliers for animal teeth are presented here using LA-ICP-MS trace-element maps. The final portion of the analysis was a comparison of all samples by site across time periods. For this purpose, I employ a broad temporal division that groups the Early and Middle Copper Age together, while the Bronze Age is subdivided into Early Bronze Age and the Middle Bronze Age phases.

Chapter 11 presents the first discussion chapter. Here I use the results presented in Chapter 10 to evaluate the hypotheses and expectations outlined in Chapter 7. The chapter is divided into two major sections, each addressing one set of hypotheses. In the first section, I assessed the proposed pathways of metallurgical intensification; in the second, I examined whether the expression of intensification across communities was homogeneous or heterogeneous. Together, these analyses synthesize the empirical findings and situate them within the broader interpretive framework of this dissertation.

Given that the nuances revealed by this research proved far more complex than originally anticipated, Chapter 12 presents a broader discussion of these complexities and their wider implications. The chapter is divided into three main sections. The first section examines intensification as a process that varies according to the scale of observation. I begin at the site level, synthesizing metallurgical, faunal, and soil evidence to reconstruct trajectories of intensification for each settlement and to highlight their differing historical paths. I then scale up to the regional level, distinguishing between varying degrees of metallurgical intensity—ranging from production aimed primarily at community consumption to production geared toward export and wider distribution. This discussion also considers how the location of metallurgical activity was shaped by the immediate landscape of each site, particularly whether it lay within the wetland

zone or along its margins. I conclude this section by integrating these patterns with available climate reconstructions, which proposes an explanation for the regional trends in metallurgical intensification and the divergent histories observed at individual sites. The second section briefly addresses the contribution of Maros metallurgy to broader patterns of global contamination and outlines the wider implications of this research for archaeological, environmental, and interdisciplinary studies. The chapter concludes by identifying the study's limitations and outlining directions for future research.

Chapter 2 Theoretical Approaches to Intensification

This study is structured around the question of how the expression of intensification shifts over time and across communities. To illustrate this, I begin the chapter by reviewing the various definitions of intensification, followed by a discussion of how the concept has been studied. In this section, I highlight the conceptual challenges involved in discussing intensification and consider why archaeology is particularly well-suited to address them.

The following section examines how intensification has been approached within archaeological research, drawing primarily on evidence from subsistence and craft-production studies. This leads to a discussion of intensification within the technological cycle—a framework that describes the 'life' of individual technologies and the dynamic processes that shape their development.

The final section sees intensification as a delicate balance between costs and benefits—one that often produces unwanted consequences. I conclude the chapter by introducing one of the most pressing issues associated with the intensification of human-made technologies: pollution and contamination.

2.1 Defining Intensification

Intensification (*noun*) is defined as "the fact of becoming greater, more serious, or more extreme" (Cambridge University Press, n.d.). According to the Oxford English Dictionary, the earliest recorded use of the term dates to the 1860s and derives from the verb "intensify", meaning 'to make something more intense.' The word intensification, however, ultimately traces back to the Latin root "*intensus,"*meaning "stretched out" or "strained," a nuance that differs from the term's meaning in the nineteenth century (Oxford English Dictionary, n.d).

The nuances in the definitions of intensification reveal divergent meanings that already hint at the term's conceptual complexity and its tendency to shift with context. The 1860s' definition generally emphasizes the **outcomes** of intensification—becoming greater, more serious,

or more extreme—whereas the Latin root "*intensus"* refers to the **state of exertion** during which intensification occurs. Unlike the nineteenth-century usage, the Latin-derived meaning does not assume any particular outcome; rather, it implies that existing resources are pushed toward their limits.

In this work, I adopt the Latin-derived sense of the term, understanding intensification as a universal human experience in which existing resources are used to an extreme. In this framing, intensification is a process that demands additional inputs—time, labor, money, or cognitive effort—to meet a critical need or threshold, whether at the personal or societal scale.

2.2 Approaches to intensification

The extensive interdisciplinary literature on intensification makes it clear that the process (with its varied definitions) can be applied to many aspects of human existence; yet it has been examined most extensively in relation to subsistence and technology.

The term intensification was first studied in the 1960s by the Danish economist Ester Boserup, who examined the drivers of agricultural intensification, particularly in relation to land use. Although she identified population growth as the primary catalyst for intensification, her underlying proposition is that population pressure drives innovation and that these innovations, in turn, result in higher yields per unit of land. To achieve this increased output, the demand generated required greater labor investment, thereby generating the process of intensification (Boserup 1965). Since then, the concept of intensification has been widely debated, but it has been applied most prominently in subsistence studies to investigate the causes and responses to resource imbalances (Flannery 1969; Halstead and O'Shea 2004; Erickson 2006; Zeder 2012), and in technological studies to examine economic productivity, efficiency, and market fluctuations (Morrison 1994).

However, studying intensification is challenging for several reasons. The first, but perhaps the least obvious, reason is that the study of intensification in many sciences is challenging precisely because it is difficult to observe as it unfolds. Analyses must examine and reconstruct past episodes or processes in order to build models that help explain future patterns.

Second, although the factors, consequences, and human behaviors that drive intensification have been extensively examined, direct comparisons of different intensification processes and their expressions remain relatively rare (Morrison 1994). In fact, intensification is often treated as a singular, uniform process, rather than a highly variable one (Taylor and Taylor 2012). Each intensification episode is shaped by context-specific circumstances that determine its duration, intensity, and trajectory, all of which are framed by the particular resources and constraints available to an individual or community at a given moment (Morrison 1994:111–112).

Third, the apparent character of intensification, its pathway, trajectory, and consequences depend on the scales at which it is viewed, the field of examination, observed variables, and the particular questions being asked. For this reason, examining intensification requires a clearly defined question and a focus on its specific environmental and cultural setting. Such an approach not only illuminates the process itself and its consequences but also reveals how intensification influences the trajectory of the next cycle. Morrison (1994) argues that the divergent ways and paths of intensification observed across studies and fields often result from holding one variable—space, labor, or technology—constant while the others change (1994:115). She suggests that the choice of which variable remains fixed strongly influences which aspects of an intensification trajectory are emphasized (1994:125). Consequently, multiple models of examining intensification exist, each with its own implications and outcomes (Taylor and Taylor 2012).

Despite the differences, most definitions of intensification ultimately view it as a societal strategy for addressing newly emerging stress or demands which could be environmental, demographic, social, or political factors, or as a natural and inevitable outcome of the human condition (Morrison 1994:111–112). For example, Tringham and Krstić (1990) argue that when examining technological intensification, several elements must be considered: the composition of the labor force, the organization of work, consumer behavior, the relationship between producers and consumers, the power structures that shape production, and the role of exchange in structuring relations both within and between societies. However, only some of these elements are observable in the deeper past.

Archaeology—and anthropological archaeology in particular—offers a uniquely powerful toolkit for examining intensification. Because archaeological data is inherently rooted in the past, it allows researchers to observe intensification from multiple angles across time and space and to

compare how these processes unfolded within and between communities. By enabling the investigation of context-specific patterns and the tracing of human behavior, archaeological methods reveal how episodes and processes of intensification arose and progressed, as well as the variables and pathways that shaped them and their consequences that transformed societies and landscapes over time.

2.3 Anthropology and Archaeology: Theoretical View of Intensification

Similar to other studies, intensification in archaeology has been examined primarily in areas of subsistence and craft production. In both, intensification is often seen as a societal strategy, like specialization, diversification, and innovation (Morgan 2015).

In the examination of intensification, authors often adopted Boserup's (1965) model in which population growth and density play a role in technological innovation (and consequently intensification models). However, in archaeology, this concept has also faced criticism, which argues that the outlined population is neither the sole nor the dominant catalyst for intensification (Morrison 1994). Rather, the stressors could be one or a constellation of environmental or social factors, including social expectations such as health, prestige, and security, or the demands of external powers, such as elites or markets (Halstead 1989).

In these models, however, there is little discussion of how the type and severity of the stressor impact the expression of intensification. Instead, the majority of the discussions have focused on the type of stressors that influence how intensification is actualized. Morgan (2015) summarizes them in two main groups: top-down and bottom-up (Morgan 2015:166).

In his description, top-down approaches have tended to view intensification through the lens of political economy. Within this framework, intensification is understood as a strategic response to resource pressures imposed by elites, based on the assumption that farmers are generally not inclined to produce beyond their immediate needs (Earle 1997; Erickson 2006). This assumption follows Sahlins' explanation of the "biological law of the minimum,", where individuals are not prone to produce more than needed, as the concept of "enough food" provided stability of social life, which he deemed critical for intensification (Sahlins 1972:37). In contrast, his description of bottom-up approaches frames intensification as a risk-management strategy undertaken by households or communities to buffer uncertainty and reduce stress (Morgan 2015).

The generation of surplus—whether for elites or for communities themselves (Morgan 2015)—is a common theme in the studies of intensification of subsistence and technological practices. Yet important differences remain in how intensification is conceptualized across these domains. In technological studies, intensification is framed as a stage of production aimed at meeting broader societal needs, linked to, but ultimately extending beyond, basic survival (Godelier 1978). More so than in subsistence models, craft-production studies tend to follow the basic Boserupian model (1965) —in which intensification is expressed as an increase in output that requires greater labor investment, more time devoted to specific tasks, and adjustments to techniques to enhance production efficiency or benefits (Costin 1991, 2008; Bettinger et al. 2006; Morgan 2015:165).

Although in both subsistence and craft production studies, increased resource inputs are often represented primarily as labor, Renfrew (1982) emphasized that the organization of labor is a critical factor shaping the nature and scale of intensification. Its organization stands not only in terms of the size of the labor gathered but also in terms of its efficiency. This emphasis aligns with a broader view of technological intensification as a process oriented toward maximizing efficiency (Stankiewicz and Moulijn 2002).

2.4 The Placement of Intensification Within the Technological (Life) Cycle

As hinted in previous sections, the process of intensification can be observed either over long timescales or within individual stages of a technological sequence. These different scales of observation offer distinct perspectives on how intensification operates within a technology's lifespan. In fact, the analytical lens shift depending on whether intensification is examined along a broader technological curve or within a single technological cycle, and the choice between them depends on the specific questions being asked.

From the discovery of fire and the development of the first lithic and metallurgical tools to modern technologies such as smartphones and watches, individual technological advancement follows a common cycle: innovation, production, intensification, and overexploitation (Ottaway 2001) (Figure 2.1). This is termed a technological cycle or technological life cycle (TLC), as described in technological studies (Markard 2020).

Technological life cycles have often been treated as static, linear systems that progress predictably from one stage to the next (Tassey 2020). However, recent research argues that these cycles are far more dynamic, continuing to change and adapt throughout their duration (Markard 2020). From this perspective, each stage of the technological cycle responds to, and is reshaped by, internal and external triggers. This theoretical framework adds nuance to the earlier discussion of intensification (Morrison 1994). Intensification is not only prompted by a trigger that provokes the reorganization or reallocation of resources, but is also continuously shaped by external circumstances, which determine the duration and intensity of the process itself.

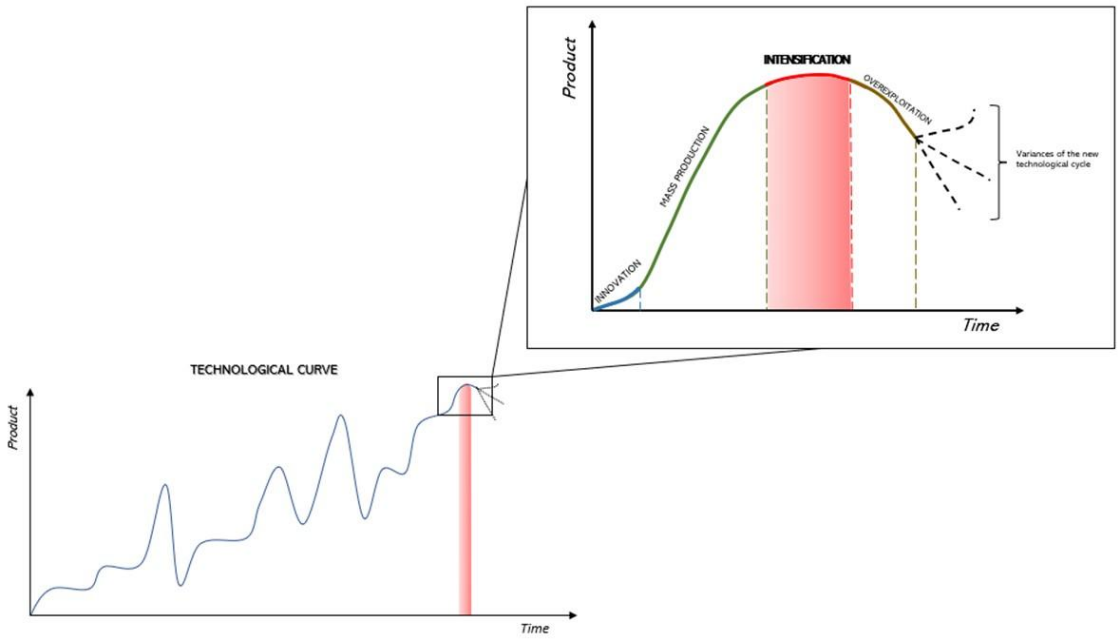


Figure 2.1 On the left - A graph illustrating the technological trajectory; on the right - zoomed-in view of a single episode of intensification, with its progression and outcomes

2.4.1 The Technological Life Cycle

To better understand the process of intensification, however, it is crucial to understand how different stages of the technological life cycle evolve. Every new cycle begins with a trigger, whether internal or external, conscious or subconscious. With accumulated knowledge and, often, a series of trial and error, the first glimpse of the solution comes to sight— 'invention'. Radivojević et al. (2021) illustrate this dynamic in their discussion of the origins of metallurgy, arguing that

familiarity with metal-rich stones—found in settlements as colorful beads millennia before metallurgy fully developed—likely represents the earliest glimpse of its innovation.

While invention can be understood as a "series of experiments," it is an external need that ultimately triggers innovation. Musiolik et al. (2020) describe innovation within the framework of Technological Innovation Systems (TIS), a perspective that can be broadly applied to studies of technological cycles. In their model, innovation occurs when intentional strategic actions are taken to reevaluate and reallocate resources—a process they term 'system building.' System building is responsible for carrying out the sequential stages of the technological life cycle, yet it remains highly dependent on—and constrained by—the resources available at any given time (Markard 2020; Musiolik et al. 2020).

The post-innovation phase is the exploitation (or production) stage. During this stage, an individual or community develops the ability to replicate or transmit innovation to others. In archaeological terms, this would be the point at which new technology begins to appear across multiple settlements within the region of discovery or initial introduction, although it has not yet become widely or uniformly adopted.

As is often the case in human societies, once a community adopts an 'innovation', it slightly modifies it according to its own social, environmental, and technological ability (Taylor and Taylor 2012). This process produces variability in the innovation, which forms the basis for both contemporaneous and subsequent innovations (Montes-Landa et al. 2024).

With the continued production, and cycle eventually reaches a temporary equilibrium in which the technology becomes widely utilized, and the initial demand that started the cycle is satisfied (Bettinger et al. 2006). At this point, a new external trigger (or a set of them) typically emerges. This trigger prompts a reorganization of the system and often necessitates an increase in resource investment, effectively 'overstretching' the existing structure. This process is called intensification.

The consequences of the system's "overstretching" become quickly evident. Examples of such consequences may take many forms, like smoke from numerous hearths in rock shelters (Kedar and Barkai 2019) or houses (Shillito et al. 2022), which impairs breathing or increases the

risk of destructive fires; the substantial waste generated during lithic or metallurgical production, which alters the immediate living environment; or, in contemporary contexts, the overconsumption of digital tools, which fosters overreliance and social isolation (Wiederhold 2025). Each of these examples reflects the cumulative effects of many smaller episodes of intensification that, over time, lead to a set of unwanted negative impacts.

It is during the intensification process that costs eventually outweigh benefits, leading to the final stage of the cycle—"overexploitation." In this phase, the strategies, mechanisms, and efforts that underpinned the current cycle are no longer sufficient to meet the needs of individuals or society. Often accompanied by internal or external pressures, overexploitation triggers a reorganization of resources—energy, time, and labor—in an attempt to manage the emerging stress. This is when a new technological cycle within the technological curve begins.

Thus, while intensification can, in the short term, successfully address newly arising stressors, the process inherently reduces a system's resilience and flexibility over the long run. Its consequences are evident in both subsistence and craft-production contexts and can significantly affect a community's quality of life by its capacity to absorb shocks. At this point, the benefits of increased production associated with intensification can give way to unforeseen—and often negative—outcomes. These include soil-nutrient depletion, environmental pollution, and long-term impacts on human and animal health (Alloway 2013; Hejna et al. 2018; Briffa et al. 2020).

2.5 The Unwanted Results of Intensification

Negative or unintended consequences of intensification in subsistence studies often arise from the desire to increase soil productivity. Concepts such as 'sustainable intensification' aimed at enhancing agricultural yields with minimal environmental impact and without expanding the agricultural land base, are grounded in these approaches (Loos et al. 2014:356). However, Loos et al. (2014) argue that the inputs commonly used to boost soil fertility, such as fertilizers and pesticides, pose severe threats to biodiversity, particularly in fragile ecosystems, and contribute to topsoil degradation by altering soil composition and compaction. This not only diminishes returns over time (Morrison 1994) but also accelerates long-term soil decline.

In contrast to substance studies, craft-production studies rarely address unwanted outcomes or diminishing returns (Morrison 1994). One reason is that intensification in these contexts is often associated with gains in efficiency and innovation, such as reduced reaction times or lower impurity levels (Stankiewicz and Moulijn 2002).

Nevertheless, both subsistence and craft-production systems are ultimately constrained by resource availability and costs, and when these limits are exceeded, negative consequences inevitably follow—from aggravated health conditions to the depletion of key resources. One of the most widely recognized historical examples is the severe health impacts caused by escalating pollution during the Industrial Revolution of the eighteenth century (Ashton 1997).

2.5.1 Pollution and Contamination as Consequences of Intensification

To this day, one of the most damaging consequences of intensified human activity is pollution and contamination. Scientists often emphasize that we live in a polluted world, filled with lead, microplastics, and other contaminants. However, one of the most dangerous forms of pollution is heavy metal pollution. Such contamination affects not only environments and ecosystems—threatening the very existence of habitats and human societies—but also human health and development (Skinner and Berger 2003). Heavy-metal pollution may result from long-term intensified production or from catastrophic events, and in both cases, the accumulation of toxic waste degrades air and soil, ultimately entering the food chain and impacting human well-being.

"Now, with the prospect of stems threaded through with copper and leaves of gold fresh stumps spilling with a silvern sap, flowers dripping their nectars of nickel; now that we find ourselves in a world iced with arsenic and soaked in lead, and it all the world of our own hands, the notion feel less ignorance than foresight." (Flyn 2021:197).

Today, we are well acquainted with numerous events that have caused severe pollution—from the 18th-century Industrial Revolution, mentioned above, to catastrophic events of the twentieth century, such as both World Wars, to nuclear-power-plant explosions exemplified by Chornobyl in Ukraine.

The lingering effects of production and warfare remain visible in many modern environments. A striking example is the Zone Rouge near Verdun, France, where extensive shelling during the First World War (1914–1918) left the soil heavily contaminated. Despite reforestation efforts, analyses conducted in 2007 revealed extremely high concentrations of arsenic, zinc, and lead (Flyn 2021:187). The area remains nearly barren today, with only a limited number of plant species able to survive. Yet it is precisely with these plants that we can observe the emergence of a new human–environment feedback loop.

2.5.1.1 Heavy-Metal-Loving Plants, as an Example of the Human-Nature Feedback Loop

This principle of the human-nature feedback loop is hardly new: comparable action–reaction dynamics have long been recognized in fields ranging from physics to ethics and policymaking. Similar feedback mechanisms also characterize the relationship between humans and their environments (Marsh 1864), where human actions alter ecological conditions, which in turn shape subsequent human responses (Figure 2.2).

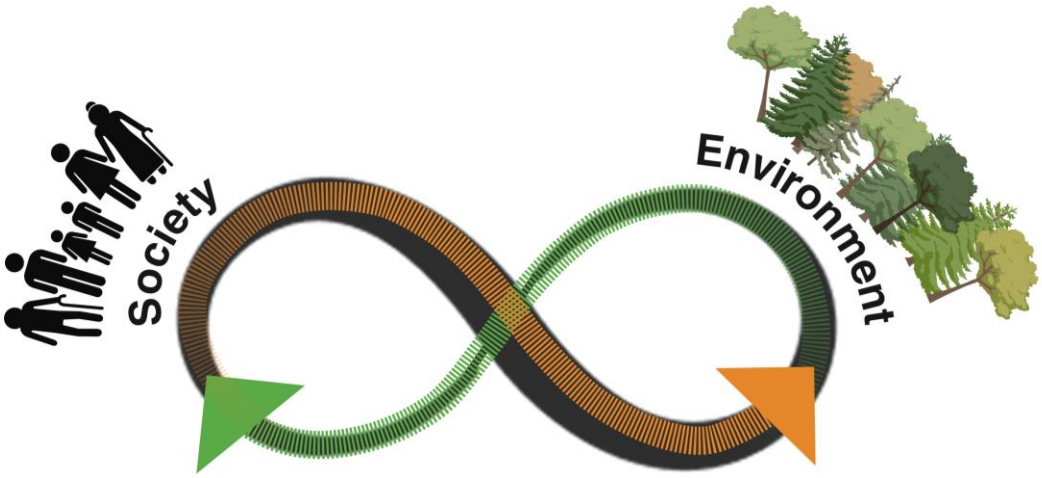


Figure 2.2 The feedback loop between humans and the environment. Created in https://BioRender.com

Feedback loops exist in nature in the absence of human interference; however, humans can certainly be considered drivers of their change (Chin et al. 2014). In fact, humans left their fingerprint on the environment even before the innovation of fire. However, our activity became more impactful from the Holocene onward, when human activities began to alter the environment.

Today, scientists stress that we live in the Anthropocene, the period when humankind is recognized as a force shaping natural processes such as evolution (Crutzen 2006; Crutzen and Stoermer 2022).

Similarly to the discussion of intensification, the full extent of human impact on the environment, and consequently on societies, will be known retrospectively. However, our human actions will be forever imprinted in both local and global scales (Longman et al. 2018). From agricultural and husbandry practices to mining, human activities have contributed to soil depletion, erosion, hydrological change, and environmental contamination, leading to widespread habitat and biodiversity loss. Through predictive models that manipulate individual variables, scientists attempt to identify which feedback loops most strongly influence the long-term sustainability of human societies. The reality is that we are likely already living within advanced stages of intensification and are rapidly approaching—if not already entering—phases of overexploitation. At this point, it is worth considering that intensification, through its continual overextension of resources, not only heightens societal vulnerability and reduces resilience but can, under certain conditions, contribute to systemic collapse. It is therefore imperative for contemporary societies to identify alternative, sustainable pathways that do not rely on intensification. Encouragingly, some of these possibilities emerge from feedback loops themselves. One such example is found in metallophyte plants.

Living in areas highly contaminated with heavy metals, metallophyte and hyperaccumulator plant species often thrive. Metallophytes are plants that have evolved increased tolerance to elevated metal concentrations and naturally inhabit contaminated environments; thus are considered an important component of regional biodiversity (Baker et al. 2012).

Hyperaccumulators, on the other hand, are a group of metallophyte plants capable of absorbing heavy metals from the soil and storing them in their above-ground tissues at concentrations that exceed typical physiological thresholds. In some cases, these plants can accumulate trace metals at levels up to 500 times higher than those found in non-accumulating species (Skuza et al. 2022). These plants grow in both naturally and anthropogenically contaminated soils. Baker et al. (2012) note that they commonly occur at historical mining sites, in areas affected by atmospheric deposition near metal smelters, and within alluvial deposits enriched by metals from river floodplains or elevated riverbanks (10–11).

"Metal-loving" plants offer one of many illustrations of human–environment feedback loops—systems that continue to shift as human activities intensify. Metallophytes thus show one way of the adaptability and flexibility of the larger system. The same flexibility and adaptability can be traced in societies and human activities. In fact, as Markard (2020) noted, the technological life cycle reacts to and adapts to changes.

In summary, while both past and present societies have witnessed the consequences of intensification—most notably pollution and environmental degradation—it remains possible that our current trajectory could give rise to a new life cycle, and with it new opportunities. Although for contemporary societies, such possibilities lie in the future, we can get insight into how past communities responded to the pressures and consequences of intensification. However, before I begin to unravel how intensification was expressed, it is essential to examine the impacts of toxic elements on people, animals, and the broader environment. The next chapter (Chapter 3), therefore, explores how different scientific fields have approached the 'real-world' implications of intensification through a detailed examination of pollution and contamination.

Chapter 3 Real-World Impacts of Intensification: Bio-Toxicological Review of Pollution

While the initial goal of intensification is increase production, and in this work is understood as the process during which resources are stretched, as discussed in Chapter 2, intensification often produces unexpected consequences. This dynamic is well captured by the psychological principle of 'too much of a good thing,' in which even beneficial circumstances can become harmful when taken to excess (Britton 2019). The same principle applies to technological processes; when overextended or overexploited (when intensified), technologies can generate unintended negative consequences for people, animals, and the wider environment. These dynamics are not limited to modern contexts; they also apply to past technologies. One of the earliest human technologies to reshape local environments was metallurgy.

At every stage of the metallurgical process, some trace elements and heavy metals, inherent components of ores, are released into the surrounding environment, altering soils, water sources, and biological systems. What makes it particularly relevant to archaeological contexts is detection of the increased volume of released heavy metals, which accumulate in living beings and the environment and offers the opportunity to track technological change, past social responses to the craft, and the impacts of ancient metallurgy on the environment.

Drawing on interdisciplinary literature from public health and environmental sciences, this chapter provides essential background on the impacts of intensified releases of heavy metals. It outlines the distinction between contamination and pollution, the associated health and ecological consequences of particular heavy metals and examines the diverse ways these issues have been approached across scientific disciplines, including archaeology.

3.1 Contamination Versus Pollution

Pollution and contamination are challenges studied across scientific disciplines, though the terminology varies. The differential use of the two terms is likely associated with the different

avenues and goals of studying contamination and pollution. Before delving into a detailed description of how different sciences use these terms, it is important to clarify the distinction between two.

In an effort to define "pollution," Chapman (2007) emphasizes that weighing the evidence is a critical first step in assessing environmental impact. The type of elements released plays a decisive role — although all pollutants are contaminants, not all contaminants qualify as pollutants. The sources and abundances of these elements are equally important for distinguishing contamination from pollution (Guidotti 2015).

Contamination refers to the introduction of substances into the environment, whether anthropogenic or natural, whereas pollution denotes the extreme stage of contamination (Guidotti 2015). Pollution is typically the result of human activity, marked by the continuous and cumulative release of harmful substances into ecosystems, with detrimental effects on humans, animals, and the environment.

Given the substantial social and political weight carried by the term pollution—particularly in contemporary discussions of environmental and social justice—in this dissertation, I use the more neutral term contamination. This choice avoids imposing a priori assumptions of societal reactions to the impacts of intensifying metallurgical production, while also describing the presence, absence, and abundance of heavy metals.

Archaeological evidence offers glimpses into how communities may have perceived or responded to these processes, allowing us to identify patterns in their reactions over time. Yet in interpreting such patterns, it is crucial not to assume societal responses, as they might not be aligned with the concerns emphasized in modern interdisciplinary fields such as public health or geo-medicine. For example, past societies may or may not have recognized or linked health or environmental issues with the effects of heavy-metal exposure. Furthermore, they may not have conceptualized or addressed their impacts in ways comparable to present-day understandings, including utilizing exposure as a measure of their own benefit. Finally, the possibilities I present may not have applied to all communities or individuals. Nevertheless, while individual reactions remain largely inaccessible, certain forms of social response to technological intensification can

be identified, even when direct health or ecological impacts cannot be fully reconstructed from the available data.

3.2 Patterns of Heavy Metal Contamination

Interdisciplinary studies define 'heavy metals' as metallic elements with greater atomic mass and densities higher than that of water (Ali and Khan 2018; Hejna et al. 2018). These include iron (Fe), cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), zinc (Zn), chromium (Cr), cadmium (Cd), mercury (Hg), lead (Pb), and arsenic (As).

Although heavy metals are generally toxic, several—including iron (Fe), iodine (I), cobalt (Co), zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo), and selenium (Se)—are essential for maintaining physiological functions in humans, animals, and plants (West 2006; Kamenov and Gulson 2014; Hejna et al. 2018). These elements are also referred to as essential microelements because they are required only in very small quantities for maintaining normal biological functions. However, although many occur naturally at low concentrations, excessive exposure can disrupt physiological processes and contribute to broader environmental pollution.

Other heavy metals, such as arsenic (As), cadmium (Cd), fluorine (F), lead (Pb), and mercury (Hg), serve no biological function and are considered hazardous to human health. These elements are commonly used as indicators of pollution and, due to their high toxicity, can induce organ damage even at very low exposure levels (West 2006; Hejna et al. 2018).

The type of contamination resulting from metallurgical activity can be linked to heavy metal contamination for two reasons. First, all ores, apart from their main components[1], contain at least trace amounts of heavy metals, including lead; second, at any stage of the activity, depending on the ore type, different amounts of heavy metals (such as arsenic, cadmium, and lead) are often released into the environment.

3.2.1 Heavy Metals: Exposure, Contamination and Consequences

The toxicity of heavy metals depends on multiple factors: the specific element, dosage, exposure pathway, and individual profiles such as sex, genetic predisposition, nutritional status, and overall health (Jaishankar et al. 2014; West 2006).

[1] Different ores contain different amount of metal mineral which includes copper, lead, zinc and iron (Robb 2020).

In this research, the heavy-metal elements discussed in detail include zinc (Zn), iron (Fe), barium (Ba), strontium (Sr), manganese (Mn), arsenic (As), lead (Pb), copper (Cu), cadmium (Cd), tin (Sn), and uranium (U). While some of these elements—such as Fe, Zn, Cu, and Mn—are essential nutrients at low concentrations, others, including Pb, As, Cd, and U, are toxic even in trace amounts.

While the threshold dose varies by element, all heavy metals in excess can cause severe effects. For humans and animals, this could include organ and nervous system damage, impaired growth and development, carcinogenesis, and, in extreme cases, death. For example, lead and mercury in soils are especially toxic to developing fetuses, infants, and young children, as they can cross the placenta and damage the fetal brain (Jainshankar et al. 2014). These elements accumulate in organs such as the liver, kidneys, and bones, though bioaccumulation is less pronounced in products like milk, eggs, and muscle tissue (Hejna et al. 2018). In soils, heavy metals can disturb soil biota, reduces soil quality and transmitting harmful effects to plants, grazing livestock, and, ultimately, humans (Table 3.1).

Element	Type	High exposure effects	Sources and bioaccumulation risk	References
Manganese (Mn)	essential nutrients	General weakness, emotional disturbances, spasms and cramps	*Food:* greens, tea, beans, oils.	Hejna et al. 2018.
Iron (Fe)	essential nutrients	Heart disease, cancer, diabetes, choroiditis, retinitis and conjunctivitis; attack the DNA- mutation, cellular damage	*Food*: meat, whole meal products, potatoes and vegetables, rice; *Other*: water, flooded soils;	Jaishankar et al. 2014; Hejna et al. 2018.
Copper (Cu)	essential nutrients	Liver and kidney damage and stomach and intestinal irritation; cardiovascular risk; lung cancer;	*Food*: bread and cereal products, vegetables and legumes, offal, milk; fish and seafood; *Other:* water; soil; ores	Bost et al. 2016; Hejna et al. 2018.

Zinc (Zn)	essential nutrients	Correlated to copper exposure; impacts brain, respiratory track, gastrointestinal track, prostate cancer; metal fume fever (MFF)	*Food*: grains, beans, citrus, corn, rice; *Other:* water, soils, industrial processes and military use (such as zinc chloride);	Plum et al. 2010; Naulas et al. 2018
Arsenic (As)	toxic	Skin issues and damage; increased risk of cancer - skin, lungs, liver and bladder; issues with circulation; cell malfunctioning;	*Food*: Fish, seafood (crab) and animal offal; *Other*: water, soil; industrial activity; pesticides; fertilizers, pesticides; Vulcanic activity, rock erosion, forest fires; by-product of copper and lead smelting	Martin and Griswold 2009; Jaishankar et al. 2014; Hejna et al. 2018.
Strontium (Sr)	present but not essential	Issues with bone mineralization; renal issues; impacts calcium;	*Other*: Industrial purposes; Water; soils	Shroeder et al. 1972; Cohel-Solal 2002; Zhang et al. 2018;
Cadmium (Cd)	toxic	Organ damage, such as kidney and liver, leading to iron deficiency; skin irritation; Disease: ulceration, enzyme inactivation, lung cancer; it accumulates in the body throughout life; replaces zinc;	*Food:* whole grains, cereals; fruit, root vegetables, wild mushrooms; shellfish; Presence in animal: liver and kidney, low in muscle, low in milk and eggs: very *Other:* tobacco smoking; batteries, pigments, fertilizers, soils, rocks;	Martin and Griswold 2009; Jaishankar et al. 2014; Hejna et al. 2018.
Tin (Sn)	present but not essential	Lung issues, gastrointestinal issues;	*Food*: grains, dairy, vegetables; *Other*: lichen and moss; canned food, mining; soils; water; soaps, industrial use;	Clima 2011; Harbinson and Johnson 2015; Hejna et al. 2018.

Barium (Ba)	present but not essential	Abdominal, breathing issues, increased blood pressure and heart issues, muscle weakness;	*Food:* milk; *Other*: Industry purposes - laps, spark plugs, vacuum tubes; fireworks, drilling, paint, ceramic, rubber; waterlogged soil;	Martin and Griswold 2009
Lead (Pb)	toxic	Impaired neurodevelopment: lower IQ, shortened attention span, hyperactivity, and mental deterioration (particularly in children), loss of memory and injury to the brain and nervous system; insomnia; Impaired bone development; Other symptoms and diseases: nausea, anorexia, weakness of the joints, red blood cells, and kidney issues; replaces calcium.	*Food:* leafy vegetable, root crops, fish and shellfish, cereals; Presence in animals: muscle (low and not significant), milk; *Other*: water; industrial activity; gasoline until 1960's; smoking, pluming pipes, paint; impacts plant growth; smelting of ores	Martin and Griswold 2009; Jaishankar et al. 2014; Hejna et al. 2018;
Uranium (U)	toxic	Cancer, severe respiratory issues and organ damage, primarily the kidney; neurological issues; cellular damage;	*Food*: Fish and seafood, oils and fats, milk; *Other*: nuclear power technology and industry; radioactive aerosols; military;	Bellés et al. 2013; Zhang et al. 2022

Table 3.1 Table showing examined elements, associated effects, sources and references

The amount and duration of exposure to heavy metals can result in either acute or chronic poisoning. Acute toxicity arises from a high exposure over a short period of time, whereas chronic toxicity reflects the bioaccumulation of low-level exposure over extended periods. Heavy metals bioaccumulate in tissues because they are stored more rapidly than they are excreted, making them particularly harmful (Hejna et al. 2018). While acute poisoning produces more immediate and drastic effects, chronic exposure, or prolonged contamination of agricultural soils can lead to long-lasting consequences, including environmental degradation (Hejna et al. 2018).

Exposure pathways include ingestion, inhalation, and dermal contact (Figure 3.1). In both humans and animals, the nutritional requirements for trace elements have been outlined by European Union legislation (EC No. 1831/2003; 2002/32/EC).

Essential elements are often added to animal feed, with concentrations adjusted according to life stage—growing, gestation, or lactation. For example, growing pigs require substantially more iron than adults; while lactating pigs require significantly higher amounts of copper. Non-essential trace elements, although not intentionally added to feed, may still be present. Their maximum permissible levels are much lower than those of essential elements, ranging from 0.1 mg/kg for mercury to 5 mg/kg for lead (Hejna et al. 2018; see Table 3, page 2159).

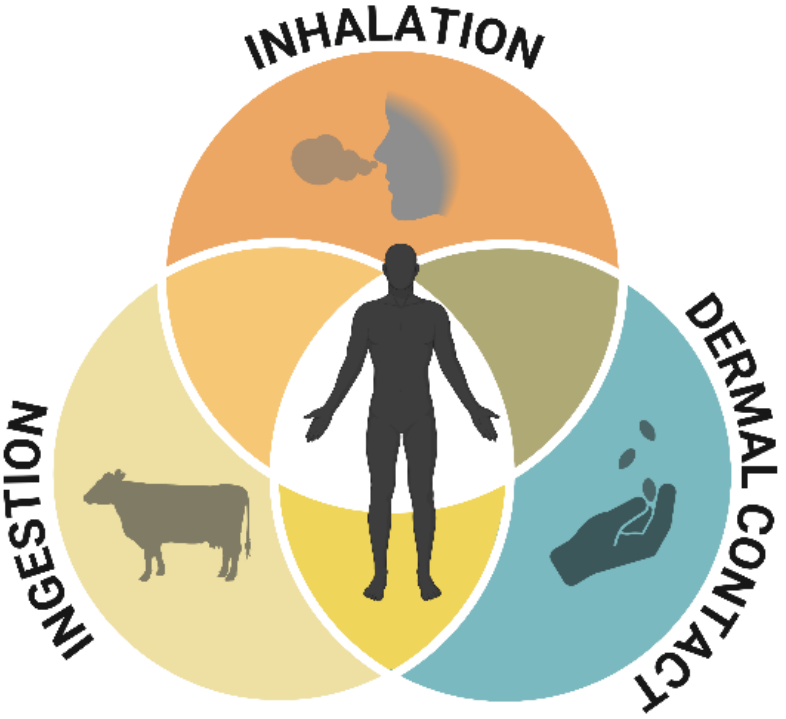


Figure 3.1 Diagram showing pathways of exposure to heavy metals affecting humans. Created in hhps://BioRender.com

The impacts of heavy metals are well studied today, largely due to the substantial increase in available data. Perhaps the sheer volume of research across disciplines has also produced a wide range of approaches to heavy-metal contamination, each shaped by field-specific questions, methodological priorities and accompanied by its own limitations.

3.3 Interdisciplinary Ways of Studying Heavy Metal Contamination

The impacts of pollution have long been investigated. As early as Ancient Greece, a work attributed to Hippocrates—*Airs, Waters, and Places* (ca. 400 BCE)—emphasized the relationship between air quality and human health (Jones 1923:83). Similar observations linking disease to environmental pollution appear across numerous civilizations, including the Roman Empire, the Arab world, the Chinese Song Dynasty, and later during the Industrial Revolution. Aristotle, for example, noted that certain activities associated with foul air were kept outside city walls; although the motivations were not solely environmental, this spatial separation persisted into the Medieval period. It was not until the 19th century, however, that formal governmental responses began to address the intertwined issues of health and environmental degradation (Fowler et al. 2020:5-6).

Investigations of historical records reveal not only an early awareness of contaminants and their health and environmental impacts but also underscore the severity of contamination levels observed in the past and today. The extent of heavy-metal accumulation is now so pronounced that researchers have concluded that "*...it is impossible to avoid the presence of heavy metals in the food chain and the environmen*t" (Hejna et al. 2018:2157). This recognition underscores the need for sustained interdisciplinary scholarly attention to the environmental dynamics of heavy metals and to the broader implications of their long-term impacts.

Since the early development of contamination studies, scientific approaches to pollution and contamination can be broadly divided into two major orientations: people-oriented and environmentally-oriented disciplines (see Figure 1 in Tomažič 2025:2). People-oriented sciences, such as public health and epidemiology, examine contamination and pollution through the lens of their immediate and long-term harms to human health, as well as their social and environmental justice implications (e.g., Cutter et al. 1996; Jaishankar et al. 2014; West 2006; Ashton 1997; McGuire 2020). They do this by examining anthropogenic activities in natural and work environments along with conducting small group examinations of individuals or animal-related studies. Within these fields, the terms contamination and pollution—including those relating to heavy metals—are often used interchangeably to describe harmful impacts on the population.

By contrast, environmentally-oriented sciences, such as environmental sciences, environmental engineering, and geo-medicine, monitor both modern and past impacts of contamination. Drawing on evidence from environmental archives—such as Greenland ice cores

(McConnell et al. 2018), snow pits (Koffman et al. 2022), local peat bogs (Grattan et al. 2004, 2013; Longman et al. 2018), soil cores, and lake sediments (Pompeani et al. 2013, 2021)—these disciplines also focus on reconstructing the long-term history, impacts, and mitigation strategies for contamination and pollution. For example, geochemical research has mapped the anthropogenic history of heavy-metal contamination in global environments, with particular attention to lead (Longman et al. 2018; McConnell et al. 2018; Pompeani 2019). These studies identified three major peaks of anthropogenic contamination prior to the modern era: the Industrial Revolution (18th century AD), the Roman period (1st century BC–4th century AD), and the Bronze Age (2500–800 BC) (Longman et al. 2018). Yet while the first peak was identified in the Bronze Age, contamination likely began with the first metallurgical activity dated to 5000 BCE (Radivojević et al. 2021).

The term pollution is primarily used to describe the introduction of toxic elements into the environment. While both people-oriented and environmentally-oriented sciences inform the public about the presence and abundance of contaminants, their shared goal is prevention: establishing guidelines and developing mitigation strategies to minimize the impacts of pollution

Nevertheless, both types of studies face notable criticisms in their study of pollution and contamination. A common critique of people-oriented research on pollution is its limited scale: experimental groups (human and animal alike) are often small and narrowly focused, and multi-generational studies remain rare. This restricts their inability to trace the long-term and wide-ranging consequences of pollutants across time and space, as the experimental groups are often placed within specific environmental conditions. Environmental studies, by contrast, are constrained by a different limitation—the tendency toward broad generalization. Because core samples frequently contain particles of toxic elements transported over long distances by processes such as wind, water, or precipitation, distinguishing localized impacts becomes challenging. Although some studies (e.g., Longman et al. 2018) have advocated for more nuanced approaches to better capture the magnitude and variability of pollution, such practices have not yet become standard. As a result, environmentally-oriented sciences often portray pollution as a homogeneous phenomenon, even though at the microscale this is frequently not the case (Longman et al. 2018).

As a result, these sciences face three major limitations:

- They cannot simultaneously observe contamination or pollution at both small and large spatial scales.

- They struggle to address both short- and long-term impacts of pollution over time.

- They rarely engage with the direct and indirect consequences of human decision-making for populations, animals, and environments.

These, however, are precisely the strengths of archaeology. By integrating micro- and macro-scale evidence, situating processes within long-term temporal frameworks, and linking material traces to human choices, archaeology offers a uniquely powerful perspective on the dynamics of contamination and pollution. However, studies of heavy metal contamination in archaeology are rare and often struggle to distinguish between metabolic and diagenetic contamination.

3.4 Contamination Studies in Archaeology

There are several reasons why archaeological research has only recently begun to engage more deeply in studies of contamination. One major factor has been the historical lack of appropriate methods and analytical techniques—a limitation that has shifted dramatically over the past two decades. Beginning with the radiocarbon revolution (Renfrew 1970), archaeology entered a new phase of interdisciplinary engagement. Today, the field employs a wide array of analytical approaches, including isotope analysis, trace-element studies, ancient DNA from humans and sediments, and proteomics, with new techniques emerging continually.

However, the rapid expansion of methods and the growing emphasis on interdisciplinarity have also produced challenges. Archaeological research can appear fragmented and overly specialized, now often lacking its interpretative power, which can only be gained by taking into account the information gained from the archaeological record. The need for holistic, yet scientifically rigorous and innovative, research is a balance that currently presents a challenge for certain studies.

Other subfields of archaeology already faced these challenges, as a similar call for holistic research has already been made in archaeometallurgy (Thornton and Roberts 2009). After almost 15 years, it appears that the subfield has moved toward a more holistic approach by incorporating technological developments and changes within community-specific contexts (for example,

Radivojević et al., 2010; Radivojević et al. 2021; Orfanou et al. 2024). Perhaps a similar trajectory will also characterize other archaeometric studies, including heavy-metal contamination in archaeology, which is at its "inception" stage.

A second reason for archaeology's hesitancy to contribute to contamination studies lies in sampling strategy (outlined in more detail in Chapter 8). Although trace-element analyses have long been applied across archaeological subfields—including archaeometallurgy (Brill and Wampler 1967; Killick and Fenn 2012; Killick, Stephens and Fenn 2020; Pernicka 2014, 2020; Pollard et al. 2009; Radivojević et al. 2019; Roberts and Thornton 2014; Stos-Gale and Gale 2009), bioarcheology, and geoarchaeology (Budd et al. 2000; Kamenov et al. 2018; Kamenov and Krigbaum 2023; Liu et al. 2013; Samuelsen and Potra 2020; Silva-Sánchez and Armada 2023; Bertacchi et al. 2024; Sharpe et al. 2022; Hillman et al. 2017)—the use of trace elements to discuss questions of pollution and contamination in archaeology have rarely been addressed.

This reluctance stems largely from issues of effectively detecting and isolating the diagenetic signal. Described as a chemical and physical process between the object and the buried environment, diagenesis affects all types of buried material. The extent of diagenetic impact on the material varies depending on the duration of the interaction with the burial environment, the type and conditions of the burial environment, and the material itself prior to deposition, including its porosity (Hedges 2002; Loy et al. 2023; Müller et al. 2011; Nielsen-Marsh and Hedges 2000; Price et al. 1992).

Thus, quantifying the extent of diagenetic impacts remains challenging. Including differentiating between the metabolic (in vivo anthropogenic signatures result from contamination and pollution) from post-depositional alteration (Hedges 2002; Loy et al. 2023; Nielsen-Marsh and Hedges 2000; Price et al. 1992; Bertacchi et al. 2024). However, with appropriate sampling strategies and analytical methods (discussed in Chapter 8), this research argues that these challenges might be mitigated, opening new possibilities for investigating contamination in the archaeological record.

By combining the archaeological record with contamination signatures from environmental datasets, it becomes possible to track fluctuations in pollution across time and space. Global environmental data (Longman et al. 2018) have demonstrated that increases in contamination levels can be linked to varying intensities of past metallurgical production, revealing these fluctuations on a global scale. However, if metallurgical activity can be detected at such broad scales, it is reasonable to expect that some of these shifts may also be observable at more local levels. Even more so on the local level it may be possible to identify changes within the metallurgical technological curve and cycle, offering insights into the societal expressions of intensification. To establish such lines of evidence, however, it is first necessary to situate metallurgical development within a broader historical trajectory. For this reason, the next chapter (Chapter 4) examines the history of metallurgy, providing the foundation for assessing its wider social and environmental impacts.

Chapter 4 Background to the Intensification of Metallurgy

Chapter 4 presents the state of the art of intensification of metallurgical activity, organized around two major themes. The first section traces the evolution of scholarly discourse on metallurgy. I begin with anthropological perspectives on the significance of metallurgy, drawing on theories that address its diffusion across societies. The discussion then turns to concrete examples of metallurgy's societal implications, including depictions of metallurgists in European iconography and literary traditions. I conclude this section by identifying ongoing challenges within these debates and outlining current academic discussions, thereby setting the stage for a more focused examination of why certain aspects of metallurgical activity remain difficult to identify and interpret archaeologically.

The second part of the chapter turns to metallurgical production as a process, drawing directly on archaeological evidence. Here, I adopt Ottaway's concept of the metallurgical *chaîne opératoire* (Ottaway 2001) as an analytical framework, while maintaining a holistic perspective that situates metallurgy within its broader technological and social contexts. This approach enables a systematic presentation of metallurgical stages, operational sequences, and their associated archaeological signatures. The chapter concludes by situating metallurgical activity and its intensification within the technological cycle introduced in Chapter 2 and hints at ways it could be studied, as presented in Chapter 3. Together, this perspective clarifies the broader implications of intensification for metallurgical practice, setting the stage for the case study presented in Chapter 5.

4.1 The Social Role of Metallurgy and its Problems

The enduring qualities of metal—its preservation, durability, malleability, and relative rarity in archaeological contexts—have positioned metal artifacts as "cultural barometers" within archaeological research (Prescott et al. 2000:215). This framework builds on the foundational work of Christian J. Thomsen, whose three-period system—Stone, Bronze, and Iron Ages—provided

not only a chronological platform for further archaeological research but also marked the inception of typological classifications for metal objects in European archaeology.

Interest in metallurgy gained significant momentum during the 19th and 20th centuries, driven by influential scholars such as V. Gordon Childe. His seminal work portrayed Bronze Age production as a technological and cultural turning point in human history (Childe 1944: 9; Childe 1951). Childe argued that the durability of metal tools (over their stone counterparts) enhanced social productivity and control over the environment, thereby catalyzing transformative shifts in societal organization and facilitating the rise of elite classes.

Other anthropologists attributed the emergence of complex societies and elites to increased and specialized production (Childe 1944; Earle 2002; Kristiansen and Larsson 2005; Earle and Kristiansen 2010) —an interpretation rooted in Adam Smith's political economy models (Smith 1776) and Karl Marx's production of wealth models (Marx 1922). Control over specialized production—particularly metallurgical activities, from ore extraction to artifact circulation—has been argued to have been an indicator of elite authority (Kristiansen and Larsson 2005; Earle and Kristiansen 2010). This dynamic underscored the perceived value of technical knowledge not just as a skillset, but as a currency of power. Within this theoretical framework, metallurgical expertise is regarded not merely as technical proficiency but as a repository of specialized knowledge encompassing materials science, environmental awareness, and climatic adaptation.

Metallurgical expertise was long regarded as both unique and highly complex, leading early scholars to argue that it was held exclusively by a select few—most notably, itinerant smiths (Childe 1944). According to Childe, these metallurgists constituted a distinct class of full-time specialists who moved between communities, disseminating technical knowledge and facilitating the spread of metallurgical innovation (Childe 1944; 1963). Their specialized skills were understood to function as a form of socio-economic currency, conferring status, influence, and even elite identity upon those who possessed them (Childe 1944; Prescott 2000). While foundational, this interpretation opened the door to a critical reassessment of the origins of metallurgy, its developmental chronology, and the societal roles of its practitioners.

4.1.1 The Metallurgist(s) Image

Determining the social position of metalworkers has yielded diverse scholarly perspectives. In contrast to Childe's idea of itinerary smiths, Rowlands (1971) and Burges (1980) argued that metalworking was often a part-time activity, shaped by fluctuating societal needs. The role of metallurgists as full-time specialists was not an idea they supported. Kienlin (2008; 2013) offered a more nuanced view, proposing a coexistence of both models—where smiths were either autonomous specialists or integrated into kinship-based structures. Earle (2002), in turn, distinguishes two kinds of metallurgists: independent specialists, who traded in exclusive knowledge, and attached specialists, who served the needs of elite individuals. This spectrum of roles was argued to reflect varying degrees of autonomy, with some craftspeople enjoying mobility and freedom, while others operated within elite-controlled systems (Earle 2002: 128–129).

To aid scholars in reconstructing the "metallurgist image", a variety of theories and techniques are used to deduce the social dimensions of metalworking, namely, ethnographies, imagery and iconography, chemical analyses, burial assemblages, and studies of objects related to metallurgical activity.

The use of ethnographic analogies in archaeological research has been widely debated (Molloy and Mödlinger 2020), and as Kuijpers (2013:140) cautions, such comparisons often lack firm contextual grounding in prehistoric technological and social realities. Bronze Age smithing, in particular, has been shaped by speculative hierarchies in which the presumed difficulty of producing certain artifacts has led to untested assumptions about the distinct roles and elevated statuses of metalworkers, especially within elite contexts (Molloy and Mödlinger 2020:173).

Historical imagery, folklore, and mythology offer divergent portrayals of metalworkers, revealing a diverse cultural narrative. In Norwegian agro-pastoralist folklore, metallurgists are imagined as "underworld dwarf-smiths," symbolic custodians of herd health and well-being, along with forces related to life and death (Prescott et al. 2000: 222). In contrast, folklore from Rodik, Slovenia, depicts smiths as brutish, gruff figures living at the fringes of society. Literary interpretations of metallurgists vary as well; Mircea Eliade's The Forge and the Crucible: The Origins and Structure of Alchemy (1956) presents metallurgists as alchemists—a depiction that echoes Childe's view of early smiths as keepers of arcane, transformative knowledge.

The social perception of metallurgists can also be found in myths and folktales. In Ancient Greek tradition, Hephaestus—the god of fire, volcanoes, and blacksmithing—is depicted with physical imperfections, possibly alluding to the bodily consequences of his craft. His Roman counterpart, Vulcan, similarly embodies this narrative (Durman 1988). These mythic portrayals highlight how metalworking was viewed not only as a skilled endeavor, but as one carrying physical and symbolic weight—sometimes evident on the body itself (Doonan et al. 2007).

Despite the physically demanding and potentially hazardous nature of metallurgy, and despite mythic and iconographic portrayals of metallurgists as deformed, no individuals with such deformities have yet been identified in the archaeological record. In response to the "search for metallurgists" some researchers have attempted to trace evidence of metallurgical activity through bioarcheological means, such as examining skeletal remains (particularly bone) for chemical signatures of exposure to metalworking environments (e.g. Levy et al. 2002). However, these studies have been met with skepticism, as critics suggest that many of the observed signals could result from post-burial diagenetic processes rather than occupational exposure (Hedges 2002; Krajcarz 2019; Millard 2006; Pike and Richards 2002; Rasmussen et al. 2019; Nielsen-Marsh and Hedges 2000).

Molloy and Mödlinger (2020) approached the question of the metallurgist's role by compiling one of the most extensive surveys on the topic, identifying 518 graves across Europe potentially belonging to metallurgists. These graves were discovered in regions including Northern Europe, West Germany, Central and Eastern Europe, and the Iberian Peninsula that contained metallurgy-related items dating to the Bronze Age. The grave goods found ranged across the full spectrum of the metallurgical *chaîne opératoire*—from mining and smelting to casting, shaping, and distribution (Molloy and Mödlinger 2020:174). However, despite the presence of rich metal objects, there is no clear evidence from cemeteries that directly links individuals or communities to metallurgical production.

This likely reflects both the limits of prehistoric burial evidence (for example, the lack of written records and tombstones) and the wide variety of grave goods. As reported by Molloy and Mödlinger (2020) the assemblages found in graves were composed of numerous artifacts and types, which complicates efforts to establish a standardized profile for prehistoric metalworkers.

Killick (2014) also argues that, even if metal artifacts are frequently classified as objects of prestige in archaeological literature, metals on their own might not possess intrinsic social value. Rather, their value is socially ascribed (Killick 2014). Apart from their cultural significance, including rarity, craftsmanship, and symbolic significance (Mauss 1954; Earle and Kristiansen 2010), metal objects often also possess a functional advantage (Childe 1944). This is especially true for tools and weapons, which, with their durability, would have presented a significant advantage (Childe 1944:9). However, when it comes to burial practices, there are numerous reasons why such objects were or were not part of the mortuary program.

In summary, the social role of metallurgy is highly theorized. The role of metallurgists themselves appears to have varied widely, and it lacks a consistent typology or status across regions. The diversity in representations and roles of metalworkers may be seen not as a challenge, but as an interpretive result in its own right. Rather than seeking a singular, fixed image of the metalworker, we might need to analyze metallurgical identities as socially constructed and contextually ascribed. Metalworking was likely only one of several social identities individuals held, and their status may have varied across time or space. Furthermore, the metallurgist's identity was likely shaped by the specific social frameworks in which metallurgy was practiced.

By gaining a better understanding of the role of metallurgy within individual societies, we may begin to reconstruct aspects of a metallurgist's identity. It is entirely possible that, although metallurgical production was significant for a community, the objects associated with it did not enter the mortuary program. In some societies, metallurgists may indeed have held special status; in others, they may not have enjoyed elevated standing, or they may have occupied an unusual social position that required burial outside formal cemetery grounds (O'Shea 1996:289). Finally, it is also possible that in cases where metallurgical activities were carried out by many individuals or by the community as a whole, the "special role" of the metalworker may never have been formally defined. In such cases, metalworking could have been regarded as a practical necessity rather than a socially marked identity—one that left little trace in funerary contexts.

The possibilities outlined above represent only a small fraction of the possible reasons behind the absence of a recognizable "metallurgist's identity" in the archaeological record. As a result, perhaps, as researchers, we should not base our interpretations solely on cemeteries. Instead,

attention must shift to settlements where the metal objects were produced, used, circulated, and sometimes discarded.

4.2 Studying Metallurgy and Metallurgical Remains

As is evident from the preceding discussion, the role of metallurgy within individual societies has long been intertwined with debates concerning the origins and spread of metallurgical technology in Europe. Childe famously proposed that traveling smiths from the Near East introduced metallurgy to Europe and facilitated its dissemination across the continent (Childe 1944). This hypothesis, later labelled as the ‘‘diffusionist perspective’’ (Thornton and Roberts 2009:181), generated extensive debate among scholars. Renfrew (1970; 1973), among many others, challenged this “*ex-oriente lux paradigm*”, arguing that there were local “metal-using communities” (Radivojević et al. 2021:601) and the local spread of metallurgy in Europe did not follow a single developmental trajectory (Gimbutas 1980; Jovanović 1971; Jovanović and Ottaway 1976; Lichardus 1991). Instead, metallurgical practices emerged through multiple, locally grounded, and often independent innovations.

The theory that metallurgy developed locally in multiple regions is now widely accepted. Yet it remains unclear how specific innovations reached different communities and how changes in metallurgical technology influenced societies at the micro-regional scale. To address such issues, archaeologists began analyzing the material remains of metallurgical production.

In contrast to studies focused primarily on finished metal objects such as weapons and tools, researchers increasingly have recognized the need for studying metallurgical byproducts, rooted in interdisciplinary approaches. This shift contributed to the emergence of scientific subfields such as archaeometallurgy and archeomaterials, dedicated to the study of metallurgical technologies. The ‘radiocarbon dating revolution (Renfrew 1973) further accelerated this development: the widespread adoption of absolute dating prompted major reevaluations of cultural sequences, technological spread, and typological relationships, research of which is still constantly evolving.

As archaeometallurgy and related archaeosciences expanded, scholars began reconstructing the full biography of metal objects—from ore extraction to final deposition. This included studies of ore sources (Killick 2014), metallurgical by-products such as slag (Bachmann 1978; Hauptmann 2014), and technological ceramics associated with production (Martinón-Torres

and Rehren 2014). Combined with object analysis, this approach examines all stages of the *chaîne opératoire*: mining, fuel procurement, smelting, waste management, casting and working, use, deposition, and recycling (Thornton and Roberts 2009; Ottaway 2001).

4.2.1 Metallurgical Chaîne Opératoire

Chaîne opératoire or operational sequence refers to the sequence of actions involved in the production of an artifact. Although initially developed within lithic studies (Tixier 2012; Pigeot 2011; Leroi-Gourhan 1964), the theory's origin has been debated (Audouze et al. 2017).

Nonetheless, the concept of *chaîné opératoire* has since become central to the study of all craft production, as it allows researchers to trace the cognitive and societal decision-making embedded in each stage of production and technological development. Given that metallurgical production encompasses a wide range of interconnected processes, understanding how each stage operates and the levels of skill and knowledge it requires (Vandkilde et al. 2005) provides critical insight into the societal decisions (Orfanou et al. 2024), organization of activity (Thornton and Roberts 2009) and technological skill that shaped the creation of particular metal artifacts. Finally, the adoption of each stage in the sequence would have required intensive knowledge transfer — either between crafts (e.g. potters and metallurgists see Amicone et al. 2020) or potentially occurring between communities situated in different ecological zones: "*...starting in the mining communities of the mountains, continuing into the rich agrarian centres of Central Europe, and ending in the metal-poor regions of the north*" (Vandkilde et al. 2005: 905).

The metallurgical *chaîne opératoire* has been divided into several categories: prospection, mining, beneficiation, smelting (including the roasting and smelting of sulfide ores), refining, alloying, casting, smithing, and fuel production (Ottaway 2001). Each stage requires a set of tools (Daumas 2011) and forms of knowledge (Table 4.1).

Group	Stage	Description	Knowledge	Required equipment
1st group	*Prospecting*	Ore and other materials scouting	Knowledge of the natural environment	possibly animals, bags or baskets, sleds?, for carrying

Ore scouting and preparation				ore and other materials
	Mining	Ore extraction (surface or underground)	Depending on the type – knowledge of ore geological conditions	Tools for ore extraction
	Beneficiation	Crushing and sorting of copper-rich minerals after extraction	Knowledge of tools needed, and ore properties	Crushing tools, hammers for example
Ore transformation	*Smelting or roasting*	Exposing ore to higher temperatures	Knowledge of ore and creating the right conditions (temperature, oven construction and other)	Pyrotechnic equipment (furnace, hearts, crucibles, tools-nozzle holder, nozzle); fuel
2nd group	*Refining*	Any process that increases the purity of the ore (breaking, pounding, grinding)	Knowledge of the ore melting temperature and properties	Crushing tools (hammers, 'chopper')
	Alloying	Mixing of different elements, for example, arsenic or tin, for the creation of a new type of metal	Pyrotechnic knowledge, knowledge or elements, the chemical composition and conditions	Pyrotechnic equipment (furnace, hearts, crucibles, tools-nozzle holder, nozzle); fuel
3rd group	*Casting*	Pouring the melted ore in a mold	Knowledge of the other crafts, for the creation of molds	Pyrotechnic and pouring equipment (nozzle, nozzle

				holder, crucibles), molds; fuel
Object making and alteration	*Smiting*	Forging the metal into the final product	Knowledge of the casted metal, depending on the metal, would require fine work or physical strength	Tools for object shaping and refining (hammer ax, braziers)
	Annealing, sharpening	Object preparation for use	Knowledge of the materials, how to sharpen, prepare and repair	Whetstones, leather straps for sharpening or polishing, and grindstones

Table 4.1 Identified groupings of the metallurgical *chaîne opératoire* based on required knowledge and tools. Based on research conducted by Ottaway (2001) and (Daumas 2011)

Recognizing that not all stages of the metallurgical *chaîne opératoire* (Figure 4.1) are consistently present at every site, in this dissertation, I group the stages, associated knowledge, and required tools into three broad categories: (1) ore scouting and preparation, (2) ore transformation, and (3) object making and alteration.



Figure 4.1 The figure shows the different stages of the *chaîne opératoire*, with ore scouting (left), preparation (middle), ore transformation and object making (right)

Ore scouting and preparation

The process of ore scouting and preparation encompasses prospecting, mining, and beneficiation. These activities required a range of tools—such as hammers, axes, and shovels—and could be carried out in several locations: directly at the ore source, in its vicinity, or within the settlement itself. Whether ore was collected from surface deposits or extracted through underground mining determined the specific technologies, strategies, and labor investments involved. The distance to the deposits, the proportion of the community (or number of communities) participating, and the seasons during which extraction took place all further shaped the organization and intensity of this stage of the technological cycle.

The archaeological evidence for these activities includes tools (stone or antler hammers), traces of fire, occasional habitational features, and indications of mining. However, the latter evidence is frequently obscured or destroyed by ancient and modern mining operations (Thomas et al. 2025). In addition, there is the consideration of ore transportation to settlements. Beneficiated ores or as ingots could have been brought by boat, cart, sled, or with animals, as illustrated in Figure 4.1.

Ore transformation

This process broadly encompasses any alteration of ore from its original form through the application of heat or force. It includes techniques such as cold hammering, which requires minimal heat exposure to modify the mineral's properties. Other methods—such as smelting or roasting—transform the ore from a solid to a liquid state. These procedures required casting tools and the ability to maintain temperatures of approximately 1100 °C or higher, potentially aided by blowpipes and bellows, and could produce varying amounts of waste depending on the mineral type. The knowledge required for smelting involved understanding the necessary conditions for the process—whether a feature, installation, or container was needed to sustain high temperatures—the types and quantities of fuel required, and the specific properties of the minerals involved (Radivojević et al. 2010: 2776–2777). The same applies to refining. Alloying, which becomes more prominent in the Bronze Age, further altered the properties of copper-rich minerals, enhancing the strength and performance of finished objects, particularly through the addition of tin.

Ore transformation processes, like those involved in ore scouting and preparation, might have been carried out in multiple locations (close to mines, or exploiting areas) or at the edge of a settlement, within it or even across different settlements. Within broader exchange networks, identifying the origins of individual components—such as ores, alloying materials, or fuel—remains a complex task. This question continues to be actively investigated through isotopic analyses, most prominently lead and tin isotope studies (Pernicka et al. 2003; Stos-Gale 1997; Radivojević et al. 2010). Ore transformation perhaps leaves the largest amount of refuse, including slags, casting debris, tools, and contamination. However, unless they are retrieved in greater quantities or in good condition, they are often misidentified.

Object making and alteration

The final stage of production is the making of objects. This may be achieved through a variety of techniques, including casting and smithing. Numerous mold types, pouring methods, and associated tools were employed in this process, and these often constitute some of the most diagnostic indicators of metallurgy in the archaeological record, yet leave a moderate amount of waste or contamination. Objects could be produced in many settings and might have been made directly from processed ore or from ingots traded into the region.

Once the objects were formed, they were further shaped for use through trimming, annealing, and sharpening. These finishing steps could be carried out with a range of tools, including grinding stones, leather straps, or whetstones. Edges could be resharpened multiple times, even after breakage or heavy wear. Depending on their intended function, objects were mounted onto wooden extensions—such as handles for axes, hammers, or sickles—or onto shafts in the case of arrowheads.

Metal objects have received considerable scholarly attention. Research has focused on how they were made, where they were produced, their typological characteristics, and the contexts of their deposition. Much of our current understanding of prehistoric metallurgy derives from the detailed study of these finished artifacts. In fact, additional stages—such as re-smelting, re-casting, or repurposing artifacts and ores—occur after 'primary production' and are widely attested in many archaeological contexts. This capacity for transformation is both the complication and the beauty of metals: once extracted, they can be melted down and reshaped into new forms in times of need or scarcity (Papalas 2008).

Embedded within the *chaîne opératoire* framework is also the dimension of change and progression. Not every stage of the sequence needs to occur at all settlements, and research has shown that the presence or absence of particular steps depends on the type of ore being processed and on the evolving skill sets of metallurgical communities—both of which appear to have changed over time. To observe these shifts, the concept of the 'technological cycle,' introduced in Chapter 2, integrates insights from metallurgical *chaîne opératoire* studies with broader models of technological development and intensity. This combined framework helps explain not only how technologies changed, but also how and why individual metal objects came to be deposited within the archaeological record.

4.2.2 Metallurgical Technological Cycle

The metallurgical technological cycle can be understood from two perspectives: a) over time, and b) within each technological cycle (see Chapter 2, Figure 2.1)

The information gained from the temporal perspective examines the long-term development of metallurgical technology by showing developments and patterns, while the information gained from each technological cycle (defined within Chapter 2)—innovation, production, intensification, and overexploitation—presents the internal sequence of each stage within each cycle. Together, these perspectives provide a deeper understanding of the craft's progression, highlighting similarities and differences across stages and how these may vary across societies.

a) Technological cycle overtime

Current evidence places the earliest metallurgy in Europe in eastern Serbia around 5000 BCE (Radivojević et al. 2010). The start of metallurgy, however, is likely to come from a long history of use of copper ores for other purposes, such as painting and adornment. Indeed, the earliest documented use of copper minerals in the Balkan peninsula dates to around 6200 BCE, when beads made from malachite [$Cu_2CO_3(OH)_2$] and azurite [$Cu_3(CO_3)_2(OH)_2$] appear in Early Neolithic settlements located in ore-rich areas (Radivojević and Roberts 2021: 13–14). Alongside copper mineral beads, evidence of tools such as stone or antler hammers is often found at mining sites, underscoring the correlation between crafts and the natural progression of existing societal knowledge rather than an abrupt discovery. Local metal production was far from uniform across Europe. In fact, early copper production did not emerge uniformly across regions; instead, its

earliest occurrences appear to have been concentrated near ore sources and their immediate peripheries.

Early metallurgists living near ore-rich regions primarily processed oxide copper ores such as malachite, azurite, and cuprite [Cu_2O], minerals that may have been selected in part for their vivid colours (Bar-Yosef Mayer and Porat 2008; Radivojević and Roberts 2021: 13). Formed through the surface alteration of sulfide ores, these oxidized minerals were relatively easy to extract and required minimal mining effort. Although early evidence of mining is known from metal-rich regions as far back as the Neolithic, the earliest confirmed metallurgical activity in Europe dates to 5000 BCE and is from Serbia, at the sites of Belovode and Pločnik. At these sites, traces of copper-ore roasting and smelting have been identified (Radivojević et al. 2021)

In his work, Wertime (1964) defined the stages of metallurgical production according to metal type: native silver or gold, native copper, and meteoric iron (Wertime 1964:1261). He argued that, technologically, cold hammering could be performed only on soft metals, one of which was native copper, which likely represents the earliest metallurgical practice (Wertime 1964; 1973). This technique is feasible when copper occurs in a relatively pure state, as the metal is sufficiently soft and workable without heating. Global examples of cold-hammered copper are well documented, including the exceptionally pure native copper deposits of Michigan, USA (Peterson 2023; LaRonge 2001), where more advanced metallurgical techniques appear to have been unnecessary for millennia. In Europe, such examples likely existed across the continent; however, the most substantial evidence comes from Southeastern Europe, the Eastern Alps, and possibly the Slovak Ore Mountains (Brozio et al. 2023).

From 5000 BCE onward, metallurgical production increases. Thomas et al. (2025) have even characterized the earliest copper exploitation in Europe as a production 'boom' during the Vinča D phase (until ca. 4500 BCE) (Thomas et al. 2025:951). After 4000 BCE, metallurgical evidence appears to decline, and mines like Rudna Glava and Ai Bunar were no longer exploited. The perceived decline in metallurgical production after 4000 BCE, also referred to as a "copper hiatus," was deemed to have lasted until the start of the Early Bronze Age (around 2500 BCE) (Powell et al. 2017). Several reasons were attributed to this pattern — societal disruptions

(Weninger et al. 2009), shifts in production practices (Thomas et al. 2025), or depositional changes (Taylor and Young 1999).

Recent work by Thomas et al. (2025), however, argues that this apparent decline may reflect a visibility bias, driven by the recycling of metal and the frequent destruction of early mining traces at sites such as Majdanpek, which continues to be exploited past 4000 BCE. Lead isotope evidence shows that Majdanpek, along with other ores with the Balkan fingerprint, such as the mine of Curak supplemented ores throughout Europe, the Alps, showing the continuation in exploitation. This interpretation aligns well with patterns observed in the Carpathian Basin (Thomas et al. 2025:936).

In the Carpathian Basin, metal artifacts appear around 4500 BCE, yet no clear evidence of local production has been identified for this period. It is plausible that metallurgical activities were concentrated near ore sources—such as the Metaliferi Mountains of Romania—while finished products circulated through established exchange networks. Trade connections with major mining centers such as Majdanpek, Rudna Glava, and Ai Bunar are well established for other parts of Europe (Pernicka et al. 2003), and these regions should not be excluded as potential suppliers for the Carpathian Basin. Additional high-purity copper sources containing minor arsenic are also known from the northwestern Carpathian Mountains and the Slovak Ore Mountains (Brozio et al. 2023).

Further supporting the 'bias theory' is the observation that metallurgical activity often leaves limited archaeological traces when it is not carried out intensively at a single location. Cold hammering or smelting of copper oxides and similar ores could be performed in simple hearth-like installations, examples of which have been identified at several sites across the region (Radivojević et al. 2016; Powell et al. 2017). These features were likely multipurpose, and in the absence of additional diagnostic evidence, many may have been misidentified as only used as domestic cooking hearths. Oxide ores tend to leave low waste material rates, which can easily be missed during excavations.

Furthermore, evidence dating to the Late Copper Age shows the appearance of clay molds alongside metallurgical tools such as crucibles, tuyères, and slag pits. Combined with the exploitation of ores beyond copper—such as tin used later for alloying—these developments contributed to notable technological advances (Bondár 2018).

The presence of such innovations provides further evidence that metallurgical technology did not experience a hiatus during this period; rather, it likely as stated by Thomas et al. (2025), became less archaeologically visible. As a result, metallurgical activity from the end of the Early Copper Age (ca. 4000 BCE) to the onset of the Early Bronze Age (ca. 2500 BCE) may be significantly underrepresented or misidentified in the archaeological record.

The Early Bronze Age marks a renewed intensification of metallurgical production accompanied by the emergence of new technologies. Although smelting was already well established during the Early Copper Age, innovations of the Early Bronze Age enabled metallurgists to more effectively separate metallic copper from its mineral matrix, facilitating the production of transportable ingots (Stos-Gale 1997). The most significant technological acceleration, however, came with the advent of intentional alloying. Owing to the natural presence of arsenic in certain copper ores, arsenical bronze represents the earliest copper alloy in the region. Particularly prominent in Greece and, to a lesser extent, in the Balkans, arsenical bronze posed considerable health risks to metalworkers because arsenic is highly volatile and has a low melting point (Tylecote et al. 1977).

The Middle Bronze Age (1900–1500 BCE) represents another period of substantial metallurgical production. Characterized by the supra-regional extensive exchange networks (Mehofer et al. 2021: 11) and intensified craft activity, this era appears to mark the point at which communities began to exploit sulfidic ores such as chalcopyrite [$CuFeS_2$] and bornite [Cu_5FeS_4], coinciding with a dramatic increase in metallurgical output (Stöllner 2009; Papalas 2008). Although access to these ores clearly influenced the volume of metallurgical debris found at Middle Bronze Age settlements, the precise timing and location of their earliest exploitation remain uncertain.

Powell et al. (2017) analyzed copper isotopes from artifacts spanning the Copper Age to the Late Bronze Age. While they argue that sulfidic ores were likely introduced only in the Middle Bronze Age, their published data show a wide isotopic range with no clear chronological pattern in $\delta^{65}Cu$ values. Notably, negative or depleted copper isotope values—typically associated with sulfidic ores—appear as early as the Copper Age, whereas positive values linked to oxide ores persist into the Late Bronze Age (Powell et al. 2017: 39–40). The mean values differ by period.

Among objects from all over modern-day Serbia, the highest average is for Copper Age artifacts, while the lowest is for Early Bronze Age artifacts. However, despite this pattern, nearly half of the objects from the Copper Age, Early, Middle, and Late Bronze Ages overlap in their $\delta^{65}Cu$ signatures (Powell et al. 2017: 45). As the authors do not report lead isotopes, it is hard to know where the ores used for these objects came from.

Nevertheless, the recovered data is significant. Rather than indicating a true hiatus in metallurgical activity, the overlapping isotopic values across different periods instead represent another line of evidence for reduced archaeological visibility, possibly resulting from recycling, mixing of materials, and the destruction of early mining traces. This interpretation aligns with the argument advanced by Thomas et al. (2025), who contend that the apparent decline in production is best understood as an artifact of preservation and recovery rather than a genuine cessation of metallurgical practices.

The addition of tin to produce bronze—first produced accidentally at Pločnik due to ore impurity (Radivojević et al. 2021), but intentionally produced during the Middle Bronze Age—enabled the manufacture of more complex and durable tools and weapons (Pernicka et al. 2003). As the exploitation of sulfidic ores required underground mining (Powell et al. 2017), this is likely that societies would invest more energy into acquiring metal ores during this period, likely contributing to the dramatic increase in metallurgical evidence during this period. The exploitation of particular ore types required multistage smelting processes to remove impurities.

As a consequence, larger quantities of metallurgical waste accumulated within settlements, producing a marked increase in the archaeological visibility of metalworking—even in regions located far from primary ore sources. A study by Mehofer et al. (2021) examining metallurgical waste, primarily slag from eastern Serbia, suggests that technological developments during the Middle Bronze Age could even have even occurred at the household level. The slag analysis showed that a series of smelts until metallic copper was obtained were performed in small open-pit furnaces, producing copper matte—a key feature of sulfidic ore smelting. The slag types show notable similarities with those from the Alpine region, while the ores themselves appear to have originated in northern Italy (Mehofer et al. 2021: 11).

Despite these widespread regional trends, the distribution of metallurgical evidence is uneven: some settlements display substantial traces of production, some even possible specialized

metallurgical workshops at settlements such as Pecica Şanţul Mare and Feudvar (Găvan 2015; O'Shea and Nicodemus 2019), others reveal only limited or no activity.

By the Late Bronze Age, metallurgical production in the Carpathian Basin and the Balkans appears to have been treated differently according to object type rather than social or spatial boundaries. This was especially noticeable for objects like axes, sickles, spears, and swords (Orfanou et al. 2024). As Jovanović (2009: 143) observed, metallurgical production begins "*…with small jewelry pieces and ends with the serial production of massive tools and weapons*." Thus, the progression toward standardization could indicate technological intensification of metallurgical production.

The major transformations outlined above represent only a fraction of the broader technological patterns, as numerous other innovations—including advances in mold-making and alloying—also facilitated metallurgical development. Despite advances in archaeosciences and the application of radiocarbon dating, which continue to reshape the broad contours of the metallurgical 'technological timeline' (Pearce 2019), many nuances remain unexplored, underscoring the need for ongoing refinement and interdisciplinary approaches.

To better understand this history, however, it is necessary to examine each stage within the technological cycle. Such an approach enables the identification of distinct historical phases and the assessment of the intensity of each process. Moreover, this framework facilitates a deeper understanding of the consequences of metallurgical development for society and the environment, underscoring the importance of contextualizing technological change diachronically.

b) Within the Metallurgical technological cycle

As outlined in Chapter 2, the technological cycle comprises four stages—innovation, production, intensification, and overexploitation— ultimately leading to the initiation of the next cycle. While the broad history of metallurgical development in Europe demonstrates the shifts and progressions between different technological cycles relied on the knowledge for effective acquisition and exploitation of copper-rich minerals. This, in turn, was likely dependent on the

mineral type and its location (surface, underground, and its proximity to communities) (Radivojević and Rehren, 2016).

Every new technological stage starts with exploration. The discovery of tin bronze at Pločnik (Radivojević et al. 2021)—now understood to result from naturally mixed ores rather than intentional alloying (in contrast to intentionally made arsenical bronze)—has sparked important debates about "learning processes" and the accumulation of metallurgical knowledge. This evidence suggests that early communities may have engaged in extended phases of experimentation before regular production was established, situating these activities within the innovative stage of the technological cycle.

Successful metallurgical production required a wide range of installations and tools—many made from clay, stone, leather, or wood—drawing on knowledge likely transferred from other crafts. The development of these supporting technologies progressed in tandem with advances in metalworking. Achieving a successful smelt, defined as the controlled reduction of ore to extract metal, and producing cast objects demanded substantial familiarity with other pyrotechnologies, particularly those commonly practiced by potters. Wertime (1964, 1264–1266) argued that the ability of potters to manipulate and reduce metal oxides for pottery surface decoration (such as cinnabar, calcite, and black-topped) was a key transferable skill between the two crafts. However, Amicone et al. (2020) showed that these two technologies were likely not entirely linked for Vinča communities. Nevertheless, the high-purity copper ores utilized for copper jewelry during this period required suitable cold-hammering techniques, which were likely used in other ways before.

Subsequent developments in ore transformation included the successful smelting of oxide copper ores, which required casting tools and the capacity to maintain temperatures of approximately 1100 °C or higher, potentially aided by blowpipes. Depending on the mineral type, these processes could leave only minimal waste. The knowledge required for smelting encompassed an understanding of the necessary conditions—whether a feature, installation, or container was needed to sustain high temperatures—the types and quantities of fuel required, and the specific properties of the minerals involved (Radivojević et al. 2010: 2776–2777).

Once the knowledge of ore exploitation and transformation was established, the production phase commenced. In metallurgy, this phase was relatively long and encompassed multiple steps — outlined above.

The intensification stage marks the point at which production expanded dramatically. However, while the reasons for intensification can be numerous (as explained in more detail in Chapter 2), there is usually a trigger that necessitates re-evaluation and adaptation of existing resources in order to meet the intensification stage. It is during this stage that environmental consequences become increasingly visible, including resource overexploitation and the accumulation of chemical contaminants in soils, sediments, and biological systems. These issues are examined in greater detail in Chapter 3.

A stage of resource overexploitation typically follows intensification. Characterized by a decline in production, this stage was often caused by internal or external pressures, including conflict, supply chain disruptions, disease, famine, or environmental change. Ultimately, overexploitation signals the inability to sustain the generated system during the intensification stage. In overexploitation, the pressures overpower the system, sparking innovation and, with it, the new technological cycle.

4.3 Contextualizing Metallurgy

Archaeological evidence demonstrates that the greatest amount of waste generated in settlements is often during metallurgical production, which derives from the intensified ore-transformation stages[2]. It is during this portion of the technological cycle that local activity at sites reaches its peak, leaving behind the most substantial and archaeologically visible traces. While achieving high temperatures was essential for a successful smelt, craftspeople also needed the skill to maintain these temperatures long enough for copper to liquefy. Current scholarship suggests that prehistoric communities were capable of doing so even in open-pit settings, using tools such as tuyères and smelting pots to regulate airflow and temperature (Radivojević et al. 2021).

However, because pits and hearths were multipurpose features, often used for heating, cooking, and pottery production, identifying them as metallurgical installations is challenging. Such features are easily misinterpreted unless accompanied by abundant metallurgical waste, particularly slags of varying types. Further complicating the issue is the evidence of portable ovens, such as those found in the Carpathian Basin during the Late Bronze Age (Orfanou

[2] While mining in particular generates substantial waste and causes significant environmental disruption, it is rare to find evidence of settlements located directly adjacent to mines. As a result, the most direct evidence of production is usually found within settlements themselves, especially when production becomes intensified.

et al. 2024). Consequently, unless the evidence is substantial, questions remain as to whether metallurgy represented a central activity within a settlement.

For this reason, considerable attention has been devoted to the analysis of slags within the *chaîne opératoire* (Ottaway 2001; Daumas 2011). Slags preserve critical information about ore composition, provenance, and the technologies employed during smelting. From temperature regimes to alloying practices, slags serve as key indicators of metallurgical activity, thereby providing a more refined chronology of technological change and innovation (Radivojević 2010; Thornton 2009; Kienlin 2010; Killick and Fenn 2012). Yet not all settlements yield large amounts of slag, particularly in regions where metallurgical activity was limited. In such contexts, societies often sought to maximize the utility of slags, re-extracting as much material as possible (Papalas 2008).

In summary, the study of metallurgy—its social role, technological development, and modes of production—has undergone substantial reinterpretation over the past two decades. Yet many of the core questions first raised in the mid-twentieth century, and in this work, remain unresolved. This suggests that our line of inquiry may need to shift. Rather than focusing on identifying individual metallurgists or seeking unequivocal evidence of metallurgical activity, it may be more productive to investigate the role of metallurgy within specific communities.

The uneven, dispersed and scant evidence described in this chapter likely reflects the fact that metallurgy was not practiced extensively and consistently across all prehistoric societies. Its importance is undoubtedly shaped by environmental conditions, resource availability, and regional economic structures. In some settlements, metallurgy may have been a central activity, deeply embedded in daily life and social organization. In others, it may have been peripheral—practiced occasionally, symbolically, or as one craft among many, with knowledge distributed more broadly across the community. Both of which could have coexisted and also varied through time.

Ultimately, it is essential to approach metallurgy within its specific settlement contexts in order to unravel its multifaceted place in prehistoric society. In Chapter 5, I integrate metallurgical activity into the natural environment of the study area—the Tisza-Maros region. The chronological framework under consideration spans 4500 to 1500 BCE, thereby encompassing the technological transformations discussed above.

Chapter 5 Integrating Metallurgical Activity Within the Natural Environment of the Tisza-Maros Between 4500 and 1500 BCE

This chapter outlines the environmental and cultural background necessary to contextualize metallurgical practices in the Tisza–Maros region between 4500 and 1500 BCE. Together with Chapter 6, which focuses on the description of individual sites, the background provided in these chapters forms the foundation for interpreting the results presented in the discussion chapters (Chapters 11 and 12).

The first part of this chapter offers an overview of contemporary ecological and climatic conditions across the broader Carpathian Basin, with particular attention to the Tisza–Maros region (see map of the region in Chapter 6, Figure 6.1). The second part examines published environmental reconstructions between 4500 and 1500 BCE, both for the eastern Carpathian basin and for the specific area of study. In this section, I critically assess the limitations of existing studies including: uneven data resolution, regional variability, and interpretive uncertainty. I emphasize that fine-resolution climatic data for the region is necessary, yet currently remain largely unavailable.

The following section focuses on the cultural dimensions and characteristics of the groups whose archaeological traces have been recovered in the broader region, with emphasis on those represented at the sites analyzed in this study. Particular attention is given to the Tiszapolgár, Bodrogkeresztúr, Hunyadihalom, and Maros communities, which date to the Early (4500–4000 BCE) and Middle Copper Ages (4000–3600 BCE), and the Early (2700–2200 BCE) and Middle Bronze Ages (2200–1500 BCE). Although no material linked to the Late Copper Age (3600–2600 BCE) was identified at the examined sites, I provide a brief overview of this period to better contextualize Early Bronze Age practices.

I conclude the chapter by presenting the metallurgical evidence associated with these cultural groups. This section begins with an overview of regional metallurgical sources, followed by a discussion of archaeological evidence related to metal production. In cases where production evidence is absent, I focus instead on the circulation and abundance of metal artifacts recovered

from the broader region. More detailed information on metallurgical evidence from the individual sites included in this analysis is provided in Chapter 6.

5.1 The Modern Environment of the Tisza-Maros

The term Tisza–Maros region refers to the area surrounding the confluence of the Tisza and Maros rivers in the southeastern part of the Carpathian Basin. Today, the Tisza–Maros region falls under the jurisdiction of three countries, encompassing the southernmost part of Csongrád County in southeastern Hungary, the Serbian portion of the Banat in northern Vojvodina, and the westernmost parts of Arad and Timiș Counties in western Romania.

The region is bounded by the Körös drainage system to the north, the tributaries of the Tisza River to the west, the Zlatica and Galacka rivers to the south, and the Carpathian Mountains to the east. For the purposes of this dissertation, particular emphasis is placed on the area framed by the Maros/Maros/Mureş, Tisza, Zlatica, and Galacka river systems, as these waterways shaped the past regional environment.

Although both the Tisza and Maros rivers originate in the Carpathian Mountains, by the time they reach the plains of the southeastern Carpathian Basin they become low-gradient rivers, prone to flooding and branching into multiple channels. Present-day hydrological conditions offer insight into past ecosystems, which were dominated by river floodplains, low-lying basins, and permanent to seasonal wetlands (Kosse 1979; Várallyay and Zilahy 1989; Gulyás and Sümegi 2011). These landscapes extended across elevations of approximately 79 m above sea level (Girić 1971; Nicodemus 2014). Seasonal flooding typically occurred in February, March, and June—coinciding with snowmelt—and again in December, when rainfall increased. Historical sources describe the region as consisting of ‘large ponds that extended for months’ (see Sava 2015:13 for broader historical descriptions).

The landscape in its current form (Figure 5.1) has existed only since the nineteenth century, when the Austro-Hungarian Empire implemented extensive channel modifications that reshaped the region’s natural water dynamics and lowered water levels by 3–4 m (Kosse 1979; Gyula 2013). Further rivers regulation was introduced in the 20th century, particularly between 1930 and 1960, aimed at preventing lateral erosion and improving river navigation by facilitating water passage during floods (Kiss and Sipos 2015). Nevertheless, the area still exhibits a relatively shallow

underground water table, ranging from 2 to 6 meters. Alongside the region's rivers, these remain its primary water sources (Girić 1971).



Figure 5.1 An example of the now drained wetlands located just north of the village of Crna Bara in the Serbian Banat

The hydrological alterations carried out during the nineteenth and twentieth centuries were, however, a primary cause of extensive wetland loss and significant declines in biodiversity. Additional environmental degradation has occurred in recent decades, particularly through soil and water pollution (Kiss and Sipos 2015).

The region's soils present a complex mosaic, of wetland-associated soils, including vertisols, humogley soils, and eugley soils (Belić et al. 2011), loamy, clay, and alkali soils (Biró 2008). Alluvial soils transported by the Tisza and Maros rivers, their tributaries, and the Zlatica River (Girić 1971:10) played a crucial role in maintaining both present and past wetland environments. Alluvium and chernozems are highly productive for agriculture, whereas greysols (meadow clays) and alkali soils are better suited for pastureland (Michéli et al. 2006). The

combination of these soil types made the region highly productive for a wide range of human activities, despite the modern negative connotations often associated with wetlands.

5.2 Environmental and Climatic Reconstructions Between 4500 and 1500 BCE

General climatic reconstructions place the Early (4500–4000 BCE) and Middle Copper Age (4000–3600 BCE) within the Atlantic phase, characterized by warmer and drier conditions. In contrast, the Late Copper Age (3700–2700 BCE) and the Early (2700–2000 BCE) to Middle Bronze Age (2000–1500 BCE) correspond to the Subboreal phase, marked by cooler and wetter climates (Gardner 2002; Nagy-Bodor et al. 2000; Schöll-Barna et al. 2012; Tapody et al. 2021).

Reconstructions of past regional vegetation and climate conditions in the Carpathian Basin and its surroundings present a long history of research and continue to be explored through a range of interdisciplinary approaches that offer increasingly nuanced insights into past ecological dynamics. Examples include erosion assessments of lake sediments (Tapody et al. 2021), water-budget and mollusk-shell analyses (Schöll-Barna et al. 2012), dust-particle reconstructions from lacustrine and peatland contexts (Longman et al. 2019), and pollen studies (Magyari et al. 2024).

These studies reveal a far more variable and complex environmental picture for the wider region between 4500 and 1500 BCE. They document not only major climatic episodes that affected much of Europe—such as the Meghalayan drying event detected between 2225 and 1950 BCE (Tapody et al. 2021)—but also emphasize pronounced differences between different areas.

Some authors argue that southeastern Europe—including the Carpathian Basin—was largely climatically disconnected from the rest of Europe during the early and mid-Holocene, both in terms of precipitation and temperature (Demény et al. 2019; Drăguşin et al. 2014). However, substantial differences also existed within the basin itself. Magyari et al. (2024), for example, contend that the eastern Carpathian Basin exhibits climatic conditions more closely aligned with those of the Carpathian Mountains than with Transdanubia. If this is the case, the Tisza–Maros region would likely have experienced climatic patterns similar to those documented in the Carpathian Mountains.

The eastern Carpathian Basin in particular, has been strongly influenced by its hydrological variability (Longman et al. 2017). However, the extensive water-management interventions

described above resulted in the loss many environmental records, leaving very few high-resolution and temporally long climatic records available for reconstructing past conditions in the region (Magyari et al. 2024).

5.2.1 Supra-regional Climatic Reconstructions

In contrast to the limited environmental records from the Plains, a substantial body of paleoenvironmental data has been recovered from the surrounding mountain regions of western Romania.

One such study, conducted by Longman et al. (2017), identified periodic changes in dust deposition—driven by both climatic variability and human activity—in peat and lake sediment cores from the Eastern Carpathians. High-dust episodes were recorded between 4200–3950 BCE, 3500–3100 BCE, 2180–1820 BCE, and 1500–900 BCE. Their analyses also revealed several major climatic shifts between 4500 and 1500 BCE, including a prolonged wet phase with elevated dust inputs between 4650 and 4050 BCE. Around 4100 BCE, they detected a marked cooling and drying event that they correlate with the broader Sahara desertification episode (Longman et al. 2017: 906). After this point, global dust-deposition patterns shifted, and another period of cold, dry conditions occurred between 2250 and 1950 BCE.

A second paleoenvironmental study by Tapody et al. (2021) examined sediment and peat sequences from Round Lake in the Romanian Eastern Carpathians. Using sedimentological, geochemical, and pollen data, they identified erosion phases linked to shifts in human activity and land-use practices. Their climatic reconstructions for the Transylvanian region indicate colder and wetter periods between 4500–3000 BCE, 2800–2500 BCE, 2500–2150 BCE, and 1900–1800 BCE, while warmer and drier intervals occurred between 3000–2800 BCE and 1800–1500 BCE.

While precipitation undoubtedly influenced erosion intensity, Tapody et al. (2021) argue that periods of heightened erosion primarily reflect increased human activity, whereas intervals of low erosion indicate reduced or absent land-use pressure. They identified several phases of high erosion dated to 5000–4500 BCE, 3000–2500 BCE, and 1800–1500 BCE, and periods of low erosion between 4500–3000 BCE, 2500–2150 BCE, and 1900–1800 BCE. The erosion patterns for

2225–1950 BCE remain 'unclear,' as the Meghalayan drying event obscured the extent to which human activity contributed to sediment disturbance (Tapody et al. 2021: 20).
Pollen evidence from the same study documents a transition from closed forest to forest-steppe environments, with open hornbeam–beech woodlands and expanding grazing pastures between 2000 and 1500 BCE. Earlier work by Willis et al. (1998), and Sümegi et al. (2012) similarly attributed these vegetation changes to deforestation for timber extraction and the expansion of arable and pastoral land.

Beyond offering more nuanced climatic reconstructions, the major strength of these studies lies in their identification of land-use changes that correspond closely with archaeological evidence. Despite numerous paleoclimatic studies across the broader region, local environmental reconstructions for the Tisza–Maros river angle remain scarce. This scarcity largely stems from the extensive nineteenth-century drainage works that transformed the landscape and removed much of the sedimentary record suitable for paleoenvironmental analysis (Kosse 1979). Nevertheless, a small number of local archives do survive.

5.2.2 Local Climatic Reconstructions

Some of the earliest pollen studies from the Tisza–Maros region were published in the volume on the Mokrin cemetery by Girić and colleagues (Marković-Marjanović 1971: 9–27). Pollen cores taken from the Serbian Banat documented climatic and biodiversity shifts during the Copper and Bronze Ages in the vicinity of the cemetery. Marković-Marjanović (1971) analyses concluded that the region was dominated by wetland vegetation, reflecting a humid grassland landscape with occasional woodland galleries composed primarily of oak and beech (20–27). Although the work of Girić and colleagues remains the most geographically proximate environmental record for the sites under study, more recent paleoenvironmental research has been conducted in adjacent regions.

The most recent climatic reconstruction relevant to the study area was conducted approximately 15 km north of the Tisza–Maros river angle in southeastern Hungary, where Magyari et al. (2024) examined pollen sequences from the Kéró-ér meander. This core provides valuable insights into regional vegetation and climatic dynamics, revealing three major climatic transitions dated to roughly 4500 BCE, 2500 BCE, and 1500 BCE. Over the span of these three

millennia, the record also documents frequent climatic fluctuations during the Early and Middle Copper Age, underscoring the environmental variability that characterized the region (Magyari et al. 2024)

Pollen evidence further indicates a semi-open landscape between 4500 and 1500 BCE, with phases of deforestation linked to extensive Neolithic agriculture. Cereal pollen (high in the Neolithic) then declines sharply in the Early Copper Age, suggesting a reduction in agricultural activity, before deforestation and cultivation activities increase again in the Late Copper Age (Magyari et al. 2024). These shifts not only correspond broadly with the climatic changes documented by Tapody et al. (2021) and Longman et al. (2017) but also imply that the climatic fluctuations of the Early and Middle Copper Age likely affected local communities and shaped their subsistence strategies (Magyari et al. 2024: 788).

Another study integrating environmental and archaeological data, although focused on the Bronze Age, is the recent work by Molloy et al. (2023). Drawing on regional archaeological datasets and environmental proxies, including paleoclimate records from roughly 200 km southeast of the study area (Davis et al. 2003; Drăgușin et al. 2014), they produced a higher-resolution reconstruction (approximately 100-year intervals) for 2000–1000 BCE that captures environmental fluctuations and corresponding social responses.

Taken together, the findings of Magyari et al. (2024) and Molloy et al. (2023) demonstrate that wetland environments—particularly seasonal wetlands—are exceptionally sensitive to climatic variability. Periods of drying, such as the Meghalayan event between 2225 and 1950 BCE (Tapody et al. 2021), or subsequent wetter intervals (Molloy et al. 2023), could have substantially altered the hydrological and ecological dynamics of these systems (Gábris 1998; Sherratt 1984; Gyulai 1993; Gyucha et al. 2011; Sommerwerk et al. 2009).

It is likely, however, that prolonged phases of stable precipitation had relatively limited disruptive effects on past societies. In many cases, sustained climatic stability supported prosperity, particularly in regions where predictable rainfall and inundation cycles were essential for subsistence activities such as agriculture. The real difficulties emerged when the climate became unstable.

Periods of climatic instability tend to have the most severe societal impacts, as the reliability of key food sources tied to agriculture—especially cereals—declines. Current evidence suggests that this was the case during both the Early and Middle Copper Age (Magyari et al. 2024) and again in the Late Bronze Age (Molloy et al. 2023). However, without more localized environmental reconstructions for the immediate region, it remains difficult to determine the precise mechanisms driving the social transformations observed in the archaeological record.

This issue is particularly significant for the Tisza–Maros confluence, where communities occupied elevated 'islands' (Hungarian: '*sziget*') above the floodplain (Girić 1971; Nicodemus 2014). Even a difference of three meters in elevation could determine whether a location was habitable (Girić 1971: 11; O'Shea 2011), as recurrent flooding shaped a complex, fragile, yet broadly predictable wetland ecosystem. In the absence of more localized paleoenvironmental records, this study relies on the broader regional datasets presented in this chapter, together with the archaeological evidence (Figure 5.2).

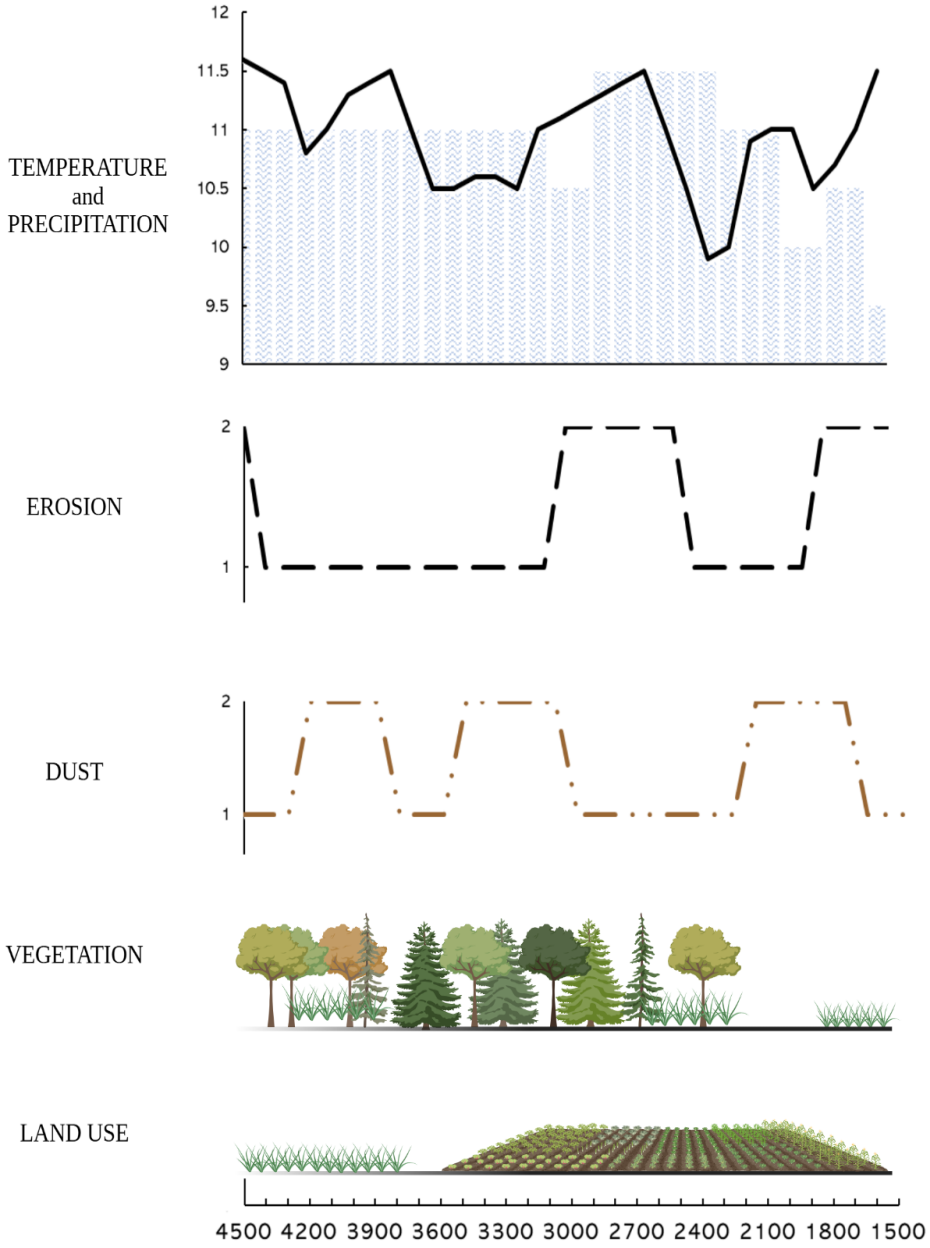


Figure 5.2 Climatic reconstruction showing the combined evidence from temperature, precipitation erosion, dust, pollen and land use data summarized from Tapody et al. 2021, Longman et al. 2017, Magyari et al. 2024. Data was also extracted from Molloy et al. 2023, based on Davis et al., 2003; Drăgușin et al. 2014. Created in https://BioRender.com

5.3 Archaeological Evidence of the Tisza-Maros and Broader Region Between 4500 and 1500 BCE

In geological terms, 3000 years may seem short, but for human societies between 4500 and 1500 BCE, communities across the Carpathian Basin experienced major shifts in social organization, settlement structure, mortuary practices, and technological innovation.

As outlined in the previous section, this span encompasses the Early, Middle, and Late Copper Age, as well as the Early and Middle Bronze Age (Figure 5.3). Although no Late Copper Age material has been identified at the sites under analysis, the following section provides a broad overview of the defining characteristics of these periods across the wider Carpathian Basin. By outlining the major social transformations visible in the regional archaeological record, this synthesis establishes a contextual framework for interpreting the material recovered from the Tisza–Maros region.

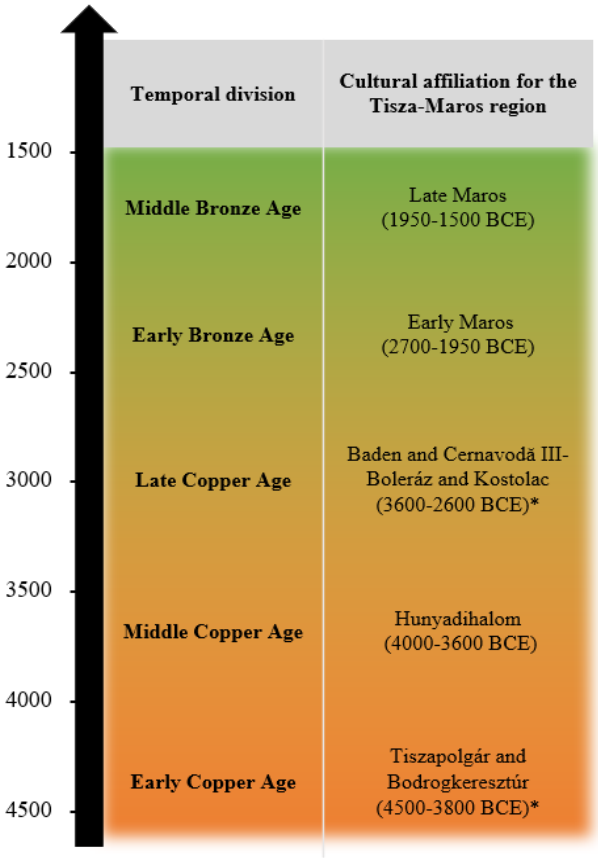


Figure 5.3 Chronological framework and cultural delineation for the Tisza-Maros region between 4500-1500 BCE. The * presents deviation from regional data. This is represented for Early Copper Age, where dates for the time period vary from the regional patterns, showing a somewhat longer existence of the cultural evidence in the Serbian

Banat. The * from the Late Copper Age indicates that while some evidence has been found in the wider region, no evidence of these cultures has been found at any of the excavated sites.

5.3.1 Copper Age – Features and Problems

Across Europe, the Copper Age (ca. 4500–2700 BCE), a remains an enigmatic period, and the Tisza–Maros region is no exception. Several factors contribute to this ambiguity. First, scholars have yet to reach a consensus on terminology. The period appears in the literature under multiple labels—Eneolithic, Aneolithic, Chalcolithic, and, in some cases, Final Neolithic. In Hungarian scholarship, the term Copper Age. In contrast, researchers working in the Balkans more frequently employ the term Eneolithic. Today, both terms are widely recognized and often used interchangeably within the study area. As the term Copper Age is the most used designation in the published literature from the region (Sava 2015; Mirković-Marić et al. 2025; Marić 2026), it is the terminology adopted in this work.

Despite this terminological flexibility, the Copper Age lacks uniform defining characteristics across Europe. Unlike the more clearly defined Neolithic (ca. 6000–4500 cal. BCE) and Bronze Age (ca. 2700–800 BCE), the Copper Age was deemed difficult to classify, largely because its diagnostic features vary considerably by region. According to Schier (2011), the period is generally marked by shifts in settlement types and patterns, the emergence of bounded cemeteries, changes in lifestyle and social organization, and the development of copper metallurgy.

One of the most notable transformations in the Carpathian Basin during this period was the shift in settlement patterns from tells to flat settlements (Gyucha and Parkinson 2013). This transition significantly affected the archaeological visibility (and likely the preservation) of settlements, contributing to the apparent reduction in their number across the region. The causes of the shift in settlement patterns in the Carpathian Basin have been widely debated, with explanations ranging from ideological shifts, economic or lifeways shifts (Bökönyi 1985; 1988), and climatic fluctuations (Magyari et al. 2024), to migration and cultural displacement (Gimbutas 1991; Gimbutas et al. 1997).

In the southern Carpathian Basin, this change has often been attributed to a shift in lifestyle—from primarily sedentary communities to groups exhibiting greater mobility (Parkinson 2006). In response to this proposed increase in spatial mobility during the Copper Age, scholars have suggested that societies became more reliant on livestock (Bökönyi 1985; 1988).

Sherratt's 'Secondary Products Revolution' theory (1981; 1997) further highlighted the exploitation of animals for secondary products such as dairy, fiber, and traction, alongside associated technological innovations including wheeled vehicles and ploughs.

In recent years, however, the "Secondary Products Revolution" theory faced growing critique as emerging evidence suggests that many of the proposed features outlined as markers of the Copper Age were present in earlier or later periods. For instance, the use of milk products has been documented in the Early Neolithic of the Carpathian Basin (Craig et al. 2005), while the introduction of wool-producing sheep is more broadly associated with the Late Copper Age (LCA, 3700–2800 BCE) or Early Bronze Age (2700-2200 BCE) (Becker et al. 2016; Benecke 1994; Bökönyi 1988; Greenfield 1988; Vretemark 2010).

The proposed high reliance on livestock, however, has been questioned by isotopic evidence presented by Giblin and Yerkes (2016). Their study analyzed d δ13C and δ15N values from human and animal collagen sampled from cemeteries dated between 4893 and 3523 BCE. The results showed no isotopically significant differences across this span, leading the authors to argue that there is no clear dietary signature indicating increased dependence on livestock during this period (Giblin and Yerkes 2016: 86).

Yet, while the overall dataset may not reveal a marked shift, subtle variations are present—not only between periods but also among individuals. These small but meaningful differences may stem from variation in bone-turnover rates, as the study compared both ribs and long bones. Collagen reflects cumulative dietary intake over the period in which a bone remodels (Fahy et al. 2017). In her earlier study, Giblin (2011) sampled long bones (e.g., femur, tibia) and ribs, according to Fahy et al. (2017) differ substantially in turnover rate: long bones over decades, and ribs far more rapidly. Such differences complicate direct comparison and may obscure short-term dietary changes that would otherwise be detectable.

An additional point worth noting is that although Giblin and Yerkes (2016: 86) attributed their dataset to the Late Neolithic and Copper Age, current chronological frameworks indicate that the sampled material spans from the Late Neolithic through the Late Copper Age. It is entirely possible if these periods were analyzed separately, a much wider range of variation would likely emerge. Even so, the modest isotopic differences they report are still meaningful. As Tomažič

et al. (2026) demonstrate, even small differences in isotopic values can reflect shifts in food-management strategies, provisioning systems, sourcing practices, or consumption patterns. Such changes align with the broader transformations visible in the archaeological record during this period, including shifts in settlement organization, mortuary practices, and regional interaction networks. Alternatively, it is also entirely possible that the differences detected by Giblin and Yerkes (2016) reflect seasonal or short-term mobility rather than a fully pastoral or nomadic way of life.

Nevertheless, given the currently available evidence—including the reduced archaeological visibility of flat settlements and the climatic fluctuations detected particularly during the Early and Middle Copper Age (4500–3600 BCE) (Magyari et al. 2024)—the hypothesis of a more mobile lifestyle, accompanied by a greater reliance on livestock, remains plausible and has yet to be convincingly challenged.

With the reduced visibility of settlement sites, the dominant archaeological marker of Copper Age landscapes in the Carpathian Basin became burial grounds. Inhumation graves appear either as isolated burials or as components of bounded cemeteries. For example, Early Copper Age single graves are known to 'seal' earlier Neolithic settlements, with examples as far south as the tell of Vinča–Belo Brdo (Borić 2015). More characteristic, however, is the emergence and increasing prominence of bounded cemeteries—a practice already present in the Late Neolithic but becoming especially widespread in the Early Copper Age, including within the study region (Tasić 1995).

During this period, the disparity between the number of identified settlements and the number of cemeteries is striking, creating the possible illusion of a dramatic increase in burial grounds. In reality, the number of interred individuals remained relatively small, with the exception of several large cemeteries such as Tiszapolgár–Basatanya, Pecica East, and Tiszavalk–Kenderföld (Bognár-Kutzián 1963; Patay 1978; Sava et al. 2017).

Cemeteries dated to the Early and Middle Copper Age in the Carpathian Basin are associated with the Tiszapolgár and Bodrogkeresztúr cultural complexes. These groups often coexist within the same burial grounds, with no clear spatial differentiation between them. As a

result, delineating their temporal or cultural boundaries—or determining whether such boundaries existed at all—remains problematic (Siklósi and Szilágyi 2021). Graves attributed to both complexes include single and multiple inhumations, and the deceased were interred with a diverse range of grave goods. Assemblages commonly feature pottery, stone tools, beads, animal remains, and, in some cases, copper and gold objects (Bognár-Kutzián 1963).

Variation in grave inventories has led scholars to identify broader social patterns that were deemed to have originated in the Copper Age, including expressions of power, gender differentiation, burial practices aligned with biological sex, and potential indicators of specialized roles such as metallurgists and craftspeople (Lichardus 1991). Schier (2011) argues that the interpretation of these features remains contested, as, similarly to the utilization of secondary products, many of them appear in earlier periods and are not exclusive to the Copper Age. Despite Schier's argument, the significance of these features lies not in their Copper Age origins, but in how these features are expressed in communities within their own social systems.

In summary, the defining characteristics of the Copper Age did not emerge uniformly across Europe. Nevertheless, by the beginning of the 20th century, the term Copper Age has been accepted, with the caveat that there is substantial regional variation, both in material and terminology (Pearce 2019; Ridge 2023). Their uneven timing, intensity, and spatial distribution, however, complicate efforts to establish both a generalized chronology and a coherent set of cultural features (Schier 2011).

5.3.2 Copper Age – Cultural Complexes

Despite the numerous issues attributed to the Copper Age, in the Carpathian basin this period is broadly defined as the Early (4500-4000 BCE), Middle (4000-3600 BCE) and Late Copper Age (3600-2600 BCE).

Early Copper Age (4500-4000 BCE)

The current consensus places both the Tiszapolgár and Bodrogkeresztúr groups within the Early Copper Age, broadly dating them to the period between 4500 and 4000 BCE. Recent research by Siklósi and Szilágyi (2021) suggests that the Bodrogkeresztúr cultural features emerged during the later phases of Tiszapolgár, which appears to have ceased across the broader Carpathian Basin after approximately 4290/4240 cal BC (Brummack and Diaconescu 2014:248).

Archaeological research shows that Tiszapolgár and Bodrogkeresztúr groups occupied similar regions within the Carpathian Basin (for the map see Ridge 2023 Figure 22), though Bodrogkeresztúr expanded into areas of the sandy Danube–Tisza interfluve and the Northern Mid-Mountains (Patay 1974; Visy 2003:124; Bánffy 1994).

Settlements attributed to Tiszapolgár and Bodrogkeresztúr groups are rare. Apart from the general low number of settlements in comparison to previous periods, a likely contributing factor is also the low visibility of flat settlements and limited excavation strategies. When found, settlements attributed to the Tiszapolgár culture were typically small (less than one hectare in size), short-lived, and spatially distinct from the prominent Late Neolithic tells, most of which were abandoned around 4500/4400 BC. Instances of Tiszapolgár habitation atop earlier Neolithic tells are rare but documented, notably at Vésztő-Mágor (Hegedűs and Makkay 1987) and Crna Bara (Garašanin and Garašanin 1957; see Chapter 6 for further detail). Only a handful of Tiszapolgár houses have been uncovered to date, all of which are rectangular, wattle-and-daub constructions. Houses are smaller (14 by 6 meters) than their Late Neolithic counterparts and appear to lack the internal divisions characteristic of longhouses (Parkinson et al. 2021).

The number of settlements dated to the Bodrogkeresztúr period are even smaller than Tiszapolgár groups. As Ridge (2023) notes, very few Bodrogkeresztúr settlements have been extensively investigated or published. As such, the settlement pattern remained characterized by small, dispersed sites. These are primarily found through limited surface ceramic scatters and characterized by large pits cut into older habitation layers, without any visible posts, framed, wattle-and-daub architecture (Patay 1974:31; Patay 2002; Ridge 2023; Skomal 1983:117). The only evidence of building material comes from pits, which may reflect a short-lived habitation that was intentionally destroyed.

Most of the available information concerning the Tiszapolgár and Bodrogkeresztúr cultures derives from cemeteries. Large cemeteries are relatively rare; thus the majority od the data stems from represents small flat cemeteries or ones sealing previous Neolithic occupations (Borić 2015). Apart from Tiszpolgar Basatanya (Bognár-Kutzián 1971), one of the largest cemeteries attributed to these two cultural complexes, one more large cemetery was uncovered in the Tisza–Maros region.

The cemetery of Pecica "East" in Arad County, Romania with its 278 graves to this day presents one of the largest cemeteries in the region (Sava et al. 2017; Sava and Ursuțiu 2020). The material assemblage of the cemetery presents both Tiszapolgár and Bodrogkeresztúr ceramics and an impressive 17 gold and 73 copper items (Sava et al. 2017). While the cemetery has not yet been fully published, the ceramics and radiocarbon dates appear similar to the cemetery of Tiszapolgár-Basatanya.

Apart from Pecica 'East,' cemeteries in the Tisza–Maros region are generally small, typically comprising around 50 graves. Examples include sites in the Serbian Banat and Bačka regions such as Srpski Krštur, Bajir, Kamara Humka, Deszk, Ószentiván, Senta, and Subotica (Grčki-Stanimirov 1998; Grčki-Stanimirov and Stanimirov-Grčki 2025; Garašanin 1957; Tasić 1995). Cemeteries containing exclusively Tiszapolgár material are rare; more commonly, cemeteries include elements associated with both the Tiszapolgár and Bodrogkeresztúr complexes—sometimes even within the same grave. A clear example comes from the cemetery of Podlokanj Nove Bašte in the Serbian Banat, which contains fifty-three individuals dated to 4300–4000 BCE (Borić 2025). The grave goods from this site include characteristic Tiszapolgár/Bodrogkeresztúr elements such as animal remains, pots on hollow pedestals, milk jugs, long flint knives and other stone tools, copper axes, gold ornaments, and limestone bead sashes (Grčki-Stanimirov and Stanimirov-Grčki 2025) The relatively late dates of this cemetery, combined with its mixed material culture, suggest that this part of the Tisza–Maros region may have formed the southernmost boundary of the Tiszapolgár–Bodrogkeresztúr cultural sphere.

Mirroring the pattern of the broader Carpathian basin, settlements in the region are much rarer in comparison to cemeteries. Apart from the site of Crna Bara–Prkos, there are rare instances of Early Copper Age settlements in the region. In southwestern Romania, eight subterranean and semisubterranean pit houses belonging to the Bodrogkeresztúr period have been reported at Pecica Site 15 (Virag 2013). The discovery partially explains the lack of evidence for post-framed houses for Tiszapolgár and Bodrogkeresztúr. However, more sites with similar construction strategies dating to this period would have to be found to assess if this was a pattern or an anomaly. Aside from a possible ditch at a site near Szabadkígyós on the Maros alluvial fan, there is no data for enclosures at Bodrogkeresztúr sites (Ridge 2023). Most of the 79 Tiszapolgár settlements recorded in the Lower Maros Valley appear to have been small and short-lived. Exceptions can be found at the tell-sites of Crna Bara in northern Serbia and Sântana "Holumb" near Arad in western

Romania, which are larger settlements with deep stratigraphy (Trifunović 2012:337-340; Sava 2015:174, 178, 182).

The end of the Bodrogkeresztúr culture period is poorly understood. Around 4000 BCE the Hunyadihalom culture became the dominant tradition throughout much of the eastern Carpathian Basin (Ridge 2023). However, evidence from the Tisza–Maros region suggests that Bodrogkeresztúr continued to exist in the southern part of the region as seen in the late dates from the cemetery of Podlokanj Nove Bašte in the Serbian Banat (Borić 2015).

Middle Copper Age (4000-3600 BCE)

Emerging after the Bodrogkeresztúr complex (Šiška 1972), the Hunyadihalom cultural complex (3900–3600 BCE) is the principal tradition associated with the Middle Copper Age in the Carpathian Basin (Siklósi and Szilágyi 2021). Archaeological evidence linked to Hunyadihalom is concentrated in the eastern regions of the basin, particularly along the Tisza River.

Similarly to preceding Early Copper Age groups, Hunyadihalom communities appear to have lived in small hamlets and were likely oriented toward animal husbandry (Patay 2005, 115–118). However, in contrast to the Tiszapolgár and Bodrogkeresztúr cultures, architectural remains from Hunyadihalom settlements include mid-sized pits and limited architectural features (Kalicz 1980; Kovács et al. 2017; Mészáros and Paluch 2009; ZalaI-Gaál 2016). On rare occasions, settlements dating to this period are larger, as exemplified by the site of Tiszalúc–Sarkadpuszta in the northern Carpathian Basin. Here excavations revealed a palisaded settlement comprising 45 overlapping timber-framed structures (Patay 2005: 26–55). Houses sizes were reported to be comparable to larger dwellings of the Tiszapolgár period—approximately 10–14 by 4–6 meters—and featured internal divisions (Patay 2005).

In contrast with the Early Copper Age cultures, burials are rare, comprising approximately 100 graves in the entire region. These were primarily recovered from Slovakia (Šiška 1972; Thomas et al. 2025) and some from the Tiszalúc–Sarkadpuszta settlement in Hungary (Patay 2005). Notably, for the first time, cremation becomes a significant component of mortuary practice, while inhumations followed the known mortuary program from earlier periods with individuals laying on their left or right side, while in contrast grave goods were generally rare

(Brukner 1970). When present burial assemblages consisted primarily of ceramic vessels, along with occasional tools and weapons, metal artifacts remained rare.

In the Tisza-Maros angle, there is little evidence of Hunyadihalom. Apart from the site of Vajska located in the Bačka region (Horváth 2004), and the bottom layers of Pecica–Şanţul Mare (Nicodemus et al. 2015), there are no other known examples of the culture in the larger area in Serbian and Romanian Banat. However, two sites dating to this cultural group were found directly north of the Maros, at the site of Hódmezővásárhely–Hunyadihalom in Hungary.

Late Copper Age (3600-2600 BCE)

While there was no evidence dating to the Late Copper Age found at any of the analyzed sites, a brief overview of the regional patterns dating to this period is warranted. While short, this overview enhances the contextualization of the evidence and patterns found in the Bronze Age.
The Late Copper Age (ca. 3600-2600 BC), similarly to the preceding Early and Middle Copper Age, was a period marked by the dichotomy of novelties and migration. The period is characterized by substantial regional variation, which is perhaps not surprising considering that the period's attributed duration is around 1000 years. Among the most notable material culture innovations were the emergence of chariot models and the early use of bronze metallurgy.
In the eastern Carpathian Basin, the principal cultural groups active between 3500 and 2600 BCE included Boleraz–Baden, Kurgan/Pit Grave/Yamnaya, and Cernavodă–Coţofeni complexes (Bondár 2018).

The cultural manifestations, chronological boundaries, and internal coherence of Late Copper Age groups remain subjects of ongoing debate. For instance, while some scholars interpret Boleráz as a developmental phase leading into Baden (Bondár 2018), others argue for their classification as distinct cultural complexes (Tasić 1995; Sava 2015:214). Recent radiocarbon data from Transdanubia suggest that the transition between Boleráz and Baden occurred between 3400–3350 BCE, with the Baden complex concluding no later than 2800 BCE (Oross et al. 2023:554). This evidence implies a degree of cultural continuity, yet it is crucial to recognize that Baden represents a widespread cultural entity that encompassed the entire Carpathian Basin, extending into Central Europe and the Balkans.

Due to its vast territorial reach, the Baden complex—particularly in its classical phase—is described as a "conglomerate of various traditions" rather than a homogeneous cultural unit (Bondár 2018:11). This diversity recognized adds to the interpretive challenges and inconsistencies in defining its cultural boundaries.

The Boleráz–Baden phase is marked by a notable increase in settlement activity, ranging from ephemeral campsites to more substantial habitation sites. A similar diversity was also recognized in the deposition of the dead. As of 2018, the number of documented Baden burial grounds remains relatively low, totaling just 143 sites (Bondár 2018:12), which further complicates assessments of its social and ritual structure. In contrast to earlier phases, the Late Copper Age exhibits considerable diversity in burial practice. While formal cemeteries—such as the large Budakalász–Luppacsárda site containing 436 graves (Bondár and Raczky 2009) —were in use, numerous individuals were also interred within settlements, often in deep pits alongside material remains and animal burials (Sava 2015:236).

At the latest stages of the Late Copper Age, between 3100 and 2600 BC, hundreds of burial mounds appeared throughout the Carpathian basin. Likely built by Kugan/Yamnaya/Pit Grave culture (Gimbutas 1977; 1980), who migrated to the region likely from the Pontic Steppe. With them they brought numerous novelties, including the building of tumuli or soil mounds with a grave-pit in the center of the construction. The graves were inhumations with bodies are laid in a supine position covered with red oche, with few burial goods, likely covered with wooden planks over the burial (Dani and Horváth 2012).

Amongst other novelties, during the Late Copper Age, there was also the introduction of and use of bronze metallurgy and likely introduction of horse husbandry (Poroszlai 2003; Ecsedy 1979; Horváth et al. 2008). The more pastoralist lifestyle associated with Pitgrave culture appears to have been similar to earlier cultural groups, however they lack visible settlements.

In the broader region, evidence of Baden settlements is rare. These settlements typically include a mix of pits, depositional debris such as hearths, and graves. However, due to poor preservation and limited excavation, Sava (2015:223) notes that it remains difficult to establish broader cultural patterns for the Lower Maros region during this period. The same goes for

mortuary patterns,, where the deceased were also found in storage pits as at the site of Sântana "Cetatea veche" (Sava 2015).

Another recognized and highly debated cultural group in the study region was Cernavoda III-Boleraz, which was primarily present in the western half of the Lower Maros region, where only six sites are recorded. However, all sites appeared highly disturbed (Sava 2015:290-305). Similarly to other cultural groups, the determination of this cultural group and its connection to Baden is debated. For example, N. Tasić (1995) Cernavodă III-Boleráz and Kostolac ceramics and saw no connection Baden-type pottery.

The low number of settlements dating to the Late Copper Age is also evident in the Tisza–Maros region (Trifunović 2012: 337–340; 2016: 331–333). A few settlements from this period have been identified in the Serbian Banat, near the modern settlements of Majdan, Padej, and Sajan (Marić 2026: 174). However, in contrast to settlements, burial grounds appear to be far more prominent in this region.

Marić (2026) notes that nearly 250 tumuli have been recorded in the Serbian Banat, though he rightly emphasizes that without excavation their dates remain uncertain, as similarly shaped mounds are also known from the Early Medieval Migration Period, such as at Crna Bara–Prkos (Mirković Marić et al. 2025). Some tumuli, however, have been securely associated with the classical Late Baden/Kostolac period, including the Aranđanska mound near Mokrin (Mokrin 52), Mokrin 71 (also known as Popin Paor), and Dilber mound southwest of Mokrin (Garašanin and Garašanin 1951: 81; Girić 1974; Marić 2026).

In addition to the Baden/Kostolac complex, evidence of Pit Grave/Yamnaya presence has also been documented in the Banat region between 3000 and 2600 BCE (Włodarczak 2026). The number of identified graves (also excavated and with confirmed association) associated with this cultural complex remains small—only seventeen have been recorded to date—one of which is the tumulus of Humka u Barnahatu near Padej (Marić 2026).

Although the landscape appears to have supported a greater number of settlements than in previous periods, the cultural attribution and chronological boundaries of these sites remain contested. One key factor contributing to this ambiguity is the lack of consistent typological patterns for the Baden period, which Bondár (2018) emphasize likely represents a cultural

"conglomerate" composed of regionally distinct traditions and practices. The second factor is the lack of evidence from the later period of the Pit Grave/Yamnaya which only show a handful of excavated graves in the study region (Włodarczak 202). These issues complicate efforts to define the culture's internal coherence.

Despite these challenges, the Late Copper Age introduced several innovations that laid the ground for the Bronze Age, which presented a survival of some cultural aspects form the previous period (Horváth 2016). These include the appearance of clay wagon models (Bondár 2008), and the intensification of metallurgical production—both of which signal emerging technological and economic shifts that would shape subsequent cultural trajectories.

5.4 The Bronze Age

Compared to the Copper Age, the Bronze age (ca. 2700 - 800 BC) presents fewer challenges in terms of its overall determination. Instead, debates have centered on the timing of its onset and the relative chronology of its subdivisions—namely, the Early, Middle, and Late Bronze Ages.

While the first relative chronological system for the Central European Bronze Age was established through typological evaluation of bronze artefacts (Reineke 1902) and played a foundational role in constructing local chronologies, these systems have since been revised multiple times, including the one proposed by Bóna (1961). For the Hungarian Early and Middle Bronze Age, the latter remains the most widely used (Kiss et al. 2019).

Numerous debates have followed regarding the precise chronological boundaries between subperiods. For example, the interval between 2800 and 2500 BCE is now generally regarded as a transitional phase—often termed Early Bronze Age 1—in which Late Copper Age and Early Bronze Age features coexisted (Fischl et al. 2015). Elsewhere in Europe, however, this same span corresponds to the later stages of Early Bronze Age 1 and the transition into Early Bronze Age 2, as in Bulgaria. In contrast, Central European scholarship classifies this interval as part of the Eneolithic (Copper Age), with the Bronze Age emerging only around 2300 BCE (P. Fischl et al. 2015)

In this study I adopt the periodization framework used for Eastern Hungary, where the Early Bronze Age (EBA) is divided into three phases—EBA 1, 2, and 3—spanning 2700 to 2000 BCE. Several cultural groups are associated with this period, including Yamnaya, Makó, Nyírség, Nagyrév, Otomani, Hatvan, and Maros. Similarly, the Middle Bronze Age (MBA) in Hungary is subdivided into MBA 1, 2, and 3, dated from 2000 BCE to approximately 1500/1450 BCE. This phase is attributed to the Füzesabony-Gyulavarsánd/Otomani, Hatvan, Nagyrev-Vatya, Vatin and Maros cultures (P. Fischl et al. 2015). The Late Bronze Age (1500–800 BCE) falls outside the chronological scope of this dissertation and will not be addressed here. For further discussion of the Late Bronze Age, particularly in the Tisza–Maros region, (see Parditka 2025).

While the Copper Age is often characterized by patterns of migration and dispersal, the Bronze Age marks a period of population re-aggregation (Gogâltan et al. 2014). During the Bronze Age settlement types found were tell-type sites and open sites.

Technologically the Bronze Age sees changes and the increased use of metallurgy, which almost completely replaced stone, particularly in regions like the Carpathian basin where stone resources were scarce to begin with. Apart from more widespread evidence of local metallurgical production, the evidence for increased metallurgical activity is visible through burials. A known example from the study region is the cemetery of Mokrin where metal artifacts are especially abundant (Girić 1971; O'Shea 1996, 1984; Žegarac et al. 2020).

The rise in metallurgical production, coupled with the expansion of long-distance exchange networks, coincided with notable shifts in social organization. Scholars have argued that the Middle Bronze Age witnessed the emergence of more hierarchical structures and the increasing visibility of elite groups (Earle and Kristiansen 2010). Among the artifacts that appear in the archaeological record during this period are swords, which have prompted various interpretations regarding the sociopolitical turbulence of the time.

5.4.1 Bronze Age – Cultural Complexes

Broadly speaking, the groups dating to the Early and Middle Bronze Ages, particularly in the region east of the Danube River, saw the emergence of tell sites, open flat settlements, large cemeteries and larger regional networks. While numerous groups have been associated with this period, the focus of this dissertation is the group whose sites provide the evidence analyzed in this dissertation—Maros/Maros/Mureș (hereafter referred to as Maros).

Dated to approximately 2700–1500 BCE (O'Shea et al. 2019), the Maros group constituted the dominant cultural presence in the wetlands formed by the Tisza and Maros rivers during this period. Archaeological evidence shows that they primarily inhabited the region along the Maros River, the eastern bank of the Tisza, and areas north of the Danube in Serbia (Deák 2005; O'Shea 2011).

Spanning both the Early and Middle Bronze Ages, the proposed early emergence of the Maros group (ca. 2700 BCE) remains contested, as it falls within the "transitional phase" defined for this region of Hungary (Fischl et al. 2015:507). This dissertation does not engage directly with debates surrounding cultural boundaries and periodization (for further discussion, see Fischl et al. 2015; Horváth 2016; O'Shea et al. 2019).

The Maros group, referred to as "swamp people" by Papalas (2008), adapted to the fragile yet predictable wetland environment of the Tisza–Maros region, much like earlier populations before them. The history of research on the Maros spans over two centuries, beginning in the 19th century and continuing into the present (Roska 1912, 1914; Childe 1929; Farkas and Lipták 1971; Bóna 1975; O'Shea 1984, 1996, 2011; O'Shea et al. 2019; Stefanović and Porčić 2013; Nicodemus 2010, 2014; Gogâltan et al. 2014; Girić 1971, 1984; Milašinović 2009; Pompeani 2020; Žegarac et al. 2020; Popescu 1944; Soroceanu 1991; Sipovac et al. 2023).

Over the course of this research history, the group has undergone several name changes. Initially, it was referred to as Perjamos (Childe 1929) or Periam–Pecica (Garašanin 1984), a designation derived from the type site of Periam—a tell-type settlement situated on the left bank of the old Aranca watercourse in western Romania. Periam has been investigated multiple times, with the earliest excavations dating to 1878 (Gogâltan 2014), followed by documentation by M. Roska in the early 20th century (Roska 1912). Despite the early history of research, it was V. G. Childe who popularized the term Perjamos in broader archaeological research (Childe 1929). Although Perjamos became the dominant name in literature, Hungarian scholars referred to the later portion of Perjamos as Szőreg Group (Bóna 1975), named after the large Szőreg 'C' cemetery

site, while the earliest portion was attributed to the Pitvaros Group, based on the Pitvaros cemetery (Bona 1975; O'Shea 1996), which falls in sequence of the Maros group[3].

Today, the group is more commonly recognized as Maros[4], from the widely recognized cemetery of Mokrin, located in the Serbian Banat (Girić 1971). Ongoing research at Mokrin dated the cemetery between 2000–1800 BCE, and have been ongoing since 1958, revealing skeletal remains and mortuary practices later classified under the Early Maros phase (O'Shea 1996).

The Maros cultural period was divided into two phases: Early Maros (2700–1950 cal. BCE) and Late Maros (1950–1500 cal. BCE) (O'Shea et al. 2019). During the Early Maros, the dead belonging to this cultural group were buried according to a strict mortuary program presenting single or multiple inhumations within bounded cemetery grounds, such as the cemetery of Mokrin. Individuals were typically interred on their side, positioned either on the right or left. Most age groups are represented in Maros cemeteries, including children. However, the interment of neonats and infants was rare and has so far has only been recognized at the Late Maros cemetery of Ostojićevo (Milašinović 2008; Milašinović et al. 2024; Marin et al. 2024; Pompeani 2020;).

Although the Maros cultural group likely functioned as a network of interconnected communities, settlements were often encircled by ditches—features whose original purpose remains debated (O'Shea 1996). As is common in human–environment interactions, built features may evolve or serve multiple functions over time. These ditches may have initially been constructed for defense, spatial delineation, or water management, but their roles could have shifted or overlapped as environmental and social conditions changed.

For example, in Maros settlements situated in wetland zones, which were highly influenced by seasonal flooding, ditches may have been built for flood management, while simultaneously serving as a separation of space between the core of the settlement and its immediate outskirts. Consequently, such settlements tend to be more densely built than the ones located further away from the flooding zone. Generally, however, the densely built environment is a feature associated

[3] For a detailed discussion of ceramic styles and nomenclature associated with the Maros cultural complexity see Parditka 2025:48-52.

[4] Despite the name shift in the 70's, regional variations of the same cultural group persist: Maros (Serbian), Maros (Hungarian) and Mureș (Romanian).

with Maros settlements. Residential areas consisted of rectangular houses measuring approximately 8–14 meters in length and around 4 meters in width, likely occupied by nuclear or small extended families (O'Shea 1996:43).

Maros houses appear to be standardized across sites and consisted of prepared clay floors (usually light yellow or gray in color) with wattle and daub walls supported by light wall posts, covered by thatched roofs (Michelaki 2008:358). Interior features included ovens, hearths, room dividers, and subterranean storage pits, all indicative of domestic activity (O'Shea 1996:43).

Across Maros communities, subsistence practices appear broadly consistent, with a primary focus on agriculture and animal herding (Nicodemus 2014). The high salinity of seasonal wetland soils surrounding many Maros settlements created favorable conditions for grazing during dry periods (Deák 2005; Nicodemus 2010, 2014; Duffy 2010; Gyucha et al. 2013).

A variety of faunal remains and ages were recovered from Maros sites include cattle (Bos taurus), sheep (Ovis aries), goats (Capra hircus), pigs (Sus scrofa), horses (Equus) and remains of dogs (Canis familiaris) (Greenfield 1991; Nicodemus 2014). This evidence suggests a diverse and flexible herding strategies, likely adapted to their immediate environmental conditions. In addition to supporting herding practices, the wetlands likely supplemented subsistence through hunting, fishing, and the exploitation of wild plants. Although direct evidence for wild plant use is limited, archaeological data indicate the cultivation of domesticated species such as barley, einkorn wheat, legumes, peas, lentils, and millet (Nicodemus et al. 2015; O'Shea 2011; Jones, Hannon, and Hunter, in press).

Beyond subsistence, Maros settlements reveal evidence of a wide range of activities, including pottery production, textile weaving, long-distance exchange, and metallurgy (Childe 1929; O'Shea 1996; Nicodemus 2014). Variation across sites has prompted interpretations of differential wealth and resource specialization, with signs of economic differentiation already visible at the household level (O'Shea 1996:296).

In summary, variation emerges as a defining feature of the period under study. Archaeological evidence spanning 4500 to 1500 BCE reflects diverse lifeways, including differences in settlement patterns and mortuary practices. Of particular relevance to this

dissertation is the variation detected in metallurgical production. The following section presents metallurgical evidence from the study region in greater detail, providing essential context for interpreting site-specific patterns discussed in Chapter 6.

5.5 Metallurgy Between 4500 and 1500 BCE in the Tisza–Maros Region

One of the most defining characteristics of the 3000-year period under study is the emergence, diffusion, and transformation of metallurgical technologies. As the archaeological record demonstrates, copper production and utilization varied significantly across Europe (Brozio et al. 2023).

The earliest evidence of copper production in the Balkans includes both cold-hammered and smelted items, dated to approximately 5000 BCE and discovered at the site of Pločnik in eastern Serbia (Pernicka 1993; Radivojević 2019). Attributed to Late Neolithic Vinča D communities, these artifacts reflect the exploitation of copper ores for the manufacture of jewelry and weapons. Evidence of ore mining has also been documented in the region, with the earliest known mines located at Rudna Glava in Majdanpek (Jovanović 1976; Antonović 2018, 2019). The ores exploited during this period were primarily oxide types, including malachite, azurite, and cuprite. Scholars suggest that one of the drawing factors to the exploitation of colorful black and green ores, was their vibrant color have made them easily recognizable against the natural backdrop (Radivojević et al., 2013).

A notable disparity exists in the distribution of copper artifacts across the archaeological record. In contrast to ore-rich regions such as Bulgaria and southern Serbia, where metallurgical production began early, areas more distant from primary sources, including the Carpathian Basin and the Tisza–Maros triangle, show evidence of copper artifact circulation only toward the end of the Late Neolithic (Banner 1960). Evidence for local production, by contrast, emerges only during the Early Bronze Age.

One likely factor contributing to the delayed appearance of metallurgy in the plains is regional geology. The local bedrock is buried beneath hundreds of meters of loess sediment, which is largely devoid of both stone and metal resources. Consequently, raw materials such as stone, gold, and copper ores were likely transported from the foothills of surrounding mountain ranges, including the Apuseni Mountains and the Eastern Carpathians, or acquired through exchange networks extending from more distant regions (Ridge 2023: 60–61).

5.5.1 Copper Age Metallurgy

Metal artifacts in the region have been documented at sites such as Čoka Kremenyák, a tell settlement dating to the Late Neolithic and attributed to the Tisa cultural group. During excavations in 1908, F. Móra uncovered a pot containing 14 malachite beads (Banner 1960). In addition to this find, other copper ornaments, including bracelets, beads, and collars, have been recovered from sites such as Hódmezővásárhely-Gorzsa and Szeged Tápé-Lebő in Hungary. Metallographic analysis conducted on several of these objects indicates that they were manufactured using cold-hammering techniques (Sava 2015:284).

While the majority of copper artifacts were recovered from burial contexts, occasional finds have been retrieved from settlement layers, despite the absence of direct evidence for on-site production (Sava 2015). This is not unexpected, as cold-hammering leaves minimal archaeological traces, making production activities difficult to detect in the material record.

The distribution of copper artifacts in the region intensifies during the Early Copper Age, particularly within the Tiszapolgár and Bodrogkeresztúr cultural complexes. During this period, copper items, primarily associated with Tiszapolgár contexts, continued to appear in graves, including jewelry such as rings, beads, and bracelets (Sava 2015).

Most copper artifacts attributed to the Tiszapolgár cultural complex consist of small items, primarily body ornaments and jewelry. Gold objects are reported far less frequently within the study area. The closest gold find to the study dating to this period comes a grave of a wealthy woman uncovered during highway construction in western Romania, which contained 169 gold rings (Cascone 2022). Nonetheless, gold circulated more widely across the broader region. Heavier copper tools and gold items associated with Tiszapolgár contexts have been documented at sites located closer to ore sources, particularly in Slovakia—for example, in the cemeteries of Tibava and Vel'ké Raškovce (Šiška 1964; Vizdal 1977).

As in the Late Neolithic, no direct evidence of local metallurgical production has been identified at Early Copper Age Tiszapolgár settlements. This absence may reflect the use of cold-hammering techniques, which leave minimal archaeological traces, or importation of finished artifacts form a different region.

Although the Bodrogkeresztúr cultural complex shares significant similarities with Tiszapolgár groups, it is more frequently associated with advanced metallurgical production (Hillebrand 1927). During the Bodrogkeresztúr phase, "massive copper artifacts" have been documented within the study region and primarily found in lowland sites (Sava 2015). These include a wide array of smelted tools like axes, chisels, awls, and knives; considerable variation in axe types: shaft-hole axes, hammer axes, single- and double-edged axes, battle axes, and flat axes (Patay 1974; Heeb 2011). In addition to utilitarian implements, copper jewelry (beads, bracelets, pins, coils) and, on rare occasions, ingots have also been found dating to this period (Heeb 2011; Skomal 1983; Sava 2015; Siklósi and Szilágyi 2019;). Some copper artifacts have been recovered from sites within the immediate study area, including Szeged-Szillér, Periam, and Pecica "Şanţul Mare" and its vicinity (Sava 2015).

Within the Carpathian Basin, gold items primarily used as body ornamentation are most frequently found in Bodrogkeresztúr burial contexts. Such items include ring-pendants, tab-pendants (Jovanović 1996:31), beads, buttons, tubes, spiral finger rings, arm rings, and other pendants (Siklósi and Szilágyi 2019; Virág 2003). Gold has also been documented in hoard contexts (Makkay 1989; Skomal 1983:115; Jankovich et al. 1998:575–579; Patay 2013).
In the Tisza–Maros triangle, however, gold finds are rare. Notable exceptions include gold pendants and a copper flat axe recovered from the site of Podlokanj–Nove Bašte, though no evidence of metallurgical production has been identified at the site (Grčki-Stamirov and Stamirov-Grčki 2025).

This period appears to mark a metallurgical peak that extended across Southeastern and Central Europe (Heeb 2011; Jovanović 1971, 1990; Makkay 1996; Muhly 1988; Renfrew 1969; Virág 2003). Especially because following the Early Copper Age, and more markedly after the Middle Copper Age, metallurgy appears to have entered a period of decline. As a result, metal artifacts associated with the Late Copper Age are relatively scarce, particularly in its earlier phases. Heavy copper items are rare, though isolated finds such as a dagger from Sármellék and a diadem from Vörs (Makkay 1996), as well as a dagger discovered by chance in the cave of Crăciuneşti "Peştera cu trei intrări" (Andriţoiu 1979), indicate that metals continued to circulate. Within the immediate study region, however, no metal artifacts—nor any evidence of production—have been identified.

Makkay (1996) has proposed that the decline in gold and copper use may be linked to increased social unrest during the Late Copper Age. Yet, this hypothesis remains speculative, as the archaeological record for this period is fragmentary and inconsistent across the region. Nonetheless, certain patterns emerge from the available evidence. Despite the broader circulation of metallurgical artifacts—some of which would have required smelting, such as axes—no direct evidence of smelting has been found. This absence may be attributed to several factors, including the limited number of identified settlements and the ephemeral nature of early metallurgical installations.

An important observation raised by Sava (2015) concerns the differential detection of items associated with metallurgy (from objects to production items) depending on whether excavations were conducted as systematic research projects or as salvage operations. This distinction raises broader questions about excavation accuracy and the visibility of metallurgical materials in the archaeological record.

This issue is particularly important in the context of early metallurgy, where the detection of production-related debris presents additional challenges. Given the ephemeral nature of early metallurgical traces—such as small-scale hearths, slag, or tool marks—the likelihood of identifying such evidence without targeted investigation is low. As a result, the absence of production indicators in many sites may reflect methodological limitations rather than a true lack of metallurgical activity.

5.5.2 Maros Metallurgy

Despite proposed deforestation during the Bronze Age—often attributed to the demands of metallurgical production (Willis et al. 1998)—direct evidence of metallurgy within the study area remains limited. A review of metallurgical evidence recovered from Maros contexts suggests a relatively simple technological repertoire overall, with a few notable exceptions (Papalas 2008). Most metal objects associated with the Maros culture were recovered from graves, including diadems and pins such as those found at Mokrin (O'Shea 1996).

Regional research indicates that locally produced metallurgy first appears during the Maros context, marking the earliest evidence of settlement-based production in the area's archaeological record. However, this craft appears to have remained small in scale. Papalas (2008) argues that

Maros communities were notably frugal with metal use. This is reflected in the rarity of primary slag, which even when present, the small size of slag fragments suggests minimal fuel consumption and limited production volume. In most cases, slag recovered from sites in the region appears to have been re-smelted multiple times.

Importantly, the deposition of metallurgical artifacts and evidence of production shifts over time. During the Early Maros phase (2700–1950 BCE), most metal objects were found in graves, as evidenced by the rich assemblages at Mokrin (Girić 1971; O'Shea 1996) and early phase at Ostojićevo (Milašinović 2008; Milašinović et al. 2024). Despite the presence of axes and jewelry, most artifacts appear to have served ornamental or sartorial functions rather than utilitarian ones (O'Shea 1996: 226–227, 270). To some extent, this pattern echoes trends observed in Bodrogkeresztúr Middle Copper Age cemeteries.

In the Late Maros phase (1950–1550 BCE), the quantity of metal artifacts recovered from cemeteries declines. For the first time in the region's history, however, metallurgical evidence begins to appear within settlements. Although signs of local production was significantly improved with targeted excavation, the evidence remains in comparison to other areas relatively low. Papalas (2008) has proposed that Maros smiths operated within settlements where access to food, water, fuel, labor, and security were readily available. Whether this hypothesis holds true is a question this dissertation seeks to address and will be discussed in greater detail in Chapter 6.

Chapter 6 Intensification of Metallurgy in Context: Evidence From Six Sites in the Tisza–Maros Region

This chapter introduces the six archaeological sites selected to examine the intensification of metallurgical production. These sites are located in southeastern Hungary, northern Serbia, and western Romania—a region referred to throughout this dissertation as the Tisza–Maros triangle, region or area. Each site is presented with details on its geographic setting, excavation history, stratigraphy, chronological framework, and evidence of land use, including metallurgical activity.

While two sites contain traces of earlier Copper Age occupation linked to the Tiszapolgár, Bodrogkeresztúr, and Hunyadihalom groups, all sites but one, have a large Bronze Age component associated with the Maros cultural group (Figure 6.1).

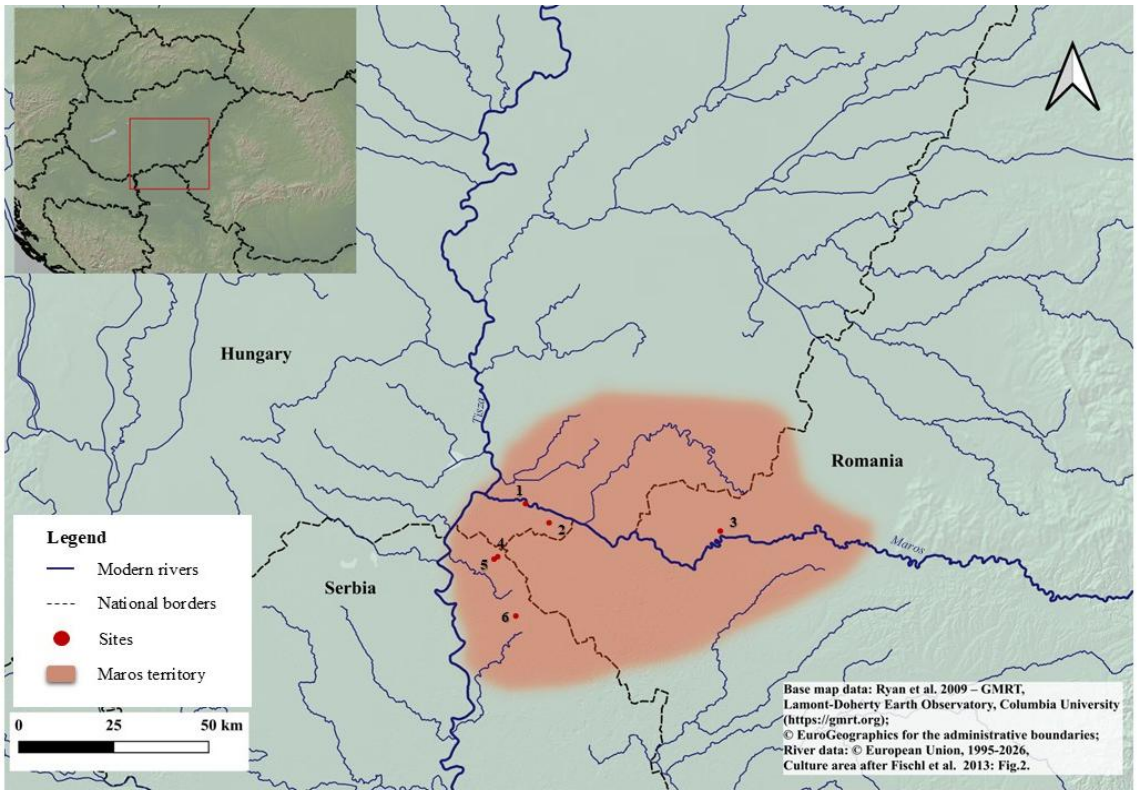


Figure 6.1 Map showing the extent of the Maros territory (after Fischl et. al 2013) with all analyzed archaeological sites: 1 – Klárafalva Hajdova, 2 – Kiszombor Új Élet, 3 – Pecica Şanţul Mare, 4 – Rabe Anka Siget, 5 – Majdan 28, and 6 – Crna Bara–Prkos. Map by Györgyi Parditka, with my alterations.

6.1 Klárafalva Hajdova

Klárafalva–Hajdova is a tell site[5] situated in southeastern Hungary, located between the cities of Szeged and Makó, within the floodplain of the Maros River. The site lies on the south bank of the river, just north of the village of Klárafalva.

The site was first excavated by F. Móra in 1931. In the 1960s, O. Trogmayer initiated work at the site in response to local agricultural plans to level the land (Figure 6.2). The research conducted on the site included coring and excavation of two blocks. The coring and excavation (a total of 40 m²) revealed 340cm of deposition, which Trogmayer attributed to the Szőreg-Perjámos cultural group, dated to the Middle Bronze Age (Horvath 1985). Fischl summarized the findings in a later publication and confirmed Trogmayer's observations that the latest sequence of the site was removed prior to excavations (Fischl 1997).



Figure 6.2 Photo of the site of Klárafalva-Hajdova, photo taken in 1976 after the local cooperative removed the upper site deposits. Photo Credit: John O'Shea (in press).

A third excavation at the site of Klárafalva took place in 1987-88, led by J. O'Shea in collaboration with F. Horváth. During the excavation, remains of houses were discovered, characterized by thick clay floors, wattle-and-daub walls, and circular and rectangular hearths or

[5] Definitions for tells varies in the region and has been debated widely. See Gogâltan 2002 and Gogâltan et al. 2014 for further discussion.

ovens (O'Shea in press). O'Shea conducted C14 dating at the site, which placed the Klárafalva occupation to from 2175 to 1550 BCE. (O'Shea et al. 2019) (Table 6.1).

Site Phase	Dates BCE	Layers
Phase 3 - Late	1690-1550	A B C D
Phase 2 - Middle	1825- 1689	E F G
		H
Phase 1 - Early	2175-1825	I J K Pre-K

Table 6.1 Overview of Klárafalva's phasing and associated layers, according to O'Shea (in press). The darker green (Phase 2 and 3) represent the Middle Bronze Age, while the bright green (Phase 1) represents the Early Bronze Age

6.1.1 Evidence of Bronze Age Land Use Klárafalva Hajdova

Evidence for land use at Klárafalva-Hajdova can be in part inferred from the site's faunal assemblage, even in the absence of extensive prior research on this topic. Nicodemus (2014) observed a predominance of animals slaughtered at prime age (between 6 and 12 months) (Munson 2000; Lattore et al. 2003), alongside a notable absence of animals used for breeding. These were usually assumed to be older animals, which were past the prime slaughter age. Nicodemus states that the assemblage was dominated by smaller livestock—particularly caprine (*Ovicapridae*) and pigs (*Sus scrofa domesticus*)—while larger animals such as cattle (*Bos taurus*) and horses (*Equus caballus*) were sparsely represented (Nicodemus 2014).

This pattern may reflect the environmental constraints of Klárafalva. While the site lay today approximately 350 m from the Maros River, it is likely that the site was even closer to the river in the past. The proximity to the river, frequent flooding, limited the arable land around the

site and appear to have influenced subsistence strategies— evidenced by the unusually high incidence of freshwater species such as carp (*Cyprinus carpio*) and pike (*Esox lucius*) in the faunal record (O'Shea 2011; Nicodemus 2014; Nicodemus in press).

Domesticated and wild animals, however, were only one component of the diet. The archaeobotanical evidence from Klárafalva reveals a rich and diverse crop assemblage, significantly more abundant than that recovered from nearby Kiszombor. Jones et al. (in press) found six cereal types, including three glume wheats—einkorn (*Triticum monococcum*), emmer (*T. dicoccum*), and Timopheev's wheat (*T. timopheevii s.l.*), along with free-threshing wheat (T. aestivum/durum), hulled six-row barley (Hordeum vulgare), and broomcorn millet (*Panicum miliaceum*). However, Jones and colleagues report that millet at Klárafalva was present only in very small quantities.

Among pulses, lentil (*Lens culinaris*) was the most prominent, with occasional finds of bitter vetch (*Vicia ervilia*), grass pea (Lathyrus sativus), and a single pea (*Pisum sativum*) seed. Wild plant foods were rare, limited to a few Cornelian cherry (*Cornus mas*) stones and indeterminate fruit/nut fragments. Jones et al. (in press) note that the weed taxa suggest a range of growing conditions, with most species adapted to relatively dry soils, though a few—such as Cyperaceae and Polygonaceae—indicate wetter micro-zones.

Despite the wetland setting around the site and periodic flooding of the Maros River floodplain, Jones et al. (in press) note that Klárafalva's Bronze Age inhabitants likely relied on cultivated crops, with little evidence for wild plant collection[6]. Their agricultural strategy appears to have focused on risk mitigation through the cultivation of cereals like einkorn and barley, mixed maslin cropping, and staggered sowing in both autumn and spring (Jones et al. in press). This suite of practices enabled successful cultivation in an unpredictable environment and reflects broader regional trends in Bronze Age crop husbandry across the Carpathian Basin. Evidence of storage and waste further supports the interpretation of Klárafalva as a site of sustained agricultural activity.

[6] The lack of wild plants, however is not uncommon as most plant material such as leaves, roots and seeds would have been consumed with little processing effort, thus leaving little evidence in the record. Such evidence would have to be record likely via archaeometrical techniques.

In terms of variation through time in botanical remains, there does not appear to have been differences at the site. However, evidence suggests certain crops were generally stored in different locations. Namely, barley appears to have been separated from other cereals, while lentils and legumes were stored in the same area (Jones et al. in press). It is possible that such evidence might indicate a separate processing of barley, either for brewing, food, or animal feed. Alternatively, this separation, and the presence of other plans like legumes and peas could indicate the presence of gardens at the site. While gardens have not been commonly identified in the Bronze Age, their presence and importance for local subsistence have been debated since the Neolithic (Mlekuž 2015). Isotopic evidence from Iron Age Germany suggests that separation of plants due to storage or processing might indicated different activities, in addition to gardens in Iron Age hillstops (Styring et al. 2017). Recovered evidence of manuring (Bogaard et al. 2007), particularly in gardens, further supports the community understanding of soil production and necessities. It is thus it is not to exclude that Klárafalva being impacted by flooding and thus presenting limited immediate cultivation space, that gardens could have been placed in the site's core, while larger agricultural areas, were likely placed in drier areas further away form the site and the river.

Metallurgical evidence at the site was retrieved from two stratigraphically superimposed furnaces and associated pit features containing refuse, including slag (Papalas 2008:44).
Over time, both furnaces changed in size but retained similar construction techniques: the earlier furnaces were built from yellow silt, while the later, significantly larger one was lined with clay. Although both furnaces were devoid of internal debris, the surrounding areas exhibited signs of burning (O'Shea in press).

Additional indicators of metallurgical activity were fragmentary remains of metallurgical objects form the site. Such example includes a possible tuyère fragment—likely part of a blowpipe or bellows nozzle—which showed discoloration and heavy burning. Multiple crucible fragments were also found, in addition to metallurgical waste, such as several slag pieces recovered from the same context (O'Shea in press). Evidence from the excavations suggest small-scale metallurgical activity at least for a portion of the duration of the site. Evidence of crop remains were found in the thermal feature 11, placed in Phase F (Jones et al. in press), and slags, indicates that these

features were likely used for multiple purposes. Crops could have ended in the feature as part of cooking or were mixed in animal dung that was used as fuel.

Furthermore, based on the prevalence of refractory material, Papalas (2008: 208) argues that it is likely that not all aspects of metallurgical production were discovered at the site. Instead, it appears that casting was the most prominent metallurgical activity conducted at the core of the site. Considering that Klárafalva–Hajdova was located close to the river Maros and prone to flooding, most activities likely took place within the settlement itself. These activities may have been timed around seasonal floods, which would have shaped how space was used and when tasks were carried out. It is not to exclude that other metallurgical activities were conducted in the site's surroundings, likely during regular environmental cycles, which influenced how the community planned its settlement, organized subsistence, and organized shared spaces.

6.2 Kiszombor-Új-Élet

Although both Klárafalva–Hajdova and Kiszombor-Új-Élet are considered to be tell-type sites (O'Shea in press), Kiszombor presents a larger but less densely occupied settlement area [7]. Located roughly 10 km east of Klárafalva-Hajdova, Kiszombor was situated on a naturally elevated area, making it less prone to flooding. Located approximately 8 km from the River Maros and near the Porgany Creek the site presented a larger dry area surrounding the site.

The site has been investigated multiple times since 1928. The 1980s rescue excavations led by L. Horváth was prompted by the discovery of ceramic vessels during the digging of seven large grain storage trenches by the local agricultural cooperative (O'Shea in press). The excavations' results revealed a Bronze Age settlement, along with suspected evidence of Late Copper Age finds (Parditka 2025, after Horváth 1985). However, no evidence for a Copper Age component was found during subsequent excavation (O'Shea in press). Further investigations of the site were carried out in 1988–89 by J. O'Shea in collaboration with F. Horváth (Figure 6.3). These excavations revealed an occupation horizon with three distinct phases associated with Maros

[7] O'Shea reports (in press) that during their And previous excavation campaigns researchers were not able to test the very core of the site. However, differences between the areas excavated were sufficient to give an idea of the spatial density of the site.

cultural remains. Features included storage pits, house floors, and wattle-and-daub wall fragments (O'Shea in press).



Figure 6.3 Photo of the site of Kiszombor-Új-Élet taken prior to 1988 excavation. Photo credit: John O'Shea (in press)

Based on ceramic typology identified by Horváth, the site was initially dated to the Early Bronze Age (Horváth 1985). This assessment was later confirmed by O'Shea, through radiocarbon analysis, placing the primary occupation between approximately 2700 and 2000 BCE (O'Shea et al. 2019) (Table 6.2).

Site phases	Dates BCE	Layers
Phase 4	1935-1825	A1-A2
Phase 3	2165-1935	Trench 1: B1-4 Trench 5: B45-47
Phase 2	2525-2165	Trench 1: B5-6 Trench 5: B48-49
Phase 1	2715-2525	Trench 1: B7-12 Trench 5: B50-51

Table 6.2 Overview of Kiszombor's phasing according to O'Shea (in press). The darker green (half Phase 3 and 4) represent the Middle Bronze Age, while the bright green (Phase 1,2 and half of 3) represent the Early Bronze Age

6.2.1 Evidence of Bronze Age Land Use at Kiszombor-Új-Élet

Zooarchaeological evidence from Kiszombor, analyzed by Nicodemus, suggests several key patterns. First, the faunal material appears less fragmented, which may reflect different disposal practices—refuse was likely spread across the general occupation area rather than concentrated in middens. Alternatively, this could indicate lower occupation intensity at the site (Nicodemus in press). The reduced fragmentation may be related to overall spatial use: while Klárafalva exhibits a more condensed occupation, the evidence from Kiszombor suggests a broader settlement footprint, possibly due to its greater distance from flood-prone zones.

The sites also differ in animal representation. Compared to Klárafalva, Kiszombor shows substantially less evidence for hunting and fishing. Similarly to Klárafalva, at Kiszombor, caprines were the most numerous, followed by pigs and cattle, with only a few horses (Nicodemus in press).

While livestock composition varies only slightly, more significant differences emerge in animal demography. All livestock species show signs of local breeding, indicated by the presence

of both neonates and infants, as well as older individuals. The presence of adult animals suggests that they were valued not only for meat but also for secondary products such as dairy, wool (in the case of caprines), and labor (Nicodemus in press), all of which are linked to the larger availability of grazing areas and dry land.

The archaeobotanical evidence from Kiszombor is modest but suggests the cultivation of several cereal crops, most prominently einkorn wheat (*Triticum monococcum*), with lesser evidence for barley (*Hordeum vulgare*). Other crops, including free-threshing wheat (T. *aestivum/durum*) and broomcorn millet (*Panicum miliaceum*), were also present. Notably, Jones et al. (in press) show that broomcorn millet appeared more frequently at Kiszombor than at Klárafalva, despite Kiszombor predating Klárafalva and presenting overall lower quantity of plant remains. Among pulses, small quantities of lentil (*Lens culinaris*) were identified. Wild plants were rare, though occasional finds included Cornelian cherry (*Cornus mas*) stones and indeterminate fruit or nut fragments (Jones et al. in press). However, the limited crop evidence from Kiszombor could also be due to the fact the very central part of the settlement was not excavated (O'Shea in press), thus restricting finer spatial or temporal analyses.

As with the faunal assemblage, the botanical remains suggest that Kiszombor relied on locally adapted subsistence strategies centered on cultivated crops (Jones et al. in press). The presence of multiple cereal types—likely sown in a seasonal rotation to mitigate risk—and the limited evidence for garden crops, such as peas and other legumes, may indicate a reduced emphasis on garden cultivation in this portion of the site.

Evidence of metallurgical activity was identified at the site in silage trenches 1 and 5, where thermal features were uncovered (Papalas 2008). These trenches were placed at some distance from one another (60m), suggesting that metallurgical activity was spatially dispersed across this portion of the settlement.

Artifacts associated with metalworking included possible crucibles, a copper awl or chisel, and a fragment of a tuyère. Slag analysis conducted by Papalas revealed a broader range of material types at this site compared to Klárafalva, likely reflecting technological variation over time (Papalas 2008).

From present evidence, it is possible to suggest that multiple technological steps were likely carried out at Kiszombor, ranging from smelting to object production. Evidence for smelting

includes varying types of ore and metallurgical waste such as tuyère fragments and crucibles. It is possible that some first level smelting was conducted at the site considering broader range of ore types identified.

In conclusion, it is thus possible to suggest that while the settlement itself was used for most daily activities, with the peripheral portions used for a range of activities, including subsistence and metallurgy. The surrounding dry areas were likely employed for pasturing and agriculture. The breeding and use of animals for secondary products, along with the predominance of mixed cereal cultivation, likely reflect the broader availability of dry and grassland areas. Similar patterns are evident in metallurgical production, which appears to have been small-scale but involved multiple technological steps—likely all carried out within the same areas of the settlement. Kiszombor predates Klárafalva, thus it is possible that some of the evidence is a result of temporal trends [8]. Alternatively, the observed patterns might be a result of the environmental setting, as Kiszombor presents more dry land around the site, while Klárafalva, was located nearby wetland zones.

6.3 Rabe Anka Siget

Rabe Anka Siget ('*sziget*' meaning "island" in Hungarian) is a tell settlement with a long history of research (e.g., Banner 1931; Bóna 1975; Girić 1974, 1984, 1987, 1994; Reizner 1891; 1902; Трифуновић 2012) located just southwest of the village of Rabe, near the Serbian-Hungarian-Romanian border. The site is located approximately 14km from the Maros and Tisza rivers, respectively. Despite its relative distance, the site locality would nonetheless have been affected by seasonal flooding (Figure 6.4).

The site was first reported in 1890, when vineyard digging exposed archaeological materials. Initial excavations at the site began in 1891 and 1902 under J. Reizner, followed by smaller campaigns by I. Tömörkény (1908) and later by the National Museum in Kikinda. Despite this activity, documentation was poor (Nicodemus 2017).

[8] Even so, the earliest phase of Klárafalva overlaps with the last occupation phase at Kiszombor, showing a partial overlap, although no differences were detected during this phase.

Reizner's 1891 excavations uncovered a high artifact density of a possible residential area attributed to the Maros cultural with deposits up to 2 meters deep. In addition to Maros pottery, evidence of imported pots from Otomani and Encrusted Ware were found, faunal remains (cattle, red deer, pigs, horses, freshwater mussels), crafting tools (axes, antlers, net weights, spindle whorls, tuyère), and while rare, also metal finds—only a needle and half a mold with two pins (Reizner 1902).



Figure 6.4 The site of Rabe Anka Siget. Photo taken in 2021 from the east portion of the site and was facing the West tell and forest gallery where the Main excavation block was placed in 2022

In addition to the settlement, Reizner also reported five graves on the western slope, likely Maros. Reizner reported that the graves contained pottery, including decorated vessels and cups, as well as a 'fish plate,' along with a stone axe, but no recovered metal or prestige items (Reizner 1902) (Figure 6.5).[9] Furthermore, burials within settlements are rare for Maros groups, who typically used communal cemeteries (O'Shea 1996) although occasional human remains have been found at Kiszombor and Pecica. Nevertheless, settlement burials remain hard to interpret.

[9] However, to this day no evidence of these graves have been found at the site, thus warrants further investigation.



Figure 6.5 Pins and mold from Reizner's investigations in 1900, housed at the Móra Ferenc Múzeum, Szeged. Photo taken from Nicodemus (2018), credit of Györgyi Parditka

However, evidence of habitation emerges beyond the immediate site of Rabe. Pedestrian surveys conducted by Трифуновић (2012) and Daković (2023) documented extensive Bronze Age artifact scatters across elevated areas, river terraces, and levee banks encircling the site, raising the possibility of additional, short-lived occupation in its vicinity.

Additional systematic surveys conducted by the Rabe Anka Siget Archaeological Project (RASAP) between 2017 and 2021 confirmed earlier findings, while also revealing a longer occupation of the larger area around the site. Apart from the dominant Bronze Age component, Early Neolithic and Copper Age pottery has been identified along the southern canal edge, while there is a general presence of Late Medieval remains around the site. A survey conducted in 2021 also showed that there might have been a short-term occupation in the surroundings of the site (which was confirmed) particularly immediately north, west, and south. This suggests a long history of occupation and possible episodic engagement with the landscape across millennia.

As part of the RASAP project, geophysical mapping (magnetic gradiometry, susceptibility, and conductivity), coring, and excavations were conducted on the site (Nicodemus 2017, 2018). In 2018, two units (Test unit 1- central mount and 2- west mound) were opened at the site, to test the results from the magnetometry. From 2022 to 2024, excavations of a large block on the western tell was conducted as part of the RASAP project. In 2021, I conducted additional coring at the site and its surroundings. In 2022, I excavated one additional test unit (Test Unit 3), located in the eastern part of the site, where geophysical results indicated an area of high disturbance (Figure 6.6). Results from coring in 2021 and test excavations conducted at the site in 2022 by me are reported in the Appendix of this dissertation (see Appendix A).

The results from the excavations confirmed that the site was created by the Maros cultural group, between 2050 and 1550 BCE (Table 6.3), and was interpreted as a fortified tell. The site's area spanned nearly eight hectares (450 × 200 m), with two hectares concentrated in the western and central tells (Nicodemus 2018). Here clustered houses, pits, and open spaces, separated by an enclosure with two gates were found. The eastern portion showed signs of heavy disturbance (Hanks et al. 2018). However, excavations of test unit 3 revealed that the area served as an activity zone, with its purpose evolving over time, exhibiting evidence of domestic, pastoral, and craft-related activities.



Figure 6.6 Map with core and excavation locations at Rabe Anka Siget and Majdan 28

Site phases	Dates BCE
Phase 3	1646-1550
Phase 2 - Expansion phase	1825-1645
Phase 1 - Early phase	2050-1825

Table 6.3 Overview of proposed Rabe phasing according to the excavation results until 2022. Layers were not associated with this table, as they are subject to further evaluation of the excavators. The darker green (Phase 1, 2 and 3) represent the Middle Bronze Age

6.3.1 Evidence of Bronze Age Land Use at Rabe Anka Siget

To address subsistence patterns, this study draws on faunal remains recovered during the 2018 and 2022 field seasons at Rabe Anka Siget. Data from the 2023 and 2024 seasons are excluded from the present analysis. Faunal analysis was conducted by Nicodemus; here, I present my interpretations based on Nicodemus' identifications.

The faunal assemblage from the site is dominated by domestic livestock, particularly caprines, followed by cattle. Suids and equids appear in lower frequencies. This pattern may reflect a landscape well-suited for pastoral activities, with ample space for grazing and herding. Remains of wild fauna were also recovered, the majority of which consisted of freshwater shellfish and fish—most notably carp—likely sourced from the adjacent wetland environments, including nearby streams and canal systems.

In terms of demographic distribution, most livestock—particularly sheep, cattle—exhibit signs of local breeding, as indicated by the presence of females alongside both juvenile (including neonates) and adult individuals. The occurrence of senile specimens further suggests that animals may have been retained for labor or secondary use purposes, such as wool and dairy products. In contrast, the pig assemblage is composed exclusively of young individuals—neonates and adolescents—implying a focus on meat production rather than long-term husbandry or local breeding.

Although botanical remains have been recovered from the site, formal identification has not yet been conducted; consequently, no archaeobotanical data can be reported at this time. Nonetheless, the site's position on fertile chernozem soils would have favored agricultural activity. Material indicators—including grain storage vessels, sickle blades, and grinding stones—suggest subsistence strategies oriented around cultivation. Unlike Klárafalva–Hajdova, however, no direct evidence of garden plots was identified at the site's core. That, however, does not exclude their presence in the site's periphery or in other areas that have so far been only minimally investigated, such as the middle tell. It is also likely that inhabitants are engaged in larger-scale agricultural production, possibly situated on the elevated areas to the north and south of the site. However, to infer this analysis of botanical remains and more soil analysis remain a crucial next step.

Metallurgical evidence from the excavation campaigns is sparse, but present throughout the examined areas. The principal indicators of metallurgical activity include crucible fragments and isolated metal fragments. Thermal features, often located adjacent to domestic structures, were predominantly concentrated on the western mound. Metallurgical evidence is confined to the upper layers of the western mound, while additional traces, including slag fragments, were identified in the eastern sector of the site, as seen in Test Unit 3 (see Appendix A).

In terms of land use, Rabe Anka Siget presents a settlement structured around two principal occupational zones, separated by a ditch, and a major activity area situated on the eastern portion of the site, surrounded by water and wetlands. The surrounding elevated terrain—likely dry during periods of habitation—suggests the presence of short-lived satellite loci beyond the core settlement (additional evidence for such practices will be discussed in relation to the site of Majdan 28).

In summary, beyond domesticated food production, the inhabitants of Rabe also appear to have drawn upon aquatic resources, as indicated by the notable presence of freshwater taxa—particularly Unio shells and carp—likely sourced from adjacent wetlands, streams, and canal systems. The potential exploitation of wetland flora should not be excluded. Metallurgical traces, though limited, are largely confined to the upper stratigraphic layers of the occupational site, suggesting that metalworking was practiced within the settlement during this phase, but did appear to constitute a specialized or dominant activity.

6.4 Majdan 28

Majdan 28 is a small, single-component archaeological site situated along a pronounced bend of the Porganj River, approximately 100 meters southwest of Rabe Anka Siget (Figure 6.7). Due to its proximity and the presence of Maros material, it has been proposed that Majdan 28 may have been part of the broader Rabe Anka Siget settlement complex (Nicodemus 2018).

The site was initially identified by Reizner in 1903 through surface collection and later confirmed via a pedestrian survey conducted by Трифуновић (2012). Subsequent investigations by the RASAP team included a systematic transect survey (Nicodemus 2018), followed by a grid-based pedestrian survey and geophysical prospection—including magnetic gradiometry and susceptibility analysis—conducted by Daković (Daković 2023; Daković and Hanks 2020).

Majdan 28 yielded material from the Maros period, with additional evidence of Avar and Post-Medieval occupation confined to the far western portion of the site (Nicodemus 2018). In 2021, I conducted an additional survey and coring program, followed by the excavation of Test Unit 4 in 2022 to ground-truth geophysical anomalies (Table 6.4) (for details see Appendix A).



Figure 6.7 The site of Majdan 28. Photo taken in 2021, facing northeast, toward the core of the site, located near the forest gallery

Site phases	Dates BCE	Layers and Features
Phase 2	1700-1645	F42
Phase 1	1780-1700	A
		B
		C
		D

Table 6.4 Overview of Majdan 28 phasing according to the excavation results until 2022. The darker green (Phase 1, 2 and 3) represent the Middle Bronze Age

6.4.1 Evidence for Bronze Age Land Use at Majdan 28

Excavation results confirmed that Majdan 28 is a single-component site, dated between 1780 and 1645 BCE, although it was impacted by modern agricultural activity (see Appendix A for coring, excavation, and radiocarbon results).

The test unit 4 revealed the bottom of a damaged thermal feature with evidence of burning, including vitrified materials and a small amount of animal, particularly caprid remains. Adjacent to this feature, were two other pits, likely used as refuse.

The surrounding fill contained faunal remains—primarily pig and caprid—as well as additional ceramic fragments and vitrified remains. One smaller pit, located in the western portion of the test unit, contained a large braiser with visible use-wear. The second, larger pit, situated south of the thermal feature, was directly associated with the thermal feature itself and served as a waste disposal pit. The pit fill included ash, slags, Maros pottery, and fish bones (for more details see Appendix A). Taken together, the diversity of materials suggests that the thermal feature functioned as a multipurpose installation, likely used for both subsistence-related activities and small-scale metallurgical processing.

The presence of both fish and livestock remains at Majdan 28 suggests that its inhabitants engaged with wild resources while maintaining domesticated animals. Although a broader excavation would be necessary to fully determine the site's function, radiocarbon dates indicate a short-lived occupation between 1780–1645 BCE, possibly linked to the expansion of Rabe and functioning as a satellite locus during that phase.

While agricultural activities may have taken place at Majdan 28 or its immediate surroundings no direct evidence for grain storage or botanical remains has been recovered, likely due to the limited excavation area. However, the site's exposed position—particularly its vulnerability to prevailing winds—may have facilitated metallurgical activity. The specific nature of production remains uncertain, whether smelting or object manufacture, and further investigation is required to clarify this. Notably, the absence of slag at Rabe Anka Siget, in contrast to the slag at Majdan 28, raises the possibility that smelting occurred at the satellite site, with subsequent processing or finishing conducted at Rabe.

6.5 Crna Bara–Prkos

Crna Bara–Prkos is a stratified archaeological site located just outside the village of Crna Bara, in the municipality of Čoka, within the Serbian Banat region. The site lies on an elevated area locally referred to as '*Pašnjak*' (meadow), situated at the edge of former wetland zones (Figure 6.8). Although currently found approximately 12 km from the Tisza River and 30 km from

the Maros, LiDAR research conducted in 2023 identified a dried stream along the margin of the Tisza's Pleistocene meander, just southwest of the site—likely utilized during its period of occupation (Mirković Marić et al. 2025).

The site was initially discovered between the First and Second World Wars by J. Strasser, a local teacher from Mokrin, who collected surface finds and reported them to L. Nikolić, then director of the National Museum in Zrenjanin (Marinković 2013: 8).

First limited excavations at Crna Bara–Prkos were conducted during World War II, beginning with L. Nikolić in 1943 and followed by M. and D. Garašanin in 1944. These campaigns excavated approximately 150 m² across several trenches (Garašanin and Garašanin 1957:199). The results revealed a multicomponent site, with cultural material spanning from the Vinča B complex and Copper Age occupations to Medieval remains dated to the 8th century AD (Tasić 1996).



Figure 6.8 The site of Crna Bara–Prkos. Photo taken in 2023, facing north. In the photo is the artificial mound and the excavated profile in the center of the photo, while behind the mount there are the now drained wetlands. Test unit 1 was located right at the elevated edge (before the curve) while test unit 2 was placed behind the mound.

Both settlement features and burials were identified at the site. A child burial from the central portion of the site, associated with Bodrogkeresztúr ceramic vessels, was found in a flexed position on the right side. Additional skeletal remains were recovered from areas containing Tiszapolgár cultural material. However, much of the documentation and artifacts from these early excavations were lost due to wartime conditions, which also delayed the publication (Garašanin

and Garašanin, 1957). Surviving materials are currently curated at the Zrenjanin Museum in Serbia (Tasić 1996).

More recent investigations at Crna Bara–Prkos include a survey conducted by Trifunović (2016:78), as well as earlier limited research by Girić (1996) and Stanojev (1989). Between 2020 and 2021, a survey team led by N. Mirković Marić mapped the extent of the site and conducted geophysical prospection over 1.8 hectares, spanning from the marsh's northern edge to the western portion of the site. The geophysical results revealed multiple enclosure ditches and several subsurface anomalies (Mirković Marić et al. 2025).

The most recent pedestrian grid survey and coring campaign was conducted in 2022 by myself, N. Mirković Marić, and M. Marić. Although Mirković Marić et al. (2025) had previously noted the presence of a 'mound' at the site, this feature had not been documented in earlier research. Our 2022 campaign recovered material spanning from the Neolithic to the present day, with distinct zones of artifact distribution. Notably, Late Neolithic Tisza ceramics and Copper Age material attributed to the Tiszapolgár–Bodrogkeresztúr cultural horizon—previously identified by the Garašanins—were concentrated along the edge of the 'mound.' This area also contained large animal burrows, likely created by badgers or foxes, at the margins of which the pottery was recovered. These findings support our hypothesis that settlement evidence is preserved beneath the mound itself.

In addition to the Late Neolithic and Copper Age material, archaeological remains from the Bronze Age Maros culture, the Sarmatian period, the early Medieval period (8th–9th century AD), and a 19th-century brick factory were also recovered around the mound. The brick production remains were located to the south of the mound, close to the previously identified Medieval cemetery by Garašanin and Garašanin (1957). The combined results of the geophysical survey and surface collection informed our research questions that guided our 2023 excavation campaign. The 2023 campaign included LiDAR analysis, the excavation of two test units, and the cleaning of the mound's eastern profile. Test Unit 1 was placed on the southeastern edge of the site, just north of the trenches previously excavated by the Garašanins, where a Medieval cemetery had been identified. Test Unit 2 was located on the western flank of the mound (Figure 6.9). As part of the same campaign, we also investigated the mound's eastern profile to gain a better understanding of its formation and stratigraphy (Mirković Marić et al. 2025).



Figure 6.9 Map of the site with the geophysical overlay, coring (red dots), sondages from 1940s (in yellow) and 2023 (in white). The sondage 1 from 2023 was on the south while sondage 2 was in the north, left of the northern sondage form 1940s

In summary, the excavation of the two test units confirmed the presence of Tisza, Tiszapolgár–Bodrogkeresztúr material at Crna Bara–Prkos. However, no architectural or stratified features were identified within the units, suggesting that the units were likely positioned at the periphery of the settlement. Recovered materials included pottery, faunal remains, and obsidian, while no botanical evidence was retrieved.

The cleaning of the eastern mound profile required stepped excavation due to its steep gradient and the risk of collapse. These arbitrary steps revealed a mixed depositional sequence containing materials from the Medieval, Iron Age, and Bronze Age (Maros) periods, along with daub and bone fragments. The irregular stratigraphy prompted consultation with the local hunter

community, who regularly visited the site. Through these discussions, we learned that the site had been bulldozed in the 1970s by the Yugoslav army, which subsequently used the area as a shooting range. This intervention explains the mound-like formation, its 6-meter depth of disturbed deposits, the absence of its mention in Garašanins's report, and the abundance and diversity of bullets recovered during profile cleaning.

Despite this disturbance, the final 2 meters of deposition contained intact archaeological layers (Figure 6.10). These included several features: pits, discrete deposits, and an unburned floor surface. Beneath the floor, an adult human burial was uncovered, accompanied by additional deposits. Materials recovered from these contexts included pottery and faunal remains. A radiocarbon sample taken from a pig maxilla found in the last deposit before sterile yielded a calibrated date of 4360–4250 BCE, confirming the Tiszapolgár–Bodrogkeresztúr occupation of the site (Mirković Marić et al. 2025).

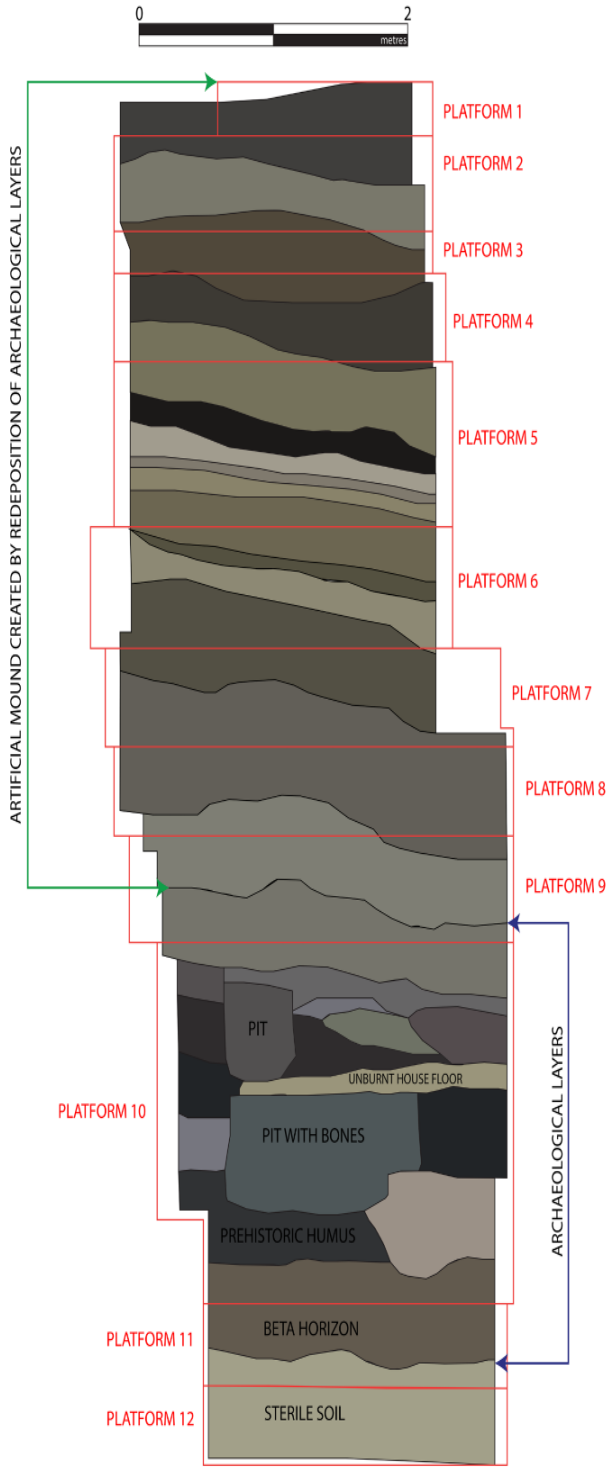


Figure 6.10 Overview of stratigraphy of the mound at the site, showing both artificial deposits and archaeological layers. Figure credit: Miroslav Marić

6.5.1 Evidence of Prehistoric and Modern Land Use at Crna Bara–Prkos

The site of Crna Bara–Prkos presents extensive and diachronic evidence of land use, reflecting a dynamic history of occupation and transformation. Its functions have shifted over time—from prehistoric settlement and burial ground to 19th-century clay mining and brick production, to a military shooting range in the 1970s, and more recently, a hunting ground and informal waste deposition area.

Today, the western portion of the site is under agricultural use, while the northern and eastern areas adjacent to the 'mound' border a designated natural reserve, which exhibits significant animal activity. These ongoing land-use practices have negatively impacted site preservation. Despite its long-standing presence in archaeological literature as one of the few confirmed Tiszapolgár–Bodrogkeresztúr settlement sites in the region, Crna Bara–Prkos was only recently added to the National Heritage Registry—an achievement made possible through the efforts of N. Mirković Marić and colleagues.

Our methodological approach—combining geophysical survey, LiDAR analysis (done by Nenad Jončić), coring, and small-scale excavation—demonstrated the site's long-term significance and its dynamic engagement with the surrounding landscape. These investigations revealed a complex history of land-use interactions extending across the 3000-year period under study. Although the Bronze Age component remains difficult to locate securely due to extensive site disturbance, the Early Copper Age occupation presents compelling patterns of spatial organization and subsistence strategies that merit further analysis.

Subsistence evidence at Crna Bara–Prkos was reconstructed based on faunal remains recovered during the 2023 excavation campaign, as no bone material was preserved from the 1940s investigations. Zooarchaeological analysis was conducted by M. Vešović (Vešović 2023), who reported a total of 445 faunal fragments. Fragmentation levels were high, and only a small proportion of the assemblage could be taxonomically identified to the genus level. Of these, approximately 50% were recovered from Test Unit 2, while the lowest quantity of bone material was retrieved from the profile cleaning.

Cattle comprised over 60% of the identified specimens, indicating a strong reliance on bovine livestock. Other domesticates—including caprids, horses, dogs, and pigs—were present in much smaller quantities. Wild taxa were also represented, particularly in Test Unit 2, and included carp, boar, hare, and deer. Although no demographic profile was established in Vešović's report, he noted a clear difference in the proportions of domestic versus wild animals between excavation areas (Vešović 2023).

All identified specimens were adults, as indicated by epiphyseal fusion. Radiocarbon dates from Test unit 2 span from the Neolithic period (5300–5000 BCE) to the Early Copper Age (4450–4330 BCE), with a notably higher concentration of faunal remains recovered from the Early Copper Age layers, suggesting intensified activity during this phase (site excavation report can be found in Mirković Marić et al. 2025).

Test Unit 1 was dominated by domestic livestock, primarily cattle, caprids, dogs, and pigs with only a single bird specimen identified (Vešović 2023). Based on epiphyseal fusion and the presence of third molars in mandibles, the recovered specimens appear to represent adult individuals. Radiocarbon dates from this unit place the occupation within the Late Neolithic, approximately 5200–4900 BCE (Mirković Marić et al. 2025).

Faunal material recovered from the profile cleaning was limited and presented a mix of domestic and wild species. However, given that only the bottom 2 meters of the profile contained archaeologically intact deposits, these results should be interpreted with caution. Notably, an adult pig maxilla recovered from the lowest layer before sterile yielded a radiocarbon date of 4360–4250 BCE, aligning with the uppermost Early Copper Age deposits identified in Test Unit 2 (Mirković Marić et al. 2025).

Faunal remains suggest that at least a portion of the landscape surrounding Crna Bara–Prkos was dry, likely south of the site, providing favorable conditions for pasture. This is reflected in the predominance of cattle across both Neolithic and Copper Age contexts, with smaller domesticates such as caprids and pigs also present.

Notably, during the Early Copper Age, there is clear evidence for intensified exploitation of wild resources, as indicated by the presence of wild animal remains and freshwater fish. The

fish were likely sourced from a nearby stream identified through LiDAR research conducted in 2023, which traced a paleochannel running southwest of the site (Mirković Marić et al. 2025).

The absence of archaeobotanical remains likely reflects the limited excavation area and the position of the test units, rather than a true absence of plant remains. As such, the possibility of small-scale agricultural activity and continued engagement with wild resources at the site should not be excluded.

In contrast to the varied subsistence strategies, no evidence of metallurgical activity dating to the analyzed period (4500–1500 BCE) was identified. The only metallurgical traces recovered came from survey — mainly slags, which, without specific context, cannot be dated to any specific phase of site use.

6.6 Pecica Şanţul Mare

The tell settlement of Pecica 'Şanţul Mare' is located approximately 6.5 km west-southwest of the modern town of Pecica in Romania, and only 800 m north of the Mureș (Maros) River. Today the site is surrounded by dry agricultural land, but its position on the northern river slope suggests that, at least in part, it was originally bordered by wetlands, while drier terrain likely extended to the north (Figure 6.11). The mound itself measures between 0.4 and 1.5 hectares in size, yet a series of surrounding ditches encloses a much larger area of approximately 20.8 hectares (Nicodemus 2014: 136–137).

Pecica Şanţul Mare represents one of the most significant sites in the region, especially known for metallurgical production. Apart from its Medieval and Dacian occupation, Pecica showed a Bronze Age occupation span of roughly 400 years, in addition to preserving evidence of approximately 130 years of Middle Copper Age occupation—a rare phenomenon in this area.

Since its discovery, Pecica Şanţul Mare has undergone numerous research campaigns led by international and interdisciplinary teams since the 1870s.The first excavations began in 1898 under L. Dömötör, who over six years opened several long trenches across different areas of the site, reaching depths of 4.5 m in the southern sector (Găvan and Ignat 2014). However, as Găvan and Ignat (2014) note, no documentation from these early excavations has been preserved, despite the recovery of a substantial artifact collection now stored at the museum of Arad in Romania.

The first documented excavations were carried out by M. Roska in two campaigns between 1910–1911 and 1923–1924 (Roska 1912; Roska 1914; Roska 1942), though only a detailed report from the 1910 season was published. Roska confirmed the stratigraphical depth of southern part of the tell, while stressing the importance of the extensive Bronze Age deposit which he divided into 16 levels (Roska 1912).



Figure 6.11 The site of Pecica 'Şanţul Mare'. Photo taken in 2015, facing north to show the tell in the center of the photo and its agricultural surroundings

In 1943, research continued under D. Popescu, who excavated six trenches and provided both stratigraphic sequences and trench locations. His work uncovered graves without associated artifacts (Popescu 1944), likely attributed to the Dacian occupation of the tell (O'Shea et al. 2006), alongside details of the Bronze Age sequence. Further investigations were undertaken in the 1960s by I. H. Crişan, who focused on the Dacian deposits (Crişan 1978; O'Shea et al. 2005; Găvan and Ignat 2014). The Bronze Age finds from these excavations were later published by T. Soroceanu (1991) and more recently by Găvan and Gogâltan (2023).

From 2005 to 2015, American–Romanian interdisciplinary campaigns were directed by J. O'Shea in collaboration with Romanian researchers from the Timișoara and Arad Museums, including F. Drașovean, P. Hügel, and G. P. Hurezean, (O'Shea et al. 2005; O'Shea et al. 2011;

Nicodemus et al. 2015; Găvan and Ignat 2014). These campaigns concentrated on the Bronze Age levels of the site, revisiting areas initially excavated by Crişan, whose trenches in some cases had removed only the Dacian deposits, allowing the team to focus on the Bronze Age component of the site (O'Shea et al. 2005). Between 2005 and 2007, O'Shea's team also conducted a coring program supervised by S. Sherwood, with five cores taken directly from the tell and additional cores from its surrounding landscape (O'Shea et al. 2005).

J. O'Shea and his team opened Trench I on the northern part of the tell, which was later expanded into a 10 × 10 m block. In 2014, an additional trench was placed within this block to reach sterile deposits, which was reached in 2015 at a depth of five meters (Figure 6.12). The last 1.5 m of the cultural deposit were dated to the Copper Age and was attributed to the Hunyadihalom group (3935-3800 BCE) (Nicodemus et al. 2015).

In addition to Trench I—later referred to as Block 1—Trench II was excavated on the southwestern side of the tell. This trench yielded substantial metallurgical evidence, including remains of ore transformation (tuyères), object-making tools (molds), thermal features, slags, and numerous bronze artifacts such as spearheads and pendants, confirming the site's central role in metallurgical production (O'Shea et al. 2005: 85) (details about the metallurgical evidence will be presented below). In addition to O'Shea and team's work, further research was conducted in 2007 under the direction of D. Urdea, focusing on geophysical survey beyond the enclosing ditch (Găvan and Ignat 2014: 150). Off-tell excavations, but within the enclosure, were carried out as part of the PAP project by A. Nicodemus in 2008 (southern sector) and 2011 (northern sector) (Nicodemus 2014: 135).



Figure 6.12 Photo taken at dawn from the top of the tell of Pecica in 2015, showing the eastern edge of Trench I

Radiocarbon analyses by Nicodemus et al. (2015) dated the Bronze Age occupation at the site between 1950 and 1545 BCE and established a preliminary chronological framework divided into four phases—Initial, Formative, Florescent, and Final—each characterized by distinct material culture features, including shifts in pottery distribution, faunal remains, imported goods, and metallurgical production (Table 6.5).

In this dissertation, I focus specifically on prehistoric landscape use in relation to metallurgical production with some broad presentations of subsistence practices. The full extent of material associated with each phase, as these results have been and will continue to be published elsewhere (for more details see O'Shea et al. 2005, O'Shea et al. 2011, Nicodemus 2014 and Nicodemus et al. 2015).

Site phases		Dates BCE	Layers
Final	1	1615-1545	B1-3
	2	1680-1615	C1-3
Florescent	3	1765-1680	C4-5/ D0-2
	4	1820-1765	D3, E1
Formative	5a	1875-1820	E2-3
	5b	1900-1875	E4-6
Initial	6	1920-1900	E7-F
	7	1950-1920	G-I
Copper Age		3935-3800	J-M

Table 6.5 Overview of the Pecica phasing with dates and associated layers. The darker green (Initial, Formative, Florescent and Final) represent the Middle Bronze Age, while the orange was dated to the Middle Copper Age. The Late Copper Age age component has not been found at the site

6.6.1 Evidence of Prehistoric Land Use at Pecica Șanțul Mare

Pecica Şanţul Mare, with its Copper and Bronze age occupation along with the on-tell and off-tell research, provides important evidence for diachronic and spatial changes in land use. In addition, while on and off tell excavations were fruitful, the on-tell excavations generated large amounts material, including faunal, archaeobotanical, and metallurgical datasets, which will be briefly presented here. Faunal analysis has been conducted primarily by A. Nicodemus (2014), with an additional report by Meyer (2018) as part of his undergraduate thesis. Both authors highlight shifts in subsistence practices as economic strategies across the site's occupational phases (see Table 6.5).

6.6.1.1 Middle Copper Age

The earliest evidence of habitation at the site derives from the Middle Copper Age (3935–3800 BCE). The Copper Age component is represented by material recovered from a trench placed on the tell, alongside the western profile of Excavation Block 1, and excavated between 2013 and 2015 — part of which was led by me in 2015.

The deposits were attributed to Hunyadihalom cultural group, which indicated a predominance of domesticated animals (65%), though wild resources were also exploited. Among domesticates, cattle dominated the assemblage (45%), followed by pigs and caprids. While most livestock specimens were adults, senile and juvenile individuals were also present among cattle and caprids. The assemblage suggests that animals were likely locally bred (as seen by the recovery of neonate, juvenile and female animals) and primarily raised for meat, but the presence of senile cattle and caprids points to secondary uses such as traction and dairy production.

Alongside domestic animals and livestock herding, the Hunyadihalom inhabitants of Pecica–Şanţul Mare engaged in hunting, trapping, and the exploitation of aquatic resources. Deer were the primary target of hunting, comprising approximately 60% of the identified wild fauna, with red deer vastly predominating. Other hunted species included boar, fox, beaver, and hare, together representing about 1% of the assemblage, while aurochs (*Bos primigenius*) accounted for roughly 5%. Aquatic resources were also utilized, with river mussels (*Unio spp.*) forming the majority of remains. Apart from mussel collection there was also evidence for fishing, primarily carp (Nicodemus et al. 2015).

Archaeobotanical evidence recovered from the Copper Age deposits indicates a strong reliance on cereals (73%), with einkorn predominating, followed by wheat. Legumes were present in smaller quantities (2.6%), while weeds accounted for a significant proportion of the assemblage (21%). No chaff was identified in this period (Nicodemus et al. 2015); however some level processing was likely conducted as seen by the large quantities of obsidian dating to this phase of the site. In terms of metallurgical production, no evidence was recovered from this stratum, despite the presence of a thermal feature in the trench.

After the Hunyadihalom community abandoned the site, the tell area was not occupied until the Bronze Age.

6.6.1.2 Initial Phase

The Middle Copper Age component found was subsequently sealed and leveled by the Initial phase (1950–1900 BCE) of the Maros occupation, corresponding to the final stages of the Early Bronze Age (2500–1900 BCE) in Hungarian scholarship (Kiss et al. 2019). O'Shea (forthcoming) reports that the Maros occupation at the tell, began with one or more ritual structures containing fragments identified as 'altar' legs, perforated pig mandibles, and broken or unfinished

stone axes. Beyond these ritual features, O'Shea (forthcoming) describes a series of temporary constructions that were soon replaced by more substantial rectangular buildings.

Faunal remains from this phase show a predominance of mollusks, which constitute approximately 76% of the assemblage. When mollusks are excluded, wild resources—including fish—are minimal, comprising less than 1% overall; among these, red deer accounts for 79% of the wild taxa (Meyer 2018). Domestic livestock dominates the mammal assemblage, with caprids representing roughly 72%, followed by pigs (18%) and cattle. Only a single horse specimen was identified, along with dogs. Age profiles indicate a predominance of subadult and adult animals, with juveniles also present among caprids and pigs (Nicodemus et al. 2014).

Archaeobotanical remains from this phase present a similar pattern observed in the Copper Age, with cereals continuing to predominate. While the proportion of einkorn (*Triticum monococcum*) decreased, barley (*Hordeum vulgare*) increased to approximately 6%. The assemblage also shows a rise in weeds and wild seeds gathered compared to the Copper Age.

In terms of metallurgy, O'Shea and Nicodemus (2019) argue that the importance of Pecica from a metallurgical perspective was already established in the early stages of the site's occupation. They emphasize that during this phase there was a particular focus on raw ore processing (O'Shea and Nicodemus 2019: 70). Evidence from Trench 2, located on the southern part of the site, includes a complex of thermal features, a series of ovens and kilns (O'Shea et al. 2005: 85), as well as artifacts such as a bow pendant and a bronze belt buckle.

6.6.1.3 Formative Phase

The Formative phase (1900–1820 BCE) was marked by what appears to be a reorganization of the settlement. On the tell, O'Shea (forthcoming) reports a shift in house orientation, and a central open area, referred as "plaza". A larger structure—likely a two-story house with a wooden plank floor—dated to this period was found on the northern portion of Block 1. During the Formative phase, a ditch was built around the tell, enclosing the site.

The faunal assemblage from the tell shows a predominance of domestic animals (approximately 90%). Caprids form the majority, followed by pigs and cattle, with horses

increasing in frequency from about 6% to 14% toward the end of the phase. Wild animals were exploited to a much lesser extent (around 10%), with mollusks comprising roughly half of this category (5%) (Nicodemus 2014).

Livestock demography indicates the presence of juveniles and subadults among caprids and cattle, although adults—including horses—remain the dominant age group. This pattern suggests that while animals were primarily raised for meat, they were also exploited for secondary purposes such as traction, evidenced by arthritic conditions found in cattle (Nicodemus 2014).

Archaeobotanical remains from the tell during this phase indicate a drastic decline in cereal representation. Relative to earlier levels, cereals first drop to 50% of the assemblage and then fall further to only 27%. Within this reduced cereal component, einkorn and barley occur in equal proportions, with emmer appearing for the first time. In contrast, wild plants—including weeds and gathered taxa—show a marked increase, reaching 72% toward the end of the period. Chaff also rises significantly, comprising approximately 87% of the assemblage (Nicodemus et al. 2015)[10].

Metallurgical activity expanded during this phase appears to be focused on ornament production (O'Shea and Nicodemus 2019: 70). Nicodemus (2014) further notes that all metals recovered from this phase were found in general fill outside of structures, some of which continued in use into the subsequent Florescent phase (Phase 4).

Alongside the metal objects, in their report Nicodemus et al. (2015) present the discovery of a structure with an elaborate oven/furnace, in the western part of the Block I, extending into the trench, interpreted as a possible workshop (Nicodemus et al. 2015: 107). To this day, beyond the site of Feudvar near Mošorin in Vojvodina Serbia, dated between 1900-1600 BCE and attributed to the Vatin cultural group, no other workshops have been securely identified in the wider region (Falkenstein et al. 2016: 7-8; Găvan 2015). As a result, the archaeological record provides little basis for understanding what a workshop might have looked like in this region, or what variations in form and function we should expect. Nevertheless, the high frequency of metallurgical production at Pecica does support the possibility of workshops on the tell.

[10] O'Shea (forthcoming) notes a large amount of grain processing grain occurred at the site Livada Lui Onea, near Semlac, while grains were more common on the tell of Pecica (Oas 2010; Nicodemus et al. 2015).

6.6.1.4 Florescent Phase

The Florescent phase (1820–1680 BCE) represents the peak of occupation at Pecica. This period saw the greatest spatial expansion of the site, including off-tell occupation and the construction of multiple enclosing ditches (Nicodemus 2014; O'Shea and Nicodemus 2019). On the tell, this phase is marked by the construction of a substantial platform composed of diverse waste materials and fired at extremely high temperatures—so high that embedded ceramics became vitrified. The platform, reported by O'Shea (forthcoming) to exceed one meter in thickness in some areas, was subsequently levelled. During the Florescent phase, all activities on the tell appear to have diminished except for metallurgy. Nevertheless, a substantial quantity of material, including flora and fauna remains dating to this period was recovered.

Faunal evidence from the tell during the Florescent phase demonstrates the predominance of livestock, particularly caprids (35%), followed by pigs (27%), horses (19%), and cattle (17%) (Nicodemus 2014:228). As Nicodemus notes, horse remains increase nearly sevenfold compared to the Formative phase, while dog remains triple in frequency (Nicodemus 2014:226).

In comparison, the off-tell assemblage still shows a predominance of mammals, dominated by caprids (60%), a proportion higher than that observed on the tell, while horses—so prominent in the on-tell assemblage—are far less represented off-tell. Small amounts of pig and cattle are also present (Nicodemus 2014:260–261). In comparison to the tell, the off-tell shows higher proportion of wild resources like mollusks (34%) and other wild fauna (40%). Deer comprised 87% of the wild fauna, with red deer representing the overwhelming majority (96%). Boar were the second most frequently hunted species (5%), while evidence of trapping was present but minimal. Aquatic resources were also exploited, likely from the Maros River, as indicated by the substantial presence of river mussels, which accounted for approximately 21% of the total faunal assemblage.

While domestic animals continued to dominate the assemblage during the Florescent phase, notable differences between the on- and off-tell faunal compositions likely reflect the differentiated character of these two settlement zones. Even so, the Florescent period as a whole—on-tell and off-tell alike—indicates an overall intensification of animal husbandry and a diversification of domestic species, consistent with a higher density of occupation during Pecica's peak phase.

In addition to the spatial differentiation on the site, variation in subsistence patterns was also notable throughout time. Evidence from the faunal analysis from the tell shows that both domestic and wild animals were abundant in the early portion of the phase (pre-platform), but toward its end the period, the quantity of faunal material decreases by nearly half (Nicodemus 2014:233). These shifts might reflect an imminent shift in the character or use of this area of the site. Furthermore, the late Florescent deposits also yielded a small number of human remains (two bones), an unusual though not unprecedented occurrence within the Maros cultural sequence (Nicodemus 2014), where human burials are typically placed in cemeteries rather than settlements (O'Shea 1996).

Demographic analysis indicates that most animals were bred locally and primarily raised for meat, with few kept into senility. Horses (majorly found on tell) however, present a striking exception: 95% of specimens derive from older individuals, suggesting prolonged use beyond meat production (Nicodemus 2014:232–233).

The archaeobotanical evidence from the Florescent phase also shows differences between on and off-tell. The recovered on-tell botanical evidence shows that domesticated crops, similarly to the evidence from the fauna, decrease in frequency toward the end of the phase.

Across both on- and off-tell contexts, cereals—primarily einkorn wheat—continue to predominate. Barley also increases in frequency, as do domestic legumes such as fava bean (*Vicia faba*), pea (*Pisum sativum*), and lentil (*Lens culinaris*), though these legumes are found only on-tell (Nicodemus 2014). Wild plants likewise rise sharply, nearly tripling in frequency, with grasses and chenopods (*Amaranthaceae*) most common. While botanical remains are most abundant on-tell, certain taxa—particularly grasses—are more frequently recovered off-tell. New species also appear for the first time during this phase, including buckwheat (*Fagopyrum esculentum*), which occurs only off-tell, as well as mint (*Mentha*) and nightshade (*Solanaceae*), which are similarly restricted to off-tell deposits (Nicodemus 2014). In contrast, botanical remains from the pre-platform deposits are generally sparse (Nicodemus 2014; Nicodemus et al. 2015).

Taken together, the archaeobotanical and faunal evidence from the Florescent phase—particularly the marked increase in wild resources—likely reflects a higher population density at Pecica. The rise in chaff and grasses off-tell suggests intensified activities such as landscape

modification and house construction, as chaff could have been used as preparation for walking surfaces, roof construction alike and general grain processing (Nicodemus et al. 2015).

However, as the off-tell population increased, occupation on-tell appears to have declined during this period. In addition, the area of the central platform showed evidence of storage (O'Shea (forthcoming). O'Shea and Nicodemus (2019) emphasize that this pattern may indicate that the tell was inhabited by an elite population that was provisioned by residents of the off-tell areas.

Metallurgical production also flourished during the Florescent phase and yielded the largest concentration of metallurgical evidence at Pecica. O'Shea and Nicodemus (2019) note a shift in both the location and types of metallurgical processes conducted at the site. As Nicodemus (2014: 310–312) observes, while metal pieces were frequently recovered within houses and external deposits, molds and crucibles were absent from structures in the northern part of the tell. Instead, these were found in general fill deposits.

The northern part of the tell produced the largest concentration of finished artifacts, peaking during the platform phase and continuing into the later portion of the Florescent phase. These artifacts included ornaments such as pins, beads, pendants, and rings, as well as metal fragments—sheets, wires, rivulets, and cast bars—alongside possible tools such as a damaged chisel or awl (Nicodemus 2014: 310). Additional objects curated in the Arad Museum, including horse harness fittings, axes, chisels, spearheads, and daggers, were reported from earlier excavations (Găvan 2015: 57; Găvan and Gogâltan 2023: 1). Although a total of 43 metal objects have been documented from earlier excavations, none were recovered with secure archaeological context. Nevertheless, the evidence presented by O'Shea and Nicodemus strongly suggests that most of these finds are associated with the Florescent phase.

In contrast to the Block I (northern part of the tell) the southern portion of the tell shows the highest concentration of casting activity during the Florescent phase (Nicodemus 2014: 310–312; O'Shea and Nicodemus 2019: 71). This area contained abundant casting debris, large superimposed kilns, and associated objects such as molds and crucibles (O'Shea et al. 2011; Nicodemus 2014). Pecica overall produced some of the largest volume of casting debris in the region, including more than 31 casting mounds and cores s b made of both stone and clay (Găvan 2015: 60, 75; Gogâltan 1999: 100–101; Găvan and Gogâltan 2023: 13). Găvan and Gogâltan (2023) further report that artifacts from the Arad collection show clear evidence of use, with heavy

firing marks and soot stains, underscoring the objects use and Pecica's central role in metallurgical activity and its importance for the wider region (Găvan and Gogâltan 2014; Găvan and Gogâltan 2023: 15). Outside of Pecica, the only other comparable site in the amount of metallurgical evidence (currently reported and published) is the of Feudvar near Mošorin (mentioned above) which yielded a comparable scale of metallurgical evidence (Găvan 2015).

Metallurgical evidence during the Florescent phase was widespread across Pecica–Şanţul Mare, extending even into off-tell contexts. Thermal features, located outside the houses, were found with associated slags, furnace linings, and partially smelted ores were identified throughout the site. Although O'Shea and Nicodemus report no direct evidence of smelting at the site during this period, metal ores such as malachite/azurite and iron-rich ores (*Kupferschiefer*/bog iron) were recovered from general fill deposits (Nicodemus 2014). In addition, A. Găvan notes a substantial number of tuyères recovered from earlier excavations at Pecica, though without associated contextual information (Găvan 2015: 179). It is therefore plausible that the majority of the metallurgical *chaîne opératoire*—including ore transformation and object manufacture—was carried out at the site. At the same time, the spatial differentiation of the retrieved evidence during the Florescent period likely reflects a corresponding spatial differentiation in metallurgical activity, with distinct areas of the settlement devoted to different stages of production. This large expansion of Pecica, however, is short-lived and only lasted for about 140 years.

6.6.1.5 Final Phase

The Final phase (1680–1545 BCE), often referred to as the 'collapse phase,' presents a marked contrast to the preceding Florescent phase, although its onset was likely foreshadowed toward the end of the Florescent period (Nicodemus 2014). During the Final phase, both occupation density and patterns of land use changed dramatically. Off-tell occupation was abandoned entirely, while on the tell only a few scattered houses remained (O'Shea forthcoming).

Subsistence continued to center on livestock, with caprids becoming even more prominent—comprising nearly half of the domestic faunal assemblage—followed by pigs and cattle. Horse remains, in contrast to the Florescent period, declined sharply, returning to levels comparable to the Initial phase. The exploitation of the wild fauna increased significantly, with deer and boar hunted alongside extensive exploitation of riverine resources. Fishing (carp, wells,

catfish) and mollusk collection were particularly important, with river mussels comprising 70% of the wild faunal assemblage (Nicodemus 2014).

Animal demography indicates continued local breeding, though most livestock were slaughtered before reaching adulthood. While meat production remained the primary focus, some senile cattle were retained, likely for traction. The small number of horses recovered were primarily juveniles, which Nicodemus (2014) suggests may have died of natural causes.

Botanical evidence shows a general decline in floral remains overall. The distinction between domestic and wild plants narrows considerably in this phase. Domestic crops remain dominated by cereals, particularly einkorn wheat and wheat, while wild plants are represented by chenopods, grasses, carnations, and buckwheat—the latter reaching its highest frequency in this period (Nicodemus 2014; Nicodemus et al. 2015).

Taken together, these subsistence patterns suggest a likely reduction in population size at Pecica during the Final phase, with the discontinuation of the off-tell occupation, accompanied by a diversification of diet and greater reliance on wild resources to supplement food intake. The impact of land use appears diminished compared to earlier phases, and notably, no metallurgical debris was recovered from this phase (O'Shea and Nicodemus 2019; Nicodemus 2014: 314).

In conclusion, Pecica underwent significant transformations throughout its occupation, beginning with substantial evidence for Copper Age activity and developing from a small hamlet in the Initial phase into a large, complex settlement of roughly 20 hectares at its Florescent-phase peak, before rapidly contracting to a scale comparable to its earliest occupation. Patterns of land use closely tracked population dynamics: the site's expansion was likely supported by a favorable environment that facilitated increased animal herding and the exploitation of wild resources. Metallurgical activity also appears to have been tied to demographic growth, although its importance was established early, as indicated by metallurgical evidence from the Initial phase onward. The site's strategic position along the river—providing access to routes connecting the lowlands with the Apuseni Mountains—likely further enabled the movement of raw materials and finished metal objects (O'Shea 2011). Ultimately, Pecica represents a distinctive case of metallurgical intensification within the Maros cultural sequence, diverging from patterns observed at sites in the Lower Maros region.

6.7 Summary

This chapter examined six key sites—Klárafalva–Hajdova, Kiszombor–Új Élet, Rabe Anka Siget, Majdan 28, Crna Bara–Prkos, and Pecica Şanţul Mare—highlighting both their local environmental settings and the broader subsistence and land-use strategies that shaped their occupations.

While all sites demonstrate engagement with their landscapes, the intensity and character of land use varied— both between sites and through time. While Klárafalva appears particularly tied to local environmental conditions, with subsistence reflecting adaptation to its immediate surroundings, Kiszombor and Rabe show evidence of mixed economies, balancing livestock with exploitation of wild resources. Majdan 28, on the other hand, presents a more modest scale of activity but still reflects the broader regional patterns, closely comparable to the off-tell evidence from Pecica. At Crna Bara, while not presenting reliable evidence of a Bronze Age occupation, faunal remains emphasize cattle husbandry in a dry landscape well suited for pasture in its earliest stages of occupation. Yet the Early Copper Age from Crna Bara contexts reveal significant reliance on wild animals and fish, pointing to flexible strategies of resource use. This pattern however, comes to a stark contrast to the Copper Age evidence of Pecica, which shows evidence of both domestic and wild animals along with agricultural activity, which was not recovered at Crna Bara.

Pecica Şanţul Mare is the only site presenting both Copper and Bronze Age components, offering diachronic picture between the periods. While the Middle Copper Age at Pecica shows reliance on cattle and cereals, the Bronze Age phases marked by shifts in livestock composition, botanical diversity, and intensive metallurgical production, which decreases in the later phase of the site.

Together, these sites illustrate both continuity and variability in subsistence, land-use practices and metallurgical activity across the region from 4500-1500 BCE, showing how communities balanced domestic production with wild resource exploitation, and how shifts in environmental conditions, population, and craft specialization shaped their strategies over time, even if (in the Bronze Age) part of the same cultural group.

Although all sites demonstrate some degree of metallurgical intensification, the extent to which this occurred appears to vary. Further analysis, including evidence presented in the results section, will clarify these patterns and help explain some of the observed anomalies. In the following chapter (Chapter 7) I will introduce the models and hypotheses developed in this study, building directly upon the evidence presented thus far.

Chapter 7 Models and Research Design

As described in Chapters 2 and 5, researchers have examined intensification as a stage within the technological cycle that outstretches existing resources. The process of intensification is context-dependent, with mechanisms that vary across societies and contexts, and over longer timescales. Regardless, the process of intensification generates a range of consequences, and these are the focus of this dissertation.

With this context in mind, in this chapter, I present the models of and research design for this dissertation. I start by presenting the questions guiding this work, followed by a definition of the domains, variables, and measures, which constitute the baseline for Chapter 8, where the materials used in this work will be presented in greater detail. I conclude this chapter by presenting a set of hypotheses and the proposed outcomes.

7.1 Questions

Evidence for local metallurgical production in the Tisza–MarosMaros region becomes archaeologically visible only during the Bronze Age. All communities in the Tisza–MarosMaros region lived in an ore-poor landscape, which meant that the raw materials required for metalworking had to be brought to settlements. Securing these materials demanded coordinated effort, labor organization, and the reallocation of daily activities—each of which reflects the kinds of structural changes typically associated with intensification (for further explanation and resources, see Chapter 5).

The questions that therefore guided this dissertation are:

- How does the intensification of metallurgical production change during the Early and Middle Bronze Age?
- How do different Bronze Age communities in the Tisza-Maros region express the intensification of metallurgical production? What are the impacts of intensification on these communities?

In examining the expression of intensification of metallurgical production in this work, I primarily focused on presenting the technological aspects of metallurgy by combining archaeological and chemical data and utilizing reports from archaeometallurgists who examined metallurgical debris like slags and metals. While archaeological evidence for metallurgical activity was available for all sites, the resolution varied between sites due to sampling and excavation differences. Furthermore, the reports from archaeometallurgists were only available for the sites of Klárafalva Hajdova, Kiszombor Új-Élet, and Pecica Şanţul Mare. For other sites, such as Rabe Anka Siget and Majdan 28, metallurgical examination will be conducted in the future. In contrast, metallurgical evidence from Crna Bara–Prkos was identified only at the surface and not during excavation (for details about the excavation results, (see Mirković Marić et al. 2025).

To identify differences in metallurgical intensification between communities, I compared the presence and types of identified metallurgical debris, as well as the locations of metallurgical activity relative to living areas or animal housing, to infer environmental contamination.

To examine differences in metallurgical production, it was necessary to compare production over a longer period, from the Copper and Bronze Ages, when possible, across the same site. The description of metallurgical evidence from individual sites (see Chapter 6) enables identification and comparison of variations in metallurgical production, particularly during the Bronze Age. The reason is the higher-resolution data for sites dating to this period, which is especially possible at the tell sites Klárafalva Hajdova, Kiszombor Új-Élet, Pecica Şanţul Mare, and Rabe Anka Siget. These sites showed a deep preserved stratigraphy and record of occupation for more than 500 years (O'Shea et al. 2019).

The Copper Age deposits (the bottom layer of Pecica Şanţul Mare and Crna Bara–Prkos) show less prominent phases of occupation (Chapter 6). As such, they present a much lower occupation resolution. In particular, the Early Copper Age cultural complexes of Tiszapolgár and Bodrogkeresztúr, which in the wider region extend only to 4000 BCE, in the Tisza-Maros region extend up to 3800 BCE (Borić 2015). Furthermore, no local metallurgical activity has been identified in the region for the Copper Age; thus, at this stage of research, the Copper Age deposits primarily serve as a baseline for analyzing intensification.

To enable comparison of metallurgical activity across sites, I employ a temporal framework summarized in Table 7.1. This framework follows the broader chronological divisions commonly used in regional scholarship, which consolidate the site-specific phases identified by researchers (O'Shea et al. 2019; O'Shea in press) into wider categories that align with the established chronological sequence for each period (Bondár 2008; Siklósi and Szilágyi 2021; Kiss et al. 2019).

While the chronological framework employed here is appropriate for regional comparison, the temporal resolution of individual site phases necessarily imposes certain limitations. Each phase encompasses multiple depositional events and potentially several generations of activity, meaning that short-term fluctuations in metallurgical production, at this stage, cannot be resolved at a finer scale. As a result, some intra-phase variability or shifts in production intensity within a single occupational span, may be obscured when data are aggregated at the phase level. Although this temporal coarseness may smooth over micro-scale dynamics, the broader temporal aggregation enables comparison between sites, and is well suited for cross site and regional comparison, which would not be able to be the case if such approach would not have been taken in account.

Compared to the lower data resolution available for the Copper Age, the Bronze Age record is substantially richer, allowing for a more fine-grained examination of metallurgical activity. The subphases defined for the Early and Middle Bronze Age allow for a division of roughly 150-200 years (Table 7.1). This temporal structure provides a coherent framework for comparing sites and for documenting both shared patterns and divergent responses to intensification across communities in the Tisza–Maros region. It also enables a clearer assessment of how the impacts of intensification unfolded over time within a single cultural complex.

Temporal division	Cultural affiliation	Temporal divide used in this work	Cal. years BCE	Number of years
Middle Bronze Age	Late Maros (1950-1500 BCE)	**MBA 3**	1690-1550	140 years
		MBA 2	1825-1690	135 years
		MBA 1	2000-1825	175 years
Early Bronze Age	Early Maros (2700-1950 BCE)	**EBA 2**	2175-2000	175 years
		EBA 1	2715-2175	540 years

Late Copper Age	/	/	/	/
Middle Copper Age	Hunyadihalom (4000-3600 BCE)	**MCA**	4000-3700	~300 years
Early Copper Age	Tiszapolgár and Bodrogkeresztúr (4500-3800 BCE)*	**ECA**	4500-4000	~500 years

Table 7.1 Table presenting the chronological division used in this work

As highlighted in Chapter 3, evidence for intensive metallurgical production remains quite uncommon in the archaeological record of the Carpathian Basin. In fact, numerous studies (Radivojević et al. 2021, Papalas 2008; Sava 2015) indicate that while metallurgical objects are generally common in contexts such as cemeteries and hoards, evidence of production tends to be much sparser and more ephemeral. In the Carpathian Basin, evidence of sites focused on metallurgical production is rare. However, as seen from Chapter 5, most of the analyzed sites present some evidence of metallurgical activity. As a result, in cases where metallurgical activity was not the community's main economic activity, or when the activity was conducted outside the immediate habitation spaces, production debris will likely be sparse. For this reason, tracking environmental changes, including contamination in animals and soils, will provide an important control for monitoring metallurgical activity and its impacts on the community.

With the available time resolution, it is possible to track shifts in production intensity alongside major technological developments, such as the production of tin-bronze metallurgy. However, as by-products generated during metallurgical activities may contribute to environmental contamination, their distribution and signatures can aid in modeling potential social responses to these impacts.

In summary, in this work, I monitor the environmental impact of metallurgy through the presence and abundance of metallurgical remains, chemical signatures of trace elements in the second and third molars of wild and domestic animals, and sediments from within and around the sites (more about the sampling methodology and methods in Chapters 8 and 9). The results from the samples aid in monitoring changes in settlement organization, provide insight into the

integration of metallurgical activity within the settlement grounds, and trace the variations, extent, and types of contamination produced by metallurgical production.

7.2 Domains, Variables, and Measures

To examine metallurgical production and environmental contamination, I focus on two features of metallurgical production — technology and space. In this work, I refer to these features as "domains", as they are closely interrelated and interdependent. Together, they provide insight into the key aspects of intensifying metallurgical activities and their social and environmental implications.

In this work, the term metallurgical technology is used to refer to the process that leads from ore transformation to the production of the final products. As described in Chapter 3, metallurgical activity requires a wide range of knowledge, skills, and resources, which in turn help shape the different stages of the metallurgical *chaîne opératoire*. Through the concept of the *chaîne opératoire*, archaeometallurgists are able to disentangle the different steps of production and the skills required at each step, as well as present implications for the social organization of production.

Numerous researchers suggested that while there were general "recipes" for making metal artifacts, communities present individual differences in the way the objects were made, likely also linked with the available ores used. Furthermore, the range, consistency, and frequency of metallurgical activities differ substantially across time and space.

The range of metallurgical activity denotes the portion of the *chaîne opératoire* of metallurgical activities conducted at the settlement. I hypothesize that different stages of production might have been conducted in individual settlements. Communities may have conducted the entire metallurgical process on the site (entire process - from ore transformation to final object), a portion of it (segmented - ore procurement, ore transformation, object making, or trade), or could have focused on one proportion of the production (specialized - one activity at a time).

The range of activities also potentially offers insight into the interconnections between settlements, which could be particularly true for the Maros, given that all the examined sites were

in close proximity to one another. While performing the entire metallurgical process at individual sites opens the possibility for the community to remain at the settlement level of production, segmented and specialized production implies that the settlement is part of a larger, possibly regional, production system.

The consistency aspect of metallurgical activity offers insight into whether the activity was performed ad hoc or was standardized. The term ad hoc, in this case, refers to sporadic metallurgical production intended to respond to immediate local needs. By contrast, standardization implies more regular production, possibly related to an increased need for metallurgical objects, either by the settlement alone or by the larger network. Consistency also offers insight into how the community accommodated the developing metallurgical technology by producing reusable equipment and tools, such as stone molds. One might assume that societies utilized materials that were readily available in their vicinity; for example, in the region of study, such materials would be clay, as stones were not often available. However, as evidenced by the archaeological record, stone molds were also found at sites. Stone molds imply a significant investment in labor in metallurgical activity, along with reproducibility, and possibly indicate a higher frequency of production of specific objects.

The frequency of metallurgical activity refers to how often production occurred. Accurately assessing this frequency is only possible when the metallurgical context is well understood. This requires not only understanding the technological aspect of production but also situating the metallurgical activity within individual living settings. Metallurgy does not occur in isolation; the activity must be contextualized within the environmental conditions, the availability of regional resources, and the time demands of other essential practices such as subsistence activities. Taking these factors into consideration, I categorize frequency as low, medium, and high in this research. A low frequency indicates little to no evidence of metallurgical activity and minimal environmental impact. A medium frequency suggests episodic production, which may already leave discernible anthropogenic traces. In contrast, a high frequency implies sustained activity with correspondingly greater environmental consequences.

The second analytical domain in this research is spatial organization. The location of metallurgical activity within the settlement provides insight into the relationship between domestic, subsistence, and production spaces. It also aids in evaluating both the scale and intensity of production. Based on the premise that higher production intensity often necessitates a larger production area, it may also entail physical separation from residential zones. This separation may also indicate an awareness of the health risks posed by fumes or serve as a precautionary measure against fire hazards.

Metallurgical activity may have been performed within the settlement, at the outskirts, or removed from the settlement. Changes in the placement of metallurgical operations can reveal shifting social values attributed to the craft, changes in settlement organization, the status of its practitioners, and how risks were negotiated within a lived environment. If metallurgical activity was conducted within the settlement, the remains were found in houses or workshops, or in the open air, next to the structures, or in nearby or attached installations.

Ultimately, in this research, metallurgical activity is not viewed as an isolated or purely technical endeavor, but rather as an integral part of settlement life—embedded in the needs and values of its inhabitants. Its technological properties and positioning cannot be separated from the shifting community priorities, social and environmental conditions, and risk management.

7.3 Hypotheses and Expectations

Given that archaeological evidence shows broader technological changes over time, this portion of the chapter presents hypotheses related to Bronze Age societies, as they provide a finer chronological scale of relationships within the craft. To address questions of the technological aspect of intensification and its expression between communities, a set of hypotheses was formulated (Figure 7.2).

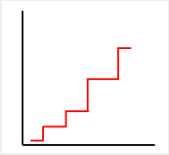
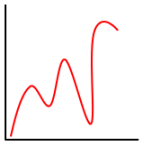
Hypothesis		Production expectation	Environmental expectation
Intensification patterns over time	*Ia. Linear increase in production* 	Steady, uninterrupted increase of production from Copper to the Bronze Age	Contamination will accumulate over time, with the highest signature in the Bronze Age
	I.b Stepped increase in production 	A general increase in production overtime, with intervals of rapid development	Longer periods of similar contamination levels
	I.c Non-monothetic 	Production is changing magnitudes overtime, presenting a low and high level of production, with the highest in the Bronze Age	Levels of contamination are variable - both in abundance and chemical signature
Community responses to intensification	*II.a Similar expression of intensification*	All communities will perform the same type of metallurgical activity, with the same technology, in the same location, and same scale	Contamination will be the same in all analyzed settlements
	II.b Differential expression of intensification	Communities show differential production, including activities, technologies, scales, and location	Sites with greater production will have a higher signature

Table 7.2 Hypothesis and expectations detected in production and environmental aspects of the research

7.3.1 Hypotheses About Technological Change

The first set of hypotheses relates to the character of metallurgical intensification observed from the Copper Age to Bronze Age systems. Three possible trajectories are evaluated.

Hypothesis 1a- The intensification of metallurgical production detected during the Bronze Age is a result of a steady increase in metallurgical activity starting in the Copper Age.

If this hypothesis holds true, I expect gradual changes in the range, consistency, and frequency of metallurgical production and changes in the location of metallurgical activities. The

steady increase in production over time would also have been visible throughout the gradual environmental contamination, with the highest peak dating toward the end of the analyzed time period, with no sudden peaks or periods of "stagnation."

Hypothesis 1b- The intensification of metallurgical production detected during the Bronze Age is a result of a stepped increase in metallurgical activity starting in the Copper Age.

If intensification resulted from a "stepped" increase in activity, I would expect alternating intervals of consistent and then rapid development over time, while still maintaining the Bronze Age peak. During the consistent period(s), I expected a gradual increase in production alongside an increase in contaminant abundance in the environment. The consistent period(s) were followed by abrupt period(s) of technological and spatial shifts that varied over time. Furthermore, this hypothesis proposes that shifts in production growth may occur at different rates, leading to distinct intensification patterns in metallurgical and environmental evidence, characterized by varying amounts and types of contaminants that continue to increase over time.

Hypothesis 1c- The intensification of metallurgical production detected during the Bronze Age results from the non-monotonic increase of activity that varied in magnitude from the Copper Age onward.

According to this hypothesis, the intensification evident in the Bronze Age in the Tisza-Maros region resulted from a highly variable production pattern rather than a steady development over time. If this hypothesis is true, I expect each contemporary settlement to exhibit a distinct pattern of change in technology and space, resulting in highly variable environmental contamination, as evidenced by soils and animal remains, over time within the study area. Thus, there would be no steady increase of production or contamination over time; rather, the settlements show individual processes within a larger regional system.

7.3.2 Hypotheses About Social Responses to Intensification

The second set of hypotheses considers how intensification was realized in different contemporary Bronze Age communities. Here, I explore two possible scenarios for the settlements under examination.

Hypothesis 2a – Bronze Age communities living in the Tisza-Maros region expressed metallurgical intensification similarly.

If this hypothesis is true, I would expect only minor differences in the expression of metallurgical intensification. Considering that all analyzed Bronze Age settlements belong to the same cultural group – the Maros - this hypothesis proposes that all analyzed communities expressed intensification of metallurgical production (range, consistency, frequency, and location of metallurgical activities) in similar ways over time. As a result, contemporaneous site horizons would have shown similar types of metallurgical remains and evidence of contamination in the same areas and at the same time. Variations over time, likewise, should be mirrored at all sites

Hypothesis 2b – Bronze Age communities living in the Tisza-Maros region expressed metallurgical intensification differently.

Alternatively, societies may have expressed the intensification of metallurgical production in different ways—a heterogeneous response. If this hypothesis holds true, I expect Maros communities to present different ranges, consistencies, and frequencies of metallurgical activities and contamination between contemporaneous settlement horizons.

The responses may have varied across settlement phases, as metallurgical intensification may have occurred at different times for different communities, or not at all. Heterogeneous responses in the expression of metallurgical intensification might also result from different engagements with the craft, which could reflect an organized regional network of cooperation and exchange between contemporaneous societies in the Tisza-Maros region.

To address the research questions and hypotheses, a detailed sampling strategy and a range of analytical methods and techniques were employed. The next two chapters—Chapters 8 and 9—outline the methodological framework of this dissertation. In the next chapter, Chapter 8, I focus on the sampling strategy and models central to this study.

Chapter 8 Methods and Approaches

This chapter presents the methods and approaches of my research. The first portion of this chapter is focused on the description of the data collection strategy, while the latter presents the materials used in this research. The data collection consisted of primary and secondary data. Primary data came from excavation and coring at sites of Rabe Anka Siget, Majdan 28 and Crna Bara–Prkos. Secondary data come from materials stored at the Móra Ferenc Museum in Szeged and at the Research Museums Center at the University of Michigan; items originated from Klárafalva Hajdova, Kiszombor Új-Élet and Pecica Şanţul Mare.

8.1 The Importance of Sampling: Archaeological Methods for Identifying Metallurgical Intensification

Archaeological research methods continue to advance, driven by rapid technological progress and the growing availability of new laboratory techniques, along with a growing amount of data generated by the increased number of excavations along with modern methods of excavation and sampling. Yet, alongside these developments, there is an increasing need for more integrated and holistic interdisciplinary approaches.

In the current landscape of archaeological inquiry, as outlined in Chapter 3, methodological and laboratory innovations are often specialized endeavors that are not well integrated with all the excavation and survey data. This over specialization can lead to weighing the lab results more heavily than other lines of information. Without a unified framework that bridges disciplines and situates data within its broader cultural and environmental setting, the interpretive potential of archaeological research remains limited.

In this research, I aimed to avoid fragmentation by prioritizing the development of a robust sampling strategy and integrating laboratory results with survey and excavation data, steps frequently neglected in favor of the application of new methodologies. The sampling strategy in

this work took several critical considerations: ability to replicate the research, taphonomic data such as site formation, broader environmental conditions, and availability of multiple categories of material.

While the sampling strategy was rigorously designed to capture variation in metallurgical signals through animal teeth and soils, the resulting dataset represents only a portion of each broader site and remains subject to excavation biases and preservation conditions. Furthermore, for some sites, the availability of suitable material for analysis was also constrained. These factors produced a disproportionate dataset that is more heavily weighted toward Bronze Age assemblages, exposing the needed larger dataset dating to the Copper Age.

However, this imbalance does not undermine the sampling procedure, the interpretive framework, or the representativeness and scale of the observed patterns ad it will be seen in chapter 10. Instead, it highlights areas where future research can further refine and expand the sampling strategy.

8.1.1 Replicability

Replicability was a central concern of this research, not only from a scientific standpoint but also to reduce noise from the numerous variables at play. The main materials analyzed in this research were animal teeth and soils. These two categories produce a wide range of information. Animal teeth, like most biological materials, contain varying information depending on the tooth, dental tissue, and factors such as the individual animal's health, diet, and environmental conditions.

For most mammals, teeth do not normally regenerate (except in rodents). However, each dental tissue captures a different time in the animals' lives. Thus, the enamel encodes information until the tooth crown stops forming, while dentin and cementum continue forming throughout life (Hillson 2005). Furthermore, different teeth begin to form at different times. For instance, in humans, enamel from permanent canines typically begins forming between four and five months of age and completes development around six to seven years of age. Third molars, on the other hand, generally begin forming between 8 and 10 years of age and complete crown development between 12 and 16 years of age (Loy et al., 2023). Yet, as variation in tooth development exists not only between species but also between individuals, teeth can provide a detailed living history of the analyzed animal or human, as well as offer insights into the broader environmental conditions in which they lived or were buried.

8.1.2 Taphonomy

Once the material is buried, it undergoes a series of physical and chemical changes affecting its preservation. Taphonomy plays a major role in this sampling strategy, as the signature encoded in the teeth can be altered by diagenetic processes.

In archaeology, research on diagenesis has focused on biological materials, with a particular emphasis on bone. However, in the current state of research, bone is often deemed too porous to accurately reflect trace-element and isotope-ratio values, such as strontium and lead. Dental enamel, by contrast, due to its high mineral content (approximately 92%–96% inorganic matter, 1%–2% organic matter, and 3%–4% water) and tight mineral structure, is a common choice of material sampled for subsistence and migration studies (Budd et al. 2000; Dudás et al. 2016; Simpson et al. 2021; Murray 1936; Teruel et al. 2015).

However, recent studies have challenged the assumption of dental enamel's impermeability in archaeological contexts. Bertacchi et al. (2024) demonstrated that enamel can be altered by environmental exposure and weathering, which poses particular challenges for the analysis of trace elements such as lead, given its low concentrations in dental tissues. This is, however, not the case for elements with higher abundance. Kamenov et al. (2018) found that strontium—present in enamel at relatively higher levels—remains largely unaffected by burial conditions, thereby supporting its reliability in post-mortem analysis. Nevertheless, for elements such as lead, distinguishing between diagenetic or environmental contamination and the original biological signal presents a significant methodological challenge that has been widely explored.

8.1.2.1 Methods and Strategies For the "Diagenesis Problem"

To determine whether the detected signal originated from metabolized exposure, was a result of post-depositional (diagenetic) processes, or a combination of both, various techniques have been employed —such as scanning electron microscope (SEM), X-ray fluorescence spectroscopy (XRF), inductively coupled plasma mass spectrometry (ICP-MS), particle-induced X-ray emission (PIXE), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS).

a) Rare elements

However, using a variety of laboratory techniques does nothing to answer the question of the element's origin within tissue without appropriate methods. One strategy has been to incorporate lithophile elements like vanadium (V), thorium (Th) and uranium (U), and chalcophile elements like lead (Pb) in the analysis (Kamenov et al. 2018; Samuelsen and Porta 2020; Sharpe et al. 2022; Giovas et al. 2016). By including elements that are readily present in the environment, yet rarely occur in biological tissues, the method proposed a way to assess the abundance of elements within a sample and determine its source (Kamenov et al. 2018).

b) Modern samples

Another method for testing trace-element concentrations in relation to diagenetic alterations is to include samples from modern humans and animals. According to the researchers, this method helped establish the background concentration of trace elements, a method often employed in stable isotope analysis (called an isoscape) (Bowen 2010). The analyzed concentrations of modern material thus aided in establishing Maximum Threshold Concentrations (MTCs) (Kamenov et al. 2018) and Maximum Threshold Ratios (MTRs) (Bertacchi et al. 2024), which served as guidelines for the values obtained from the analyzed samples. However, incorporating modern samples can prove tricky for the overall model, as they can create false negatives within the sample population. The reason is that there is an underlying key assumption that the analyzed systems are static and non-adaptive. This assumption is particularly problematic when considering biological organisms, whose bodies respond and adapt to environmental stressors.

It is well established that environmental and living conditions shape physiological responses. In fact, biological (and social) systems are highly flexible and can adapt to extreme stressors, such as harsh climates and conditions, environmental disasters, and anthropogenic disasters. For instance, a study conducted in the Andean highlands revealed that populations living in naturally contaminated environments with arsenic possess a variant of an arsenic-metabolizing gene. This gene enhances arsenic detoxification and may reduce the risk of related health complications (Nicole 2013). The gene was deemed an evolutionary trait, illustrating how the body adapts over time to environmental pressures.

A perhaps more drastic example presents nature's adaptability to anthropogenic disasters. Apart from the example of "metal-loving" plants (presented in the section on human-environment feedback loops in Chapter 2), numerous other examples exist. For example, soon after the explosion of Chernobyl on the 26th of April 1986, all life forms in the wider surrounding area were severely affected. Over the years, studies have reported that pregnant animals miscarried or developed thyroid diseases (Cardis and Hatch 2011). Trees, including evergreen pines, were dead, creating a dead zone (Flyn 2021, 94). However, not even a generation later, life adapted to the new conditions. In fact, apart from the newly established wild parks, genetic studies have shown that some plants have evolved an epigenetic response to ionizing radiation that regulates gene expression and genome stability, thereby improving plants' resistance to environmental mutagens (Kovalchuk et al. 2004).

Furthermore, a recent study conducted by Joanner-Boyau et al. (2025) showed evidence of environmental lead contamination in hominids, including Homo neanderthalensis and Homo sapiens. Exposure to lead affected genes involved in the development of speech and language abilities, ultimately affecting their evolution. These findings imply that humans have had more than two million years to physiologically accommodate exposure to lead.

Although these examples reflect different degrees and types of environmental exposure, they collectively underscore the dynamic and adaptive nature of biological systems. Such adaptability challenges the assumption that modern biological samples represent an appropriate baseline for contamination studies in archaeological contexts, particularly ones in the deeper past, and thus warrant reconsideration.

c) Comparison to soil and bedrock

Another strategy to distinguish between diagenetic and metabolic signals is to compare the material values with soils and bedrock (Samuelsen and Porta 2020). While such a method aids in the reconstruction of the burial environment, it does not necessarily speak to the extent that samples were affected by diagenesis.

In fact, diagenetic impact can vary from sample to sample, as seen by the pilot study I conducted in 2022 (Tomažič 2025). The impact of diagenesis on a specific sample also depends

on the conditions present before burial. In fact, in cases where the teeth are damaged or, for one reason or another, present higher porosity (such as non-fully mineralized teeth), they are more likely to be affected by diagenetic alterations. In the 2022 study, I also emphasized that the diagenetic impact varies with sampling location within the tooth; for example, areas closer to the masticating surface, particularly in older animals, are often more affected due to exposed recalcified dentin. Similarly, in cases where the tooth root was not completely fused, there was a higher chance that the diagenetic effect would have been greater.

The high variability between samples warrants increasing the sample size to minimize background noise, including naturally occurring biological variability. As Dudás et al. (2016) noted, the ratio of trace elements in animal teeth varies not only between species but also among individual specimens. For this reason, I stress the importance of sampling within the same location to better understand the underlying processes that may have affected living organisms and the burial deposits. By decreasing the sources of variability, we enhance the reliability of the analysis and its interpretative power.

8.1.3 Material Availability

The number of available samples was the next key consideration in developing the sampling strategy. While it is possible to anticipate the types of materials likely to be found at individual sites, archaeological contexts (and human behavior) often defy expectations with their inherent variability. For example, understanding trends in subsistence and animal husbandry in a given region and period helps create a sampling strategy that maximizes sample numbers.

Despite the lack of contamination studies done on animals, their remains may offer a more suitable study group than human remains to directly trace contamination in settlements. In regions such as the Southern Carpathian Basin, during periods such as the Early Copper Age and the Early and Middle Bronze Age, individuals were buried in single or multiple inhumation or cremation graves within communal burial grounds or cemeteries, often used by numerous communities from a wider region over multiple generations (O'Shea 1996; Siklósi and Szilágyi 2021). Such practices obscure the possibility of linking individuals to their immediate living environments—particularly in areas where provenience techniques such as strontium analysis are ineffective due to geological homogeneity, warranting further research to overcome these issues (Scaggion et al. 2025). In

contrast, although exceptions exist, animals generally lived—and their remains were deposited—within or near settlements, providing a more direct reflection of local environmental conditions.

Furthermore, compared with human graves, animal debris is often among the more common materials found within settlements and can provide a larger sample size. However, it is crucial to determine the available species and the most-represented body part for sampling before making a final choice. Choosing the appropriate sampling material depends on research questions, but it should be consistent throughout.

Like humans, animals are similarly affected by heavy metals (Pandey and Madhuri 2014), and they often exhibit similar symptoms from exposure (Hejna et al. 2018). As a result, if animals were exposed to contamination, humans likely were as well, even if only through the consumption of animal products. Data from domestic animals are thus especially valuable, as not only do they live in the same environments as humans, but they also have a substantially shorter lifespan (as they are often slaughtered before reaching full adulthood), resulting in exposure episodes of much shorter duration.

Using soil to better understand the local living and depositional environment of animal remains is only one advantage of incorporating them into archaeological research. Soils not only provide direct evidence of anthropogenic activity, but they also retain elements and signals that may not be preserved in surviving biological tissues. Although sampling from sealed archaeological contexts presents challenges—particularly for reconstructing contamination levels due to chemical and physical alterations such as bioturbation (Sposito 2008)—these deposits nonetheless capture the environmental conditions in which archaeological materials were originally embedded. As such, they offer essential background data for assessing contamination and contribute valuable insights into broader regional environmental dynamics. In doing so, they present a far more regionally specific picture of contamination than traditional archives such as cave deposits, ice cores, or lake sediments (e.g., Longman et al. 2018), which often reflect particles transported over long distances and therefore lack local specificity.

8.2 Samples Collected For This Research

In this research, I thus decided to sample animal teeth from domestic animals (pig, sheep/goat) and wild animals (red deer), along with soils from settlements (details of individual

materials are described below). While the larger portion of the sample consisted of the three mentioned species, on occasion, wild boar and other deer species, such as roe deer, were also collected. In addition to animal teeth, I sampled soils from burned archaeological features or deposits, as well as soils collected stratigraphically and via coring. Samples were collected during excavation (primary data collection) or from museum collections (secondary data collection).

8.2.1 Primary Data Collection

Primary data collection refers to the gathering of material during excavation and fieldwork. This was true for animals and soils from three archaeological sites — Rabe Anka Siget, Majdan 28 and Crna Bara–Prkos.

Samples from Rabe–Anka Siget were collected during the 2018, 2021, and 2022 field seasons. In 2018, animal teeth were sampled from the Middle and West portions of the tell, although no soil samples were collected. The 2021 season focused on coring, during which 33 cores were extracted across the site; only a subset of these was ultimately processed for this dissertation (Figure 8.1).

During the 2022 excavation season, two 2 × 2 m test units were opened—one in the eastern portion of the site and another at Majdan 28, a locality considered to be associated with Rabe. The eastern test unit was located based on preliminary work conducted between 2017 and 2021, which identified strong magnetic anomalies indicative of an activity area. This season, both animal and soil samples were collected from the test units and from the main excavation block on the western side of the site (details about the excavation are presented in Chapter 5, while the excavation report is in Appendix A).

Similarly, for the Crna Bara–Prkos, a pedestrian survey, a geophysical survey, and a coring season were conducted in 2021 and 2022 prior to excavation (for details, see Chapter 5, and for fieldwork results, see Mirković-Marić et al. 2025). The test units were placed west and south of the mound, while samples were also collected during the cleaning of the mound profile.

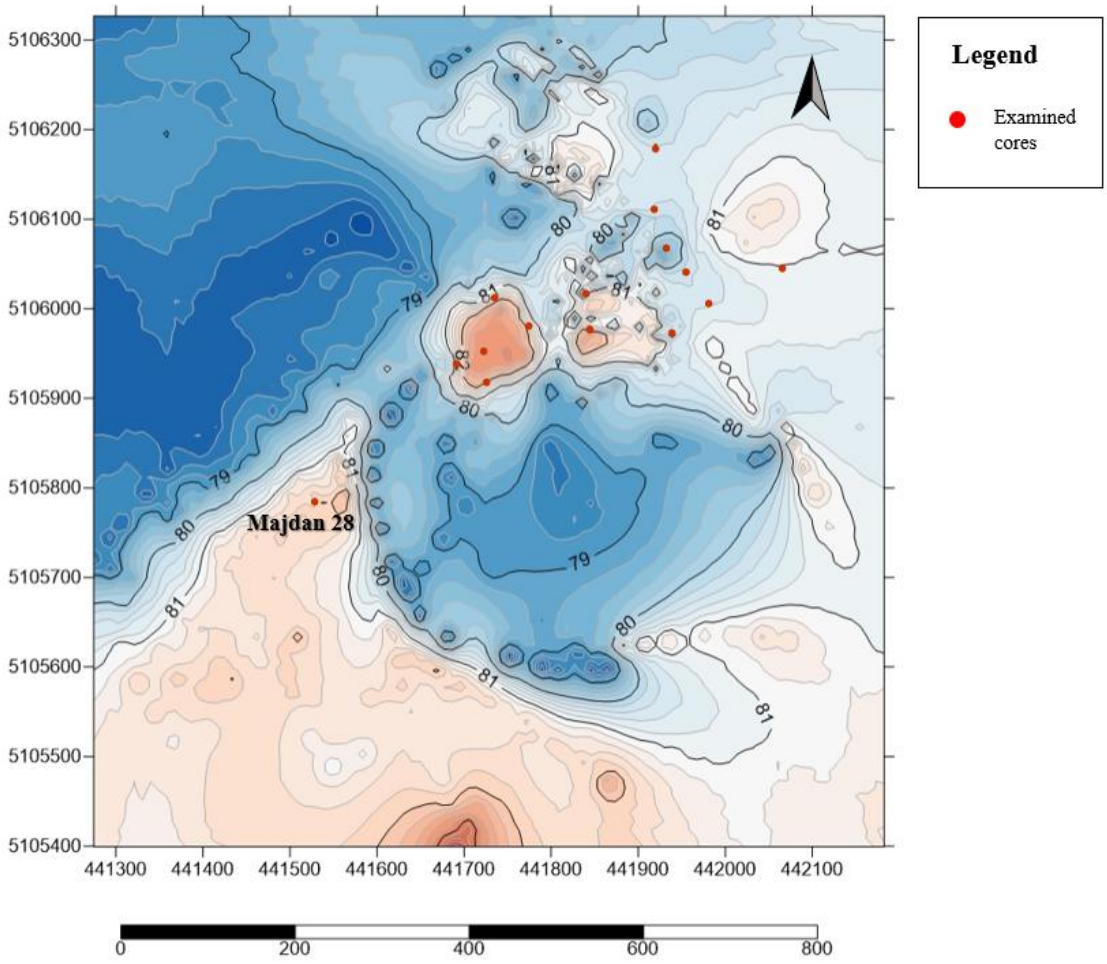


Figure 8.1 Map showing a topographic map of Rabe and its surroundings, including the marked site of Majdan 28. The original map was created by John O'Shea, but altered for this work

All test units were excavated by stratigraphic levels. During excavation, each deposit was recorded, and all recovered material sorted into categories (pottery, building materials, stone, metal, bone, and other). Suitable animal teeth (for details about animal see Appendix B) for sampling were separated from the rest during excavation, with their precise positions documented along with relevant contextual information, such as proximity to features with evidence of burning. Soil samples were likewise collected from every excavated deposit, including the A-horizon and sterile layers in each unit, as well as from contexts associated with burning. Core locations, stratigraphic descriptions, and associated samples were recorded in a spreadsheet (see Appendix C).

8.2.2 Secondary Data Collection

The secondary dataset consisted of materials collected from previously excavated sites. Klárafalva–Hajdova, Kiszombor Új-Élet, and Pecica Şanţul Mare provided the core comparative basis for this analysis, as all three were excavated using the same sampling strategy and, in most cases, are accompanied by specialist reports (such as faunal, botanical, and metallurgical remains).

The samples on this occasion were collected by following the spreadsheet of lots previously created by the excavators. The spreadsheets outlined the deposits and their types, along with surrounding artifacts and features found within each deposit. The focus was on collecting samples from strata and from the vicinity of burned deposits or features. The secondary data collection focused on teeth and soil samples when available.

8.2.3 A Chorus of (Heavy Metal Clues): Combining Lines of Evidence From Metallurgy, Soils and Animals

Although the metallurgical, faunal, and soil datasets generally converge in identifying periods and locations of intensified activity, minor discrepancies between proxies were handled through a structured interpretive framework. Because each proxy captures a different dimension of metallurgical practice—production debris reflecting direct technological activity, soils recording localized environmental accumulation, and faunal remains indexing exposure within domestic or husbandry spaces—the data shows different aspects of metallurgical activity. When proxies suggested different intensity levels, interpretations were guided by other archaeological evidence, including: stratigraphic context, spatial patterning, and magnitude of potential enrichment compared to site-specific baselines. Greater weight was given to signals supported by multiple independent lines of evidence, while isolated deviations were evaluated according to depositional processes, and activity-area organization. This approach ensures that discrepancies are treated not as contradictions but as meaningful indicators of how metallurgical practices intersect with environmental, domestic, and production spaces.

8.2.3.1 Metallurgical evidence

Metallurgical evidence from each site was either collected and recorded during excavation or drawn from existing reports by archaeometallurgists. No original analysis of metallurgical debris was conducted in this research; rather, reports and evidence were collected from

archaeometallurgists (Dr. Christopher Papalas, who analyzed the material from Klárafalva Hajdova and Kiszombor Új-Élet, and Dr. Orfanaou, who analyzed the material from Pecica Şanţul Mare). Materials collected from the sites of Rabe Anka Siget and Majdan 28 await analysis. There was no metallurgical evidence dating to the 4500-1500 BCE at Crna Bara–Prkos.

Evidence of metallurgical activity, presented in Chapter 6, is here organized into the main categories of "ore transformation" and "object-making" activities (outlined in Chapter 3) for all sites. It consisted of evidence of furnaces (all types), metallurgical waste such as slags and ash, production objects such as crucibles, tuyères, and molds, and final objects (Table 8.1).

	Thermal features	Casting artifacts	Metallic objects	Metalworking debris
Kiszombor-Új-Élet	X	X	X	X
Klárafalva Hajdova	X	X	X	X
Pecica Şanţul Mare	XXX	XXX	XX	XXX
Rabe Anka Siget	X	X	X	
Majdan 28	X			X

Table 8.1 Overview of the categories of metallurgical artifacts retrieved from sites under analysis. The category of *thermal features* implies their use in metallurgical activities but also acknowledges the possibility that they could have been used for other activities.

8.2.3.2 Geological Evidence

Soils are dynamic, living organic systems that undergo continuous transformation due to a range of factors, including anthropogenic activity and natural weathering processes (Sposito 2008). In this study, soil samples were collected from various deposits to establish a potential **baseline** for contamination.

Baseline geochemical levels were established using a combination of stratigraphic and contextual controls. For each core, the deepest sterile sediments (characterized by no cultural activity) served as the primary reference for natural background concentrations. The assessment was done for each site individually, to reflect local geological variability in the loess. The baseline was then subtracted from all analyzed soils within the core, to establish anthropological contamination. A method readily used in environmental studies (see Spahić et al. 2018 and Zhao et al. 2022).

Drawing on methods from ecological and geological research, soil composition and its potential influence on the preservation of archaeological materials, such as dental remains, the methods employed in this work carefully assess the possibility of travel of elements from different deposits, along with their impact on biological material.

Soils were collected from archaeological deposits via excavation and through coring. Coring helped establish a broader contamination region and background levels, in which the A-horizon was assumed to be the most contaminated deposit, the sterile layer the least contaminated, and the soils in between likely reflected (at least a portion) of past contamination.

Once the core was extracted and positioned on a measuring tape to determine its depth, it was photographed, collected with sterilized steel or plastic spoons, and placed in a sterilized Whirl-Pak bag. A rigorous cleaning protocol was followed in order to reduce cross-sample contamination. The cleaning protocol involves wearing and changing gloves, cleaning tools with 70% ethanol and Kim wipes, and letting the tools air dry.

Between 20-30g of soil samples were taken from each stratigraphic deposit. The layer and depth of the sample were recorded. The remaining sample from the layer was then recorded for its consistency, color, artifact or organic presence, such as the presence of roots. A similar practice for soil sample collection was employed during excavation. The samples were air-dried and then shipped to the University of Michigan for further analysis (Figure 8.2).



Figure 8.2 Soil sampling procedure during coring. Photo taken in 2021 by Györgyi Parditka

8.2.3.3 Biological Evidence

Prior to finalizing the sampling strategy—which aimed to clarify potential contamination across individual occupational phases—I reviewed faunal reports from the region and from specific sites (when available). Particular attention was given to the number, taxonomic composition, and age profiles of domestic and wild animals recovered at each site, as well as how these parameters changed through time. This step was essential for determining the availability and suitability of materials for analysis.

To avoid potential complications in interpreting early-life isotopic signals, this study focused on second and third molars, which more reliably reflect the animal's adult life stage (Hillson 2005). However, in cases where isolated teeth were recovered during excavation or sampling and could not be confidently identified, they were nonetheless collected to maximize sample availability. Whenever possible, mandibles with intact dentition were prioritized, and all three molars[11] were sampled to generate comparative datasets that help distinguish between the

[11] These distinctions were made during the sample result processing (see results in Chapter 10) evaluated using barium-to-calcium ratios to identify dietary patterns indicative of weaning (Austin et al. 2013).

first and second molars. Although mandibular molars were the primary target, maxillary molars were used when mandibular specimens were absent from a given deposit.

Following initial collection, the teeth underwent a series of sub-selection criteria. Each sample was first examined visually and then under a microscope to assess its state of preservation. Based on these observations, the teeth were grouped into categories: fully mineralized teeth with complete roots and no visible damage, and those exhibiting incomplete root formation, physical damage, or signs of burning.

In the pilot study conducted in 2022, only the best-preserved samples were selected for analysis. In subsequent phases of the research, some specimens with unfused roots were included, and their condition was carefully noted. In cases where samples were damaged, only the undamaged portions were used for analysis. The remaining details of the sampling procedure are comprehensively outlined in Chapter 9.

Diagenetic alteration was assessed systematically across all faunal samples using a multi-criteria approach that integrates both chemical and microstructural indicators. Chemically, for each specimen, preservation was evaluated through calcium concentrations and P/Ca ratios, with deviations from established enamel baselines (390,000–450,000 ppm Ca) used to flag potential alteration, alongside Pb/Ca ratios. These markers were cross-checked against LA-ICP-MS results for all examined elements (including Ca, Pb, Mn, Fe, Sr, As, and U, among others) to identify potential diagenetic overprinting. Although elements such as Mn and Fe were initially included to monitor diagenetic impact, work conducted in 2022—and subsequently published (Tomažič 2025)—demonstrated that these elements are stored in "radiating patterns" and differs to the patterns visible in heavier elements like Pb. Similarities between elements however arise in areas where teeth were cracked or damaged, reinforcing the importance for visual representation offered LA-ICP-MS results (see Figure 6, p. 11 in the cited publication).

8.2.3.4 The Animal Sampling Model

This study examined three species within the order Artiodactyla: the domestic pig (*Sus scrofa domesticus*), members of the Capridae family (including Ovis and Capra), and red deer (Cervus elaphus). To bolster the sample size, occasional specimens from roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) were also incorporated.

The inclusion of both domestic and wild species in the model was intentional, reflecting their different habitats and feeding habits. Domestic animals were likely kept in close proximity to human settlements and, as integral components of subsistence economies, their management practices may have likely been adapted to individual settlement environments and community practices. Such practices would have directly influenced their exposure levels. For example, if domestic animals were kept close to metallurgical activity or fed household food scraps—particularly crops grown near production areas (such as in garden plots), they would be expected to exhibit elevated contamination levels. Exposure via contaminated fodder would produce a longer and more consistent elemental signal than direct exposure to metallurgical activity, whether through ingestion, inhalation, or dermal contact. Signatures resulting from food contamination would vary with changes in husbandry practices.

In contrast, wild animals generally do not interact closely with humans or their activities. Consequently, shifts in their contamination levels are more likely to reflect broader, landscape-scale environmental changes—either conditions that prompted animals to move closer to human activity or circumstances that led communities to relocate metallurgical activities (Figure 8.3).

Apart from location and feeding patterns, species-specific physiologies and individual animal health also influence how contamination is absorbed, processed, and expressed in biological tissues. For this reason, the following section outlines the relevant biological and behavioral characteristics of each sampled animal species, to provide a basis for the analysis.

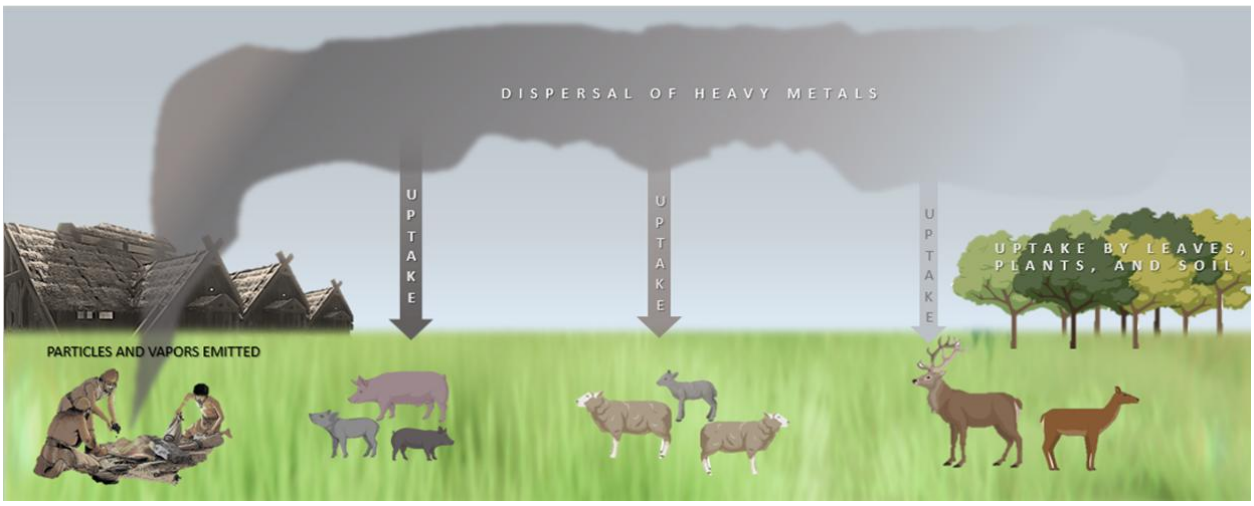


Figure 8.3 Model of contamination, showing animals and their proposed amount of contamination in relation to the contamination source

a) Pig

The domestic pig (*Sus scrofa domesticus*) belongs to the suborder Suiformes. As omnivores, pigs possess a monogastric digestive system that closely resembles that of humans. Their cheek teeth, specifically premolars and molars, are bunodont, adapted for crushing and grinding, while the canines are tusk-like. This tusk development is particularly pronounced in males and serves as a marker of sexual dimorphism. Emken et al. (2023) also showed differential timing in tooth development between male and female pigs and boars alike, showing that males develop their teeth slightly faster than females.

Pig molar crown formation varies across the dentition. The M1 (first molar) begins developing before birth and erupts around the fourth month of life. The mandibular M2 (second molar)—the tooth most frequently sampled in this study initiates crown mineralization approximately two months after birth, completes it by around nine months, and erupts at roughly twelve months (Kierdorf et al. 2019). During this period, the M3 (third molar) crown is forming; it erupts later, between 22 and 36 months of age (Legge 2013).

It is important to note that modern domestic pigs exhibit maturation and tooth eruption earlier than wild boar (Emken et al. 2023). Kierdorf et al. (2019) demonstrated that medieval pigs more closely resembled wild boar in their developmental timing, and it is likely that prehistoric pigs

followed a similar pattern. Furthermore, it is not to exclude that different species might slightly vary in their teeth eruption timing.

Although pigs shed their deciduous teeth, the permanent dentition tends to wear down rapidly, often exposing the underlying dentine (Hill 2005, 128). Pigs typically consume a varied diet consisting of tubers, bulbs, nuts, seeds, insects, and small vertebrates. When kept near human settlements, it is plausible that they also ingested human refuse. Ethnographic studies, however, suggest that pigs are sometimes pastured in surrounding galleries (Egerszegi et al. 2003) or wetlands (Molnár et al. 2021).

Pigs are well adapted to wetland environments, which may explain their prevalence at the archaeological sites analyzed in this study. A total of 80 pig teeth, representing individuals aged 12 months and older (Schmid 1972), were examined (Appendix B). Given the physiological similarities between pigs and humans—particularly in digestive function and tooth formation—pigs were also employed as proxies in this research to assess exposure to fumes and waste products from metallurgical processes.

In the model, exposure levels are closely linked to the spatial relationship between livestock and metallurgical sources. Consequently, pigs kept near settlements and sites of metallurgical activity were expected to be more likely to experience elevated exposure, primarily through inhalation and ingestion. Conversely, pigs pastured in more remote areas would have faced reduced contamination levels due to their distance from pollution sources.

As discussed in Chapter 4, heavy metal exposure in pigs can lead to damage in vital organs such as the liver and kidneys. It may also induce physiological stress, resulting in cellular damage, inflammation, and disruption of the nervous system. Additionally, growth rates may be adversely affected. Elements like zinc and copper, commonly added to animal feed to prevent diarrhea, can contribute to antimicrobial resistance (AMR) when overused. These metals are excreted in manure, which, when applied as fertilizer, can accumulate in soils and potentially affect crop health (Feng et al. 2018).

While pigs are assumed to be the species most affected by metallurgical activity, Caprids are likely to exhibit lower levels of contamination due to differences in diet and husbandry practices.

b) Caprids

Caprids, including sheep (Ovis) and goats (Capra), belong to the suborder Ruminantia (*Pecora*). As ruminants, they possess a four-chambered stomach, with the rumen serving as the primary site for microbial fermentation of cellulose-rich plant material. Food is partially digested and periodically regurgitated before passing through the remaining chambers for further breakdown. These herbivores typically consume grass, leaves, twigs, moss, and bark. They primarily have high-crowned (hypsodont) dentition, particularly in their premolars and molars, which is adapted to high rates of tooth wear (Payne 1985). In caprids, the M1 (first molar) begins forming before birth, and it erupts around 2 months of age. While the M2 (second molar) erupts between six and twelve months, the M3 (third molar) erupts between 16 and 22 months (Greenfield and Arnold 2008). Upon wear, teeth crowns gain a secondary segment and calculus, which coats the tooth crown (Payne 1985:142; Hillson 2005:132–135).

A total of 120 caprid teeth from individuals aged 12 months and older were analyzed in this study (see results in Chapter 10 and Appendix B). These two species were examined collectively due to the difficulty of distinguishing them in archaeological contexts, where only individual teeth were recovered. Sheep, as grazers, tend to be less adaptable to environmental fluctuations than goats. For instance, although sheep may be present in wetland areas, they are prone to conditions such as foot rot. Goats, by contrast, are browsers and generally more adaptable, though they too are susceptible to hoof-related issues in wetland environments (Bartosiewicz 2008; Halsted et al. 2002).

Despite their biological differences, sheep and goats were likely managed as part of the same herd (Halsted et al. 2002) and kept either within settlements or along their periphery. In regions with varied topography, herding practices often included vertical transhumance, involving seasonal movement between lowland and upland pastures (Greenfield and Arnold 2006). A comparable strategy may have been employed in flatter landscapes, where some authors have proposed the existence of horizontal transhumance—defined as the relocation of herds across

different areas throughout the year (Čakan 2011). This would be especially relevant in seasonal wetland environments, such as the Tisza-Maros region.

Given the shared management and environmental exposure, sheep and goats are expected to have experienced similar levels of contamination from metallurgical activity. However, goats may have been slightly less affected due to their more varied diet, which could reduce direct ingestion of contaminated materials.

Bioaccumulation of heavy metals in caprids can affect the liver, kidneys, and bones, potentially impairing growth. These metals disrupt homeostasis and trigger inflammation at the cellular level. In cases of chronic exposure, reproductive performance and milk yield may decline significantly (Hejna et al. 2018).

c) Deer

To assess differences in contamination levels and proximity to metallurgical activity, wild animals were also included in the analysis. Deer, herbivores, belong to the family of Cervidae, are ruminants and possess a digestive system similar to that of caprids. Their teeth, characterized by lower crowns and more prominent roots, share structural similarities with those of other ruminants (Hillson 2005, 138).

Hunting remained a subsistence strategy during the Copper and Bronze Ages in the Tisza-Maros region, though the frequency of deer hunting varied over time. The majority of the sample consisted of red deer (Cervus elaphus), with a total of 30 teeth, alongside a smaller subset of two teeth from roe deer (Capreolus capreolus), all from individuals aged approximately 12 months and older (Appendix B) (Lowe 1967; Høye 2006). Given that both species are ruminants and differ primarily in size, they were analyzed together in this study.

In terms of proximity to metallurgical activity, it is assumed that deer generally avoided human settlements, although they may have occasionally fed on cultivated plants in surrounding areas. As a result, deer are expected to exhibit the lowest levels of contamination among the species analyzed.

Similar to other species, heavy metals cause organ damage, disrupt the metabolic process, and cause nutritional imbalance that can affect bone health and overall metabolism (Jota Baptista et al. 2024; Cygan-Szczegielniak 2021).

d) Boar

In addition to domestic and wild ruminants, boars (Sus scrofa or Sus scrofa ferus) were occasionally analyzed, with a total of five teeth from individuals aged approximately 24 months and older (Appendix B). Boar tooth formation closely resembles that of domestic pigs, but with a slight temporal offset. As noted above, the developmental differences observed between modern domestic pigs and wild boar were likely much smaller in the past (Kierdorf et al. 2019).

Boars were included to provide a comparative baseline for pig husbandry practices. Ethnographic studies suggest that pigs may have been pastured in surrounding galleries rather than kept exclusively within settlements. If this were the case, the contamination signature of domestic pigs would more closely resemble that of wild boars, rather than pigs continuously exposed to anthropogenic environments.

In case boars are exposed to heavy metals, they primarily suffer organ damage, such as the liver and kidneys. However, studies showed that it appears that males were more sensitive to the negative effects of heavy metals (Boișteanu et al. 2024), which affected their metabolic functions and caused fluid accumulation in liver cells, showing cellular stress and damage (Jota Baptista et al. 2023).

The sampling strategy and models presented here help clarify the reasoning that underpins this dissertation. However, as shown in the previous sections, while the sampling strategy is essential, choosing appropriate analytical methods and procedures is equally critical. For this reason, Chapter 9 is dedicated entirely to outlining these methodological approaches.

Chapter 9 Laboratory Procedures and Analytical Methods

While Chapter 8 presented the sampling strategy and stressed its importance, this chapter presents the importance of selecting appropriate sampling collection procedures. This includes the equipment used and the protocols for sample preparation, collectively termed standard operating procedures.

The fast-growing technological advances are a double-edged sword in archaeological research. On one hand, they offer new perspectives on the data, but on the other hand, the specific knowledge required for interpretation often limits their utility.

Through experimentation methods conducted for this research, I learned the importance of using complementary methods. In fact, different methods and instruments, similar to different materials, produce different types and qualities of results. For example, certain instruments like the inductively coupled plasma mass spectrometry (ICP-MS), a method often used in public health and environmental sciences, can accurately analyze chemical elements that occur in very small amounts in the body. However, when the abundance and proportion of trace elements within a specific material are higher, like for example strontium or barium in teeth, different methods, like inductively coupled plasma-optical emission spectrometry (ICP-OES), are more suitable. While accurate, none of the instruments show where in the tissue these elements are stored. The lack of visual representation likely contributed to the raised doubts about elemental concentrations and questions regarding the material diagenetic alteration outlined in Chapter 8. For this reason, I added elemental mapping conducted with LA-ICP-MS to the methodology, as it allows us to see the location and pattern of elemental distribution and compare them across different elements.

In my pilot study, conducted in 2022 on animal teeth (Tomažič 2025), I demonstrated that the appropriate combination of instruments and methods enables the detection of contamination and storage location within the sample. In the pilot study I analyzed 14 elements: calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), barium (Ba), strontium (Sr),

manganese (Mn), arsenic (As), lead (Pb), copper (Cu), cadmium (Cd) and tin (Sn), while from 2024 I added uranium (U).

These elements were selected to construct a matrix of essential and non-essential elements, with particular attention to their interrelationships outlined in Chapter 4. Of particular focus was the link between lead (Pb) and calcium (Ca), as Pb can replace Ca in metabolic reactions. Manganese (Mn) and iron (Fe) served as supplementary indicators in diagenetic analyses, as they are frequently cited in the literature as markers of diagenetic alteration in biological material. However, the pilot study that I conducted showed that these three elements are stored differently within the tooth. This opens the question as to whether that was a sample or site-specific or it was a common pattern, which will be discussed in the results section.

9.1 Laboratory Procedures and Analysis

While several laboratory techniques were utilized during the experimentation, the final methodology includes inductively coupled plasma mass spectrometry (ICP-MS), inductively coupled plasma optical emission spectroscopy (ICP-OES), and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). All three methods were conducted at the University of Michigan, Ann Arbor Campus.

a) ICP-MS

The first method used is inductively coupled plasma mass spectrometry (ICP-MS). This method was chosen due to its wide applicability in analyzing pollution and contamination across various sciences, including environmental and people-oriented fields. This technique allows the detection of low concentrations of multiple trace elements simultaneously with high accuracy (Wilschefski and Baxter 2019).

The high sensitivity of ICP-MS is able to detect abundances up to parts per trillion (ppt), equivalent to 1ng/L, although for this research, parts per billion (ppb) or parts per million (ppm) were sufficient (Wilschefski and Baxter 2019). While the machine offers the opportunity to analyze a wide range of elements, the instrument is more suited to accurately detect elements present in low amounts and is less suitable for more abundant elements. The type of ICP-MS used in this research was the Quadrupole-ICP-MS (Thermo iCAP Q), used in 2022. The research was conducted at the MEAL lab of the University of Michigan, Department of Earth and

Environmental Sciences. For the second portion of the analysis done in 2024, a single Quadruple ICP-MS (Agilent) from the Department of Environmental and Water Engineering was used.
To enable analysis, the samples were first dissolved according to strict protocols (outlined below). Enamel subsamples were then prepared in a 2% HNO_3 (nitric acid) solution to form the final analytical matrix (Little et al. 2014). During analysis, the solution was aerosolized into a fine mist using a nebulizer and introduced into an argon-sustained plasma torch. The torch generates plasma temperatures of approximately 10,000 K—surpassing the surface temperature of the sun—which vaporize, atomize, and ionize the sample, transforming its constituent atoms into charged ions (Van Acker et al. 2023).

These ions are drawn through a vacuum interface via sampler and skimmer cones, which separate the plasma (at atmospheric pressure) from the mass spectrometer (operating under vacuum conditions). Electrostatic lenses, known as ion optics, guide the ion beam while filtering out neutral particles and photons. There are several types of mass spectrometers; for instance, a quadrupole mass analyzer filters ions based on their mass-to-charge ratio (m/z), whereas other types may operate differently. Regardless of the specific configuration, the mass spectrometer is designed to allow only ions of a selected m/z to pass through at any given time. Once the ions reach the detector, they generate signals proportional to their abundance (Van Acker et al. 2023). These signals are then processed by analytical software, which compares them to known standards to calculate elemental concentrations.

b) ICP-OES

Inductively coupled plasma optical emission spectroscopy (ICP-OES), sometimes referred to as atomic emission spectroscopy, was the method used to analyze the more abundant elements such as calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), barium (Ba), strontium (Sr), copper (Cu), cadmium (Cd) and tin (Sn). Samples used for this analysis were the same aliquots previously analyzed with the ICP-MS.
Similar to ICP-MS, Optical Emission Spectroscopy (OES) utilizes argon gas as a carrier. Samples are pumped into a nebulizer, which converts them into a fine mist. This aerosol is then transported by the argon stream into a plasma torch. As with ICP-MS, the high-temperature plasma atomizes the sample and excites its atoms and ions. Upon returning to lower energy states, these particles

emit light at characteristic wavelengths—each element producing a unique spectral "fingerprint." The emitted light is separated by a spectrometer and detected by sensors (Boss and Fredeen 2004). The intensity of each wavelength is measured and directly correlated to the concentration of the corresponding element in the sample, which is then displayed via analytical software.

c) LA-ICP-MS

The LA-ICP-MS, which stands for Laser Ablation Inductively Coupled Plasma Mass Spectrometry, added the visual component needed for this research. Compared with previous methods, the samples remain in solid form; thus, damage to the samples is minimal. This analysis was used only for the tooth samples. These were then embedded in resin and sectioned (more details below).

The LA-ICP-MS works similarly to the ICP-MS, with the addition of the laser beam, which extracts the sample from the sample surface. The laser, operating with nitrogen gas, vaporizes a tiny portion of the solid, creating an aerosol of fine particles. The aerosol is carried by a gas (argon) into the ICP torch, where it's heated to plasma levels. After that, the procedure is similar to the ICP-MS (Sylvester 2008).

The advantage of this method is that there is no need for acid digestion; however, the preparation that allows the samples to be visible under the magnifier is still needed. The entire area analyzed has to be in focus. This is particularly important in the case of elemental mapping; if the surface is not uniform, the time of sample suction will lag, creating a distortion in the final picture.

9.2 Standard Operating Procedures

In this section of the chapter, I present the laboratory procedures applied to both teeth and soil samples across all three analytical methods. Establishing a standardized protocol improved the replicability of the analyses and facilitated more robust cross-comparison of the resulting data.

9.2.1 Enamel Laboratory Operational Procedure for ICP-MS and OES

Sample preparation for wet chemistry was conducted in three steps (Figure 9.1). First, the teeth were visually inspected, extracted, documented, and mechanically cleaned. After the initial macroscopic inspection, first without and then with a low-powered stereo microscope,

mesiobuccal cups of visibly undamaged teeth were sampled. Teeth were mechanically cleaned by removing approximately 1 to 2mm off the tooth buccal mesial cusp surface with Brasseler NSK Z500 High Performance Dental Motor (Dremel) (Bianchi et al. 2017). The area was measured to establish the height of the enamel. The cusp was then cut, and the enamel was separated from the dentin. The samples for analysis were taken from the cervical area of the tooth, representing the latest stages of enamel formation. This portion of the preparation was conducted at the Anthropology Department of the University of Michigan.

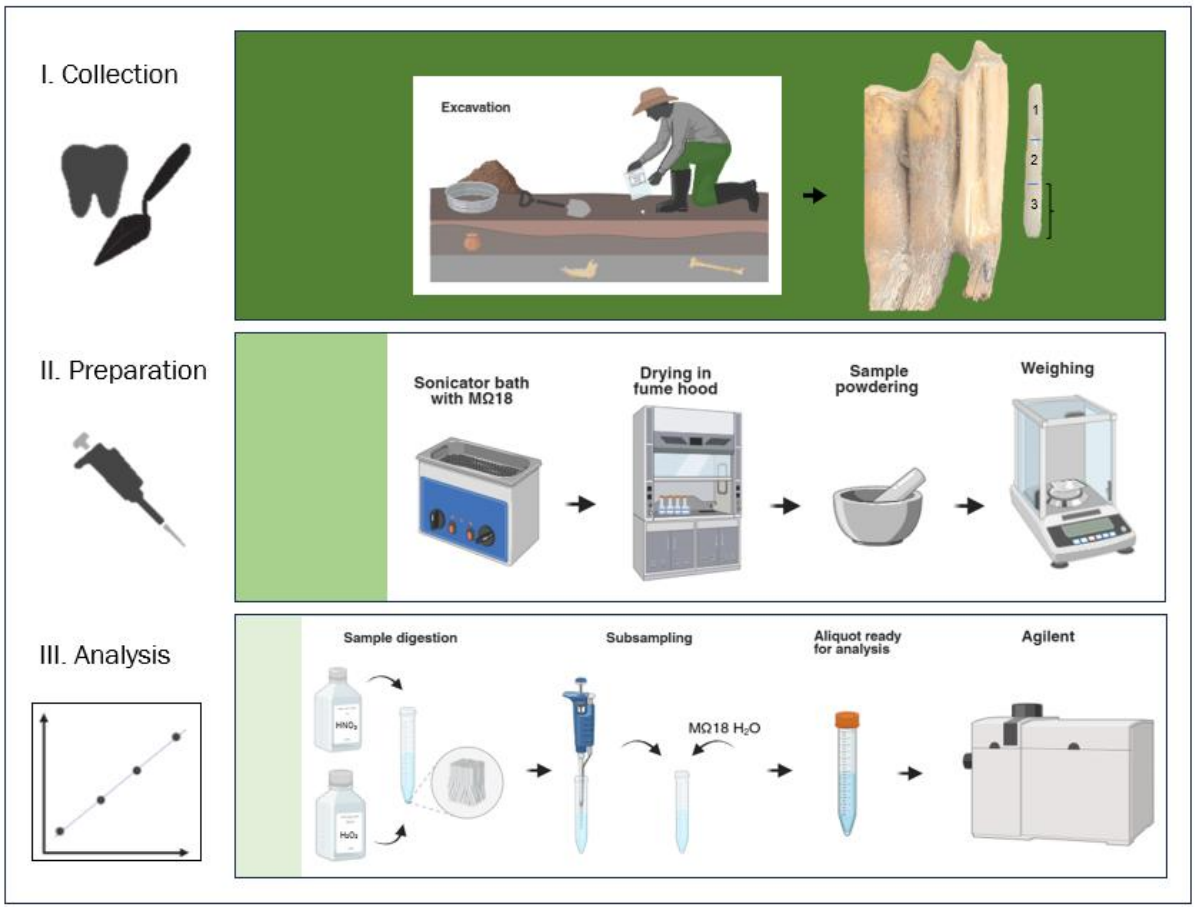


Figure 9.1 ICP-MS enamel preparation procedure. Created in https://BioRender.com

The second phase of sample preparation was then conducted in a clean laboratory, specializing for trace element analysis in the Environmental Science Department. Here, the samples were sonicated with ultrapure water (MQ H2O18.2MΩ-cm) three times and placed to air dry in a trace element-free environment in a ventilated fume hood. Once dry the samples were

powdered with a pestle and mortar, which were cleaned with Kimwipes and 70% ethanol solution. The sample digestion method followed the protocol from (Little et al. 2014).

The digested aliquot was subsampled and brought up to 10ml with 2%NHO3. The samples from 2022 were analyzed with a Thermo Cap ICP-MS in the MEAL lab, while samples from 2024 and 2025 were analyzed with an Agilent 7900 quadrupole in the Environmental Engineering Department in Ann Arbor.

9.2.2 Teeth Laboratory Operational Procedure for LA-ICP-MS

Samples that showed higher Pb concentrations were then embedded in epoxy resin from EPOTEK, with a mix of solutions 301 and 730, with a ratio 10:8 (Figure 9.2). Once dried, the samples were cut with a *Buehler Isomet* low-speed precision cutter along the mid-sagittal plane through the mesial cups to create teeth slides, which were then polished. The LA-ICP-MS sample slide preparation was done in the University of Michigan Museum of Natural History and the Environmental Science Department.

To observe the distribution of trace elements across the enamel, the enamel dental junction (EDJ), and different dental tissues, a subsample of animal teeth was subjected to elemental mapping with Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the MI-Chron lab (Department of Earth and Environmental Sciences, University of Michigan).

The teeth slides were analyzed with an Agilent 7900 quadrupole ICP-MS with an ESI NWR193 excimer laser-ablation system. Samples were ablated by consecutive line scans with a repetition rate of 150 Hz, a 20 µm square spot, 200 um/s scan speed, and a fluence of ~2.5 J/cm². A cleaning pass was conducted for each line at 1500 um/s, prior to analysis to remove any surface contamination from the previously ablated lines. The ablated material was transported to the ICP-MS using the ESI dual-concentric-injector (DCI) system with a helium carrier gas of flow rate 0.8 L/min He, providing ~50ms fast washout to prevent signal blurring in the direction of the scans.

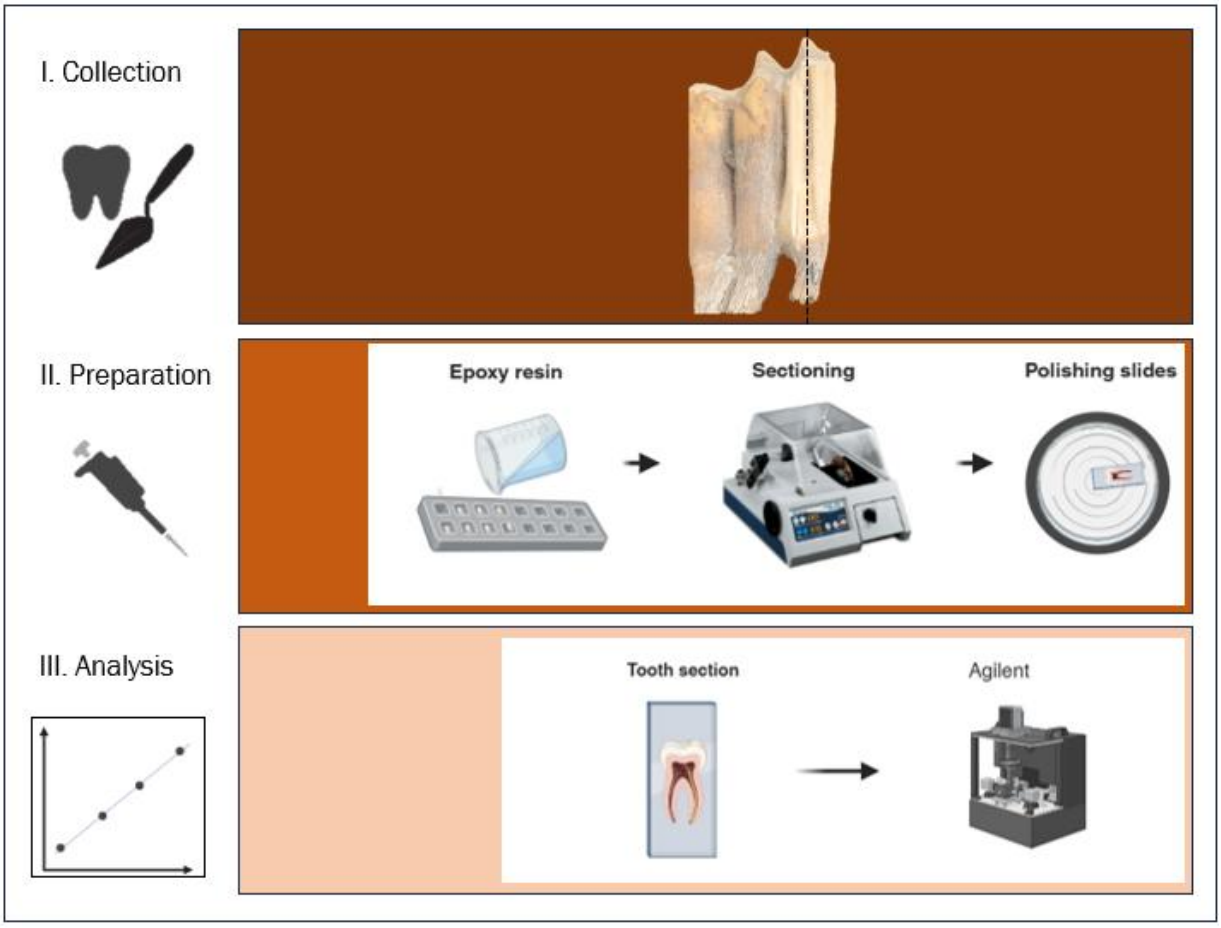


Figure 9.2 LA-ICP-MS enamel preparation procedure. Created in https://BioRender.com

ICP-MS parameters were optimized for sensitivity and stability. The follow isotopes and integration times were used—24Mg, 31P, 39K, 44Ca, 63Cu, 66Zn, 88Sr, and 137Ba for 2ms; 55Mn for 10ms; 57Fe for 3ms; 75As for 9ms; 208Pb for 28ms; and 238U for 4ms—for a total duty cycle of 0.1 seconds. The duty cycle is an integer factor of the laser repetition rate to minimize signal artifacts associated with the fast-washout DCI (e.g., van Elteren et al. 2019). The scan speed was set so that the spatial resolution of each isotope measurement corresponds exactly to the spot size: scan speed (200 um/s) = spot size (20 um) / duty cycle (0.1 s).

Maps were quantified using the commercially available software Iolite version 4, with the built-in "Trace-elements" data reduction scheme. Briefly, this consisted of (1) defining and subtracting a time-dependent baseline for each isotope measured (2) correcting for instrumental drift by sample–standard bracketing: repeat measurement of the known standard reference material

(SRM) NIST 612 every 30-60 minutes (3) calibrating the baseline-subtracted, drift-corrected counts-per-second to an elemental concentration using the same SRM, normalized to Ca as an internal standard (element of known and homogeneous concentration in the SRM and samples) to correct for any differences in the amount of material ablated during analysis (for example, due to differences in the cohesion of the material across the samples or differences in laser coupling among the glass SRM, crystalline enamel, and more porous dentin). For the samples, the internal standard concentration of Ca was taken to be 39 wt.%. Concentrations of elements in the SRM NIST 612 were taken from the currently preferred values of the GeoReM database (georem.mpch-mainz.gwdg.de; Jochum et al. 2007).

9.2.3 Soil Laboratory Operational Procedure

According to the USDA regulations, 10g of imported sediments were placed in the oven in glass bottles, covered with trace element-free weighing paper, and baked in the oven for 2 hours at 250F or 121 °C. Soil samples were sub-selected and baked in the Research Museum Center in Ann Arbor.

Samples were then further subsampled, crushed in a pre-cleaned agate mortar and pestle, and placed in acid-clean Falcon centrifuge tubes, to be leached according to a modified leaching procedure outlined in Blum et al. (2002). The sample leaching was done in the Environmental Science Department with the help of Dr. James Gleason, along with undergraduate student Grace Coon through the Undergraduate Research Opportunity Program (UROP) (Figure 9.3).

The samples were subjected to a modified sequential extraction procedure. The procedure applied to each sample for isolating the 1) bioavailable soil cations, 2) mineral available (non-silicate) soil cations, and 3) loosely bound bio-contaminants and organics.

The procedure consisted of 1) an overnight (24 hour) agitation on shaker table at room temperature, followed by 2) a 2-step centrifugation, dilution and transfer of the 1M HNO3 leachate, followed by 3) filtration of the solution at 0.45 microns. The filtered aliquots were then subjected to a multi-step HNO3 -H2O2 dry-down treatment prior to analysis using temperature-controlled hotplates under clean lab conditions to eliminate any residues/organics before analysis.

Finally, ICP run solutions of 2% nitric acid were prepared from 5 ml of 4% nitric acid solution using trace metal grade (Fisher) nitric acid.

The samples were analyzed with the ICP-MS and ICP-OES. For quality assurance, a subset of samples was sent to the University of Georgia to conduct the same analysis.

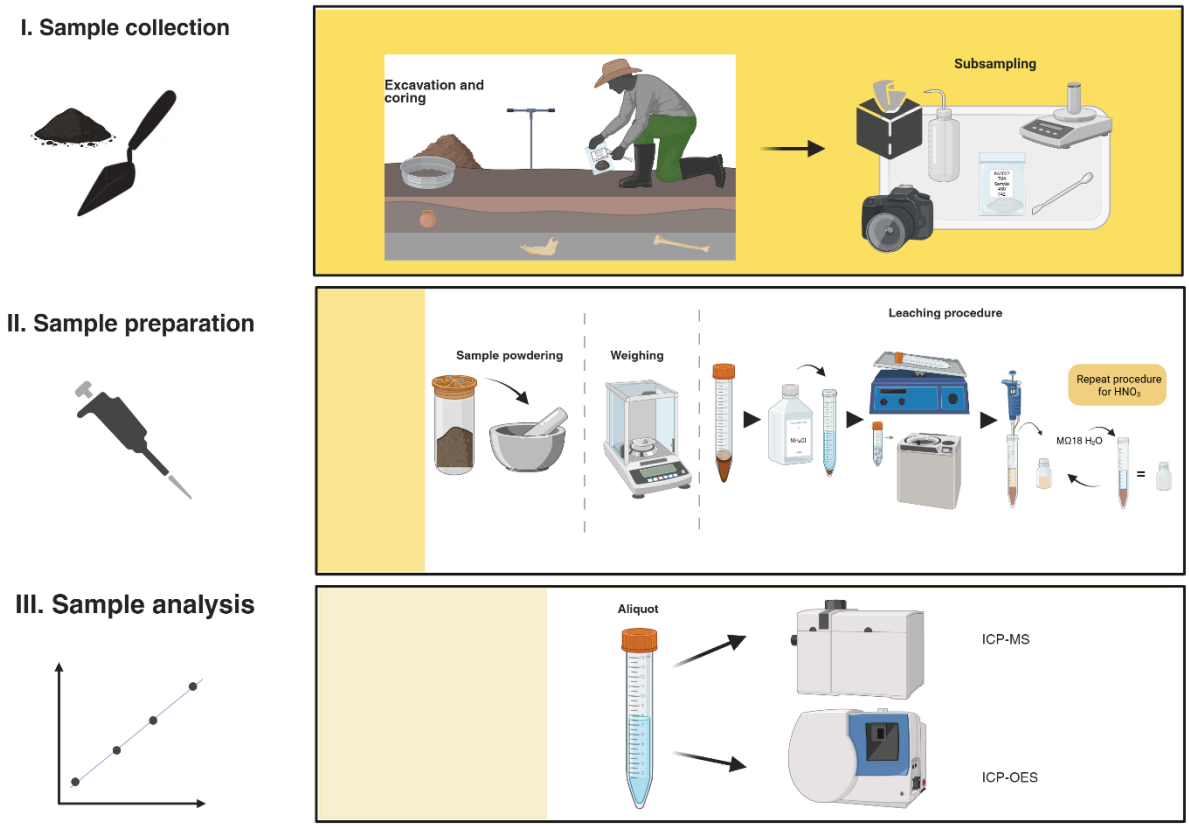


Figure 9.3 ICP-MS and ICP-OES soil preparation procedure. Created in https://BioRender.com

9.2.4 Radiocarbon Dating of Animal Remains

Considering that for this research six sites spanning between 4500 and 1500 BCE were utilized, establishing a detailed chronology of the sites was crucial. While sites of Klárafalva Hajdova, Kiszombor Új-Élet and Pecica Şanţul Mare already presented available radiocarbon dates, the focus was on sites that were excavated within the framework of this research, namely Rabe Anka Siget, Majdan 28, and Crna Bara–Prkos.

A total of 10 samples were sent to the Radiocarbon lab at the University of Georgia for analysis. Similarly to the soils, a subsample of the same material was sent to the Radiocarbon lab in Budapest to assess the quality of the data.

Radiocarbon dating aided in creating the presented models presented in Chapter 7, which aids in creating segments of time that could be compared across sites.

9.2.5 X-Ray Diffraction (XRD) of Soils

A total of five soil samples from different sites were sent to the Electron Microbeam Analysis Lab (EMAL) at the University of Michigan. The purpose was to establish the mineral composition of soils to better interpret trace element patterns.

Chapter 10 Results

In this section, I present the results for teeth and soils collected from six archaeological sites Kiszombor-Új-Élet, Klárafalva Hajdova, Pecica Şanţul Mare, Rabe Anka Siget, Majdan 28 and Crna Bara–Prkos. The teeth samples (pig, sheep/goat and deer) and soils were collected from archaeological deposits, either during fieldwork (excavation or coring) or from existing museum collections (see more details about the sampling strategy in Chapter 8). After being selected the samples were processed and analyzed with ICP-MS for heavier elements, and ICP-OES for lighter elements. Additional analysis was conducted on a subsample of teeth with LA-ICP-MS to determine the source of contamination and a subsample of soils with the X-ray diffraction to determine the samples' mineral composition (for details see methods described in Chapter 9). The results from the analysis were then processed and statistically analyzed. This chapter has three main parts: general evidence, site-specific evidence, and evidence grouped by time period.

The first part introduces the general patterns observed in both teeth and soils. For the teeth, while other elements might have impacted the animal's health, for this dissertation I focus primarily on the relationship between calcium and lead, as evidence of metallurgical production as outlined in a previous publication (Tomažič 2025). In addition to Pb/Ca ratios, this includes broad taxon-level trends for elemental ratios of Ba/Ca and P/Ca across all analyzed animals, which illuminated sample exposure to contaminants, including sample preservation.

For the soils, general patterns are presented first in the X-ray Diffraction (XRD). The geochemical dataset for soils was examined using several analytical approaches including Principal Component Analysis (PCA), which was used to explore covariance of elements. The heavy-metal concentrations were then evaluated through ecological models to assess anthropogenic impact and ecological risk. Similarly to the teeth, other elements impacted soils, however the results proved copper and tin to be significant elements for this work. With the help of these two methods, core sequences from each site were then selected to capture variation and

distribution of contamination in individual strata from A horizon, buried soils, down to sterile deposits to examine possible migration of elements through deposits.

After the initial analysis, the second part of the results examines the similarities and differences in contamination between sites. For the teeth, this involves comparing lead concentrations across locations and explaining outliers in the LA-ICP-MS results. For the soils, this section discusses samples recovered from known and securely dated archaeological contexts, allowing site-specific patterns to be evaluated alongside the dental evidence.

The final part presents the results according to time periods, broadly corresponding to the Early and Middle Copper Age and the Early and Middle Bronze Age. In this part I use broader chronological divisions to make inter-site comparisons and contrasts.

In total, 501 samples were analyzed – 270 teeth samples and 230 soil samples. For the analysis of animal teeth (Table 10.1), three main species—pigs, caprids, and deer—were examined, along with two cattle samples from Rabe Anka Siget. The cattle teeth were included to compensate for the absence of deer recovered during the 2018 and 2022 field seasons. Within the pig category there were a only three examples of boar, while the deer category included both red deer and roe deer. Most analyzed specimens were second molars, followed by third molars —both mandibular and maxillary teeth. A smaller number of first molars were also included, 17 of which were still embedded in bone. In a few cases, isolated teeth could only be classified broadly as M1 or M2. These additional samples were incorporated to increase the overall dataset, particularly for sites where fewer teeth were available.

	Pigs (*Sus scrofa*)	**Caprids (*Caprinae*)**	**Deer (Cervidae)**	**Cattle (Bos taurus)**	**Total**
M1/M2	9	12	3	1	25
M2	46	73	20	/	139
M3	31	62	12	1	106
Total	86	147	35	2	270

Table 10.1 Division of all analyzed animal teeth samples by species and molar type

For soils 230 were analyzed. This included 26 samples from A horizon and 12 from sterile deposits. In total, 100 individual samples were taken from cores from different sites. Only the main patterns are used and presented in the results section; all data are available in Appendix C.

10.1 Building a Comparative Baseline: General Results From Teeth and Soils

The section discussing general results is a crucial first step in reducing sample-level noise and establishing a comparative baseline. By combining all teeth and soils from all sites and time periods, this section highlights broad patterns within each material, allowing biological variation in the teeth and pedological variation in the soils to be contextualized. These overarching trends provide the foundation for interpreting deviations and outliers in the subsequent sections, where site-specific and temporal patterns are examined in greater detail.

10.1.1 Teeth

Although general ratios in enamel and dentin composition are well established, Teruel et al. (2015) present evidence of variation in element abundance between the tissues. Species-level variation is often attributed to differences in diet and habitat, while factors such as age and health can introduce additional variability at the individual level.

As outlined in the methodology, the focus on the relationship between lead and calcium is to trace possible signatures of metallurgical production. However, to determine contamination pathways — metabolic or diagenetic or a combination of both, and to determine outliers within each taxonomic group, I also examine ratios in barium-to-calcium and potassium-to-calcium concentrations.

The relationship between barium and calcium has long been used to infer early-life dietary transitions in primates (Austin et al. 2013), and similar approaches have recently been applied to other animals (Clark et al. 2020). In this study, I use the Ba/Ca ratio to explore dietary differences among pigs, caprids, and deer. The analyzed taxa have distinct diets and digestive systems (outlined in detail in Chapter 8). In brief, pigs are omnivores that may consume human refuse or be pastured in surrounding gallery forests (Egerszegi et al. 2003). Sheep and goats are grouped together here as caprids due to the difficulty of distinguishing single goat or sheep teeth from archaeological contexts; however, because sheep are grazers and goats are browsers, Ba/Ca values

may help differentiate them. Goats, as browsers, would be expected to show Ba/Ca patterns ratios more like deer, which are also browsers.

As a smaller portion of the collected samples were determined to either be M1 or M2, the Ba/Ca ratios along with the relationship between phosphorus and calcium help determine the mineralization stage of the tooth. As P/Ca relationship is sensitive to the amount of mineralization, it would help explain potential outliers in the dataset, due either to age or diagenetic alteration (Szostek 2009). Together, these elemental ratios provide essential context for interpreting the presence and distribution of lead in the enamel.

10.1.1.1 Pb/Ca Ratios

The Pb/Ca results reveal intra and inter species variation. In the differences between species, pigs, as expected, exhibit the highest values on average, followed by caprids, while deer display the lowest concentrations (Table. 10.2).

I have argued (Tomažič 2025) that the elevated values observed in pigs are unlikely to reflect only soil intake. LA-ICP-MS analyses of the pig sample from Klárafalva (KF6) demonstrated episodic spikes in lead, rather than uniformly elevated concentrations throughout the tooth. The Pb/Ca shows episodic intervals between high and low lead concentrations suggested exposure to contaminated environments—likely localized areas associated with metallurgical activity. It is possible that animals were kept closer to the activity for a certain period of time, during which they likely have been exposed to contamination through different pathways, from inhalation to ingestion of contaminated food.

	Pigs (*Sus scrofa*)	**Caprids (*Caprinae*)**	**Deer (Cervidae)**
min	0	0	0
max	4.2	6.2	2.1
std	0.89	0.81	0.51
mean	0.57	0.45	0.28

Table 10.2 Table presenting the minimum, maximum and standard deviation of Pb in enamel across taxa. The maximum value was recorded in caprids, while the minimum fell below detection limits for all species. Deer show the smallest range of variation, whereas pigs exhibit the largest, though the difference between pigs and caprids is relatively small

Variation is also evident within each species group (Fig 10.1). Across all three taxa, the data suggest a division into two broad clusters: one with higher lead concentrations (around 1 ppm and above) and one with low or undetectable levels (below 1 ppm). Although 1 ppm is not typically considered a high concentration of lead, it nonetheless indicates exposure, consistent with previously reported evidence (Tomažič 2025). Within the higher-lead cluster, a small number of individuals exhibit markedly elevated values of approximately 4 ppm. This group is dominated by pigs—three individuals fall around 3 ppm—while only two caprids show similarly elevated levels.

These groupings may reflect further differences in husbandry practices, possibly suggesting that certain animals were kept closer to metallurgical activity areas for extended periods. Confirming the results observed in the 2022 study.

However, the slightly elevated values observed in deer may indicate a change in deer habitat, possibly closer to activity zones. Alternatively, is it possible that the higher contamination reflects the localization of metallurgical activity, which would have contaminated surrounding soils and vegetation, ingested by the deer.

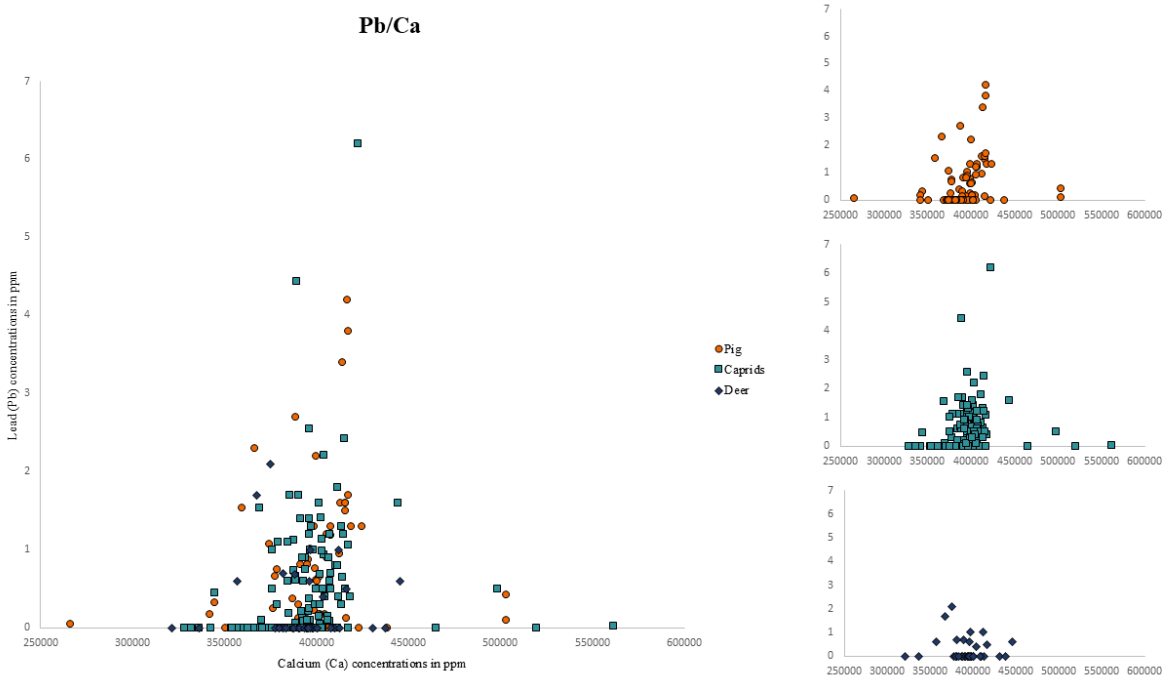


Figure 10.1 Lead and calcium ratios for all analyzed animal teeth, showing differences between species, but also intra-species variation

10.1.1.2 Ba/Ca Ratios

The Ba/Ca ratios show clear distinctions among the three animal taxa. Pigs exhibit the lowest Ba/Ca values (generally < 50 ppm) and form a relatively tight cluster. Deer also forms a tight cluster but at slightly higher values (50–100 ppm). Caprids, by contrast, display the widest range of variation (50–250 ppm), as shown in Figure 10.2.

When all species are combined (left side of Figure 10.2), some overlap becomes apparent. The most prominent overlap occurs between 50 and 100 ppm, where individuals from all three taxa fall within the same Ba/Ca range. This group is the largest and includes nearly all deer (n = 34), a small subset of pigs (n = 4), and a substantial number of caprids (n = 46).

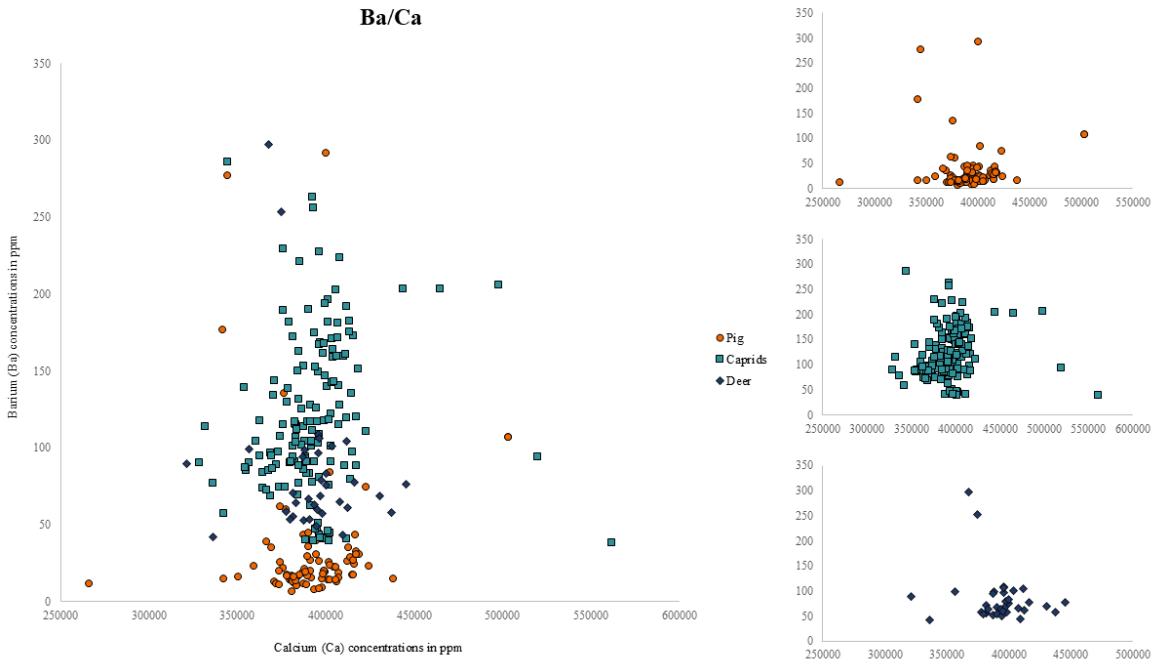


Figure 10.2 Ba/Ca scatter plot showing all data points from all taxa

As discussed above, the relationship between barium and calcium has long been used to infer diets (Austin et al. 2013; Clark et al. 2020), while in this study the Ba/Ca ratio explores dietary differences among pigs, caprids, and deer.

While elevated barium in plants can also result from growth in contaminated soils, particularly when concentrations exceed 200 ppm (Kabata-Pendias and Szteke 2015; Adriano 2001:178), this is an unlikely scenario in this dataset, as soil barium levels at the examined sites generally fall below 100 ppm (see Appendix B).

Thus, a likely interpretation of these results relates to differences in diet. Historical and ethnographic accounts from the study region indicate that pigs were often pastured in forest galleries (Egerszegi et al. 2003), where they would have consumed leaves, shrubs, and acorns—plant components known to contain higher barium concentrations than grains (Adriano 2001). Because barium levels vary not only between plant species but also among plant parts, pigs and some caprids—likely goats—foraging in these environments would be expected to show slightly elevated Ba/Ca values, perhaps closer to deer.

There is also a smaller group of outliers with elevated Ba/Ca levels for each taxonomic group. Four pigs show elevated barium levels (~135-291mg/kg). The outliers were samples KZ10-1123-0022, KZ3-1123-0020 KF16-1123-0019, and RA60-1123-0071. The KZ samples from Kiszombor, and were both animals between 3-4 years of age and the teeth did not appear damaged. As such, it is plausible that the elevated barium came from different dietary consumption, which warrants further investigation.

The Klárafalva sample on the other hand (KF) was one of the samples from the M1/M2 category. Considering that the tooth did not appear worn or damaged, it is possible that the animal was younger or the tooth was an M1, and as such it is likely that the sample captured the weaning stage of the animal. Finally, the sample from Rabe (RA) was noted to have been a younger animal and that the tooth was damaged. Thus it is possible that the elevated barium levels (176.7mg/kg) derive from both diet and contamination, thus masking the reason for the elevated levels, since the sample presents to be a slight outlier even in the calcium levels (341921.8mg/kg).

Similar to pigs, some elevated barium levels in caprids may reflect weaning (Austin et al. 2013). As several individuals appear to be relatively young (less than 12 months old), it is likely that they show some weaning signals (KF 16, 17; RA 37, 38, 39; RA33-1123-0062). For others, particularly those with elevated calcium levels, diagenetic alteration is the more likely explanation. Smith et al. (2018) note that high barium concentrations can result from diagenesis,

or from mixed signals in cases where post-depositional alteration obscures biogenic values. This is especially relevant for samples that were visibly fragile or damaged during preparation. The deer specimen from Klárafalva (KF 3), discussed in Tomažič (2025), illustrates this issue: LA-ICP-MS analysis revealed numerous structural cracks, raising concerns about enamel integrity suggesting that diagenetic processes may have contributed to its elevated barium levels.

10.1.1.3 P/Ca Ratios

Although animal teeth enamel structural integrity and diagenetic alteration have been mentioned throughout this section, the P/Ca ratios further illustrate the correlation between these elements (Figure 10.3). Alongside the taxonomic and intra-species variation discussed for the Pb/Ca ratios, several outliers appear with either unusually high or unusually low calcium concentrations. While calcium values vary slightly between species and individuals (Teruel et al. 2015), enamel typically ranges between 390,000 and 450,000 ppm. Deviations of roughly 10 percent or more above or below this range are likely attributable to diagenetic alteration.

Across all figures representing calcium, caprids show the highest number of individuals with probable diagenetic alteration, with values reaching 500,000–550,000 ppm. The outliers with higher calcium levels were: two samples from Rabe (RA44-1123-0052; RA37B) and one from Pecica (PE141-0424-0195). Two pigs (the same samples that were presented as outliers in Ba/Ca levels — KZ10-1123-0022 and KZ10-1123-0022) exhibit similarly elevated concentrations. Also questionable are samples with low calcium levels, like the sample PE76-0324-0097, which was deemed a fragile sample in the notes. This pattern likely reflects preservation issues, even if, unlike the pigs, the Ba/Ca ratios did not show such evidence. This highlights the importance of multi-element analysis.

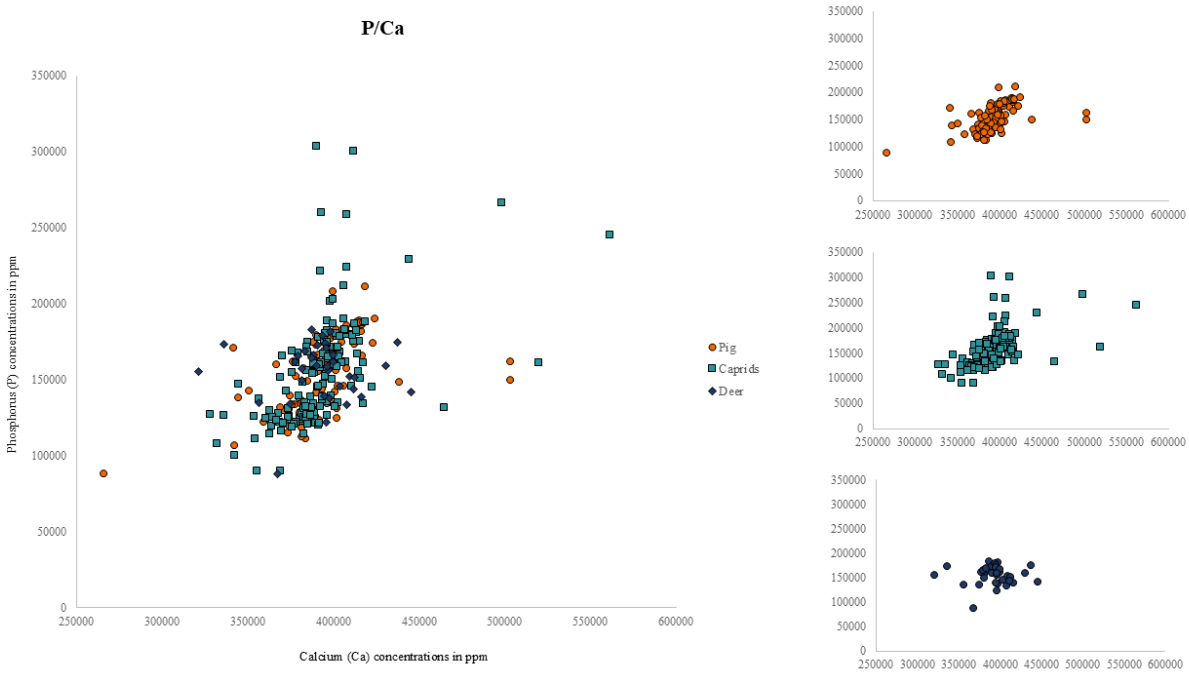


Figure 10.3 P/Ca scatter plot showing all data points from all taxa

10.1.2 Soils

Whereas the enamel analyses relied on element ratios already established in previous archaeological works, the soil analysis required the use of ecological approaches to assess the nature of contamination.

The samples were first categorized through granulometric analysis and classified as sandy, silty, or clayey (see Appendix B). These classifications were complemented by XRD results from five representative samples, which showed that the soils are primarily composed of quartz, calcite, dolomite, and gismondine, although the relative intensities of these minerals vary across samples (Figure 10.4).

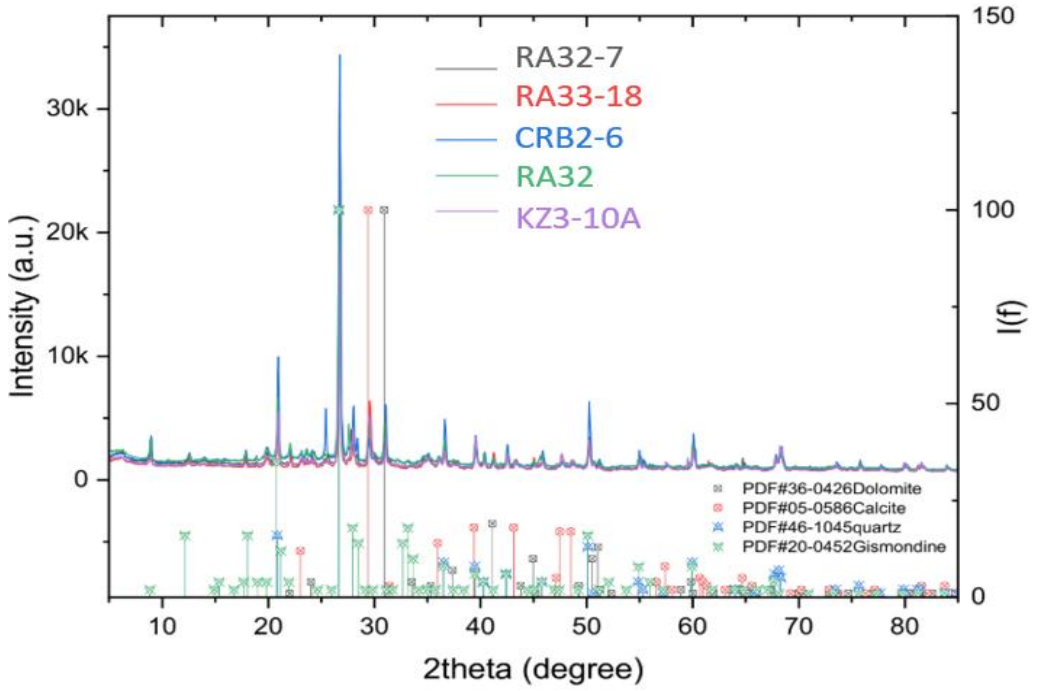


Figure 10.4 XRD results for five soil samples: three from Rabe (Core 32; Core 33, sterile deposit; and RA32, taken beneath the bronze fragment), one from Crna Bara (Test Unit 2), and one from Kiszombor (Trench 3)

While quartz, calcite, and dolomite are typical components of loess, the presence of gismondine is noteworthy. This mineral has been associated in some cases with metallurgical residues such as slag (Liu et al. 2021), suggesting that at least part of the soil matrix may reflect localized anthropogenic inputs.

The presence of gismondine possibly suggests remains of anthropogenic inputs, potentially metallurgical activity in the soil matrix. Considering this possibility, it is worth considering which elemental signatures correlated with human impact.

In their review, Bintliff and Degryse (2022) emphasize that certain elements are particularly informative for assessing human impacts on the environment in archaeological contexts, noting that some occur more prominently in specific archaeological settings and features, for example potassium being the most abundant in areas associated with manure deposits. Among the most commonly discussed elements were calcium, copper, lead, magnesium, potassium, sodium, phosphorus, and zinc.

Considering that only two elements out of the suggested Bintliff and Degryse list are presented in this study (copper and lead), I chose to combine elements that are deemed contaminants in ecological studies, along with some elements from Bintliff and Degryse (2022) list. Thus, in this study the focus is on P, Cu, Zn, As, Cd, Sn, and Pb.

Before assessing the elemental abundance and their impact on the environment, Principal Components Analysis (PCA) was performed to explore the relationships among these elements. This approach helps characterize covariance structures within the dataset and identify the dominant geochemical gradients across the sampled contexts.

10.1.2.1 PCA Results

The PCA was conducted on all suitable archaeological soil samples (n = 189). Samples from the A horizon, sterile deposits, and those exhibiting extreme values were excluded from the model. As PCA is built on variance and highly sensitive to extreme observations, I removed the samples to prevent disproportionate inflation in variation, to ensure that the components reflect the dominant geochemical structure of the dataset, rather than the outliers.

Out of the seven components, the first two principal components had eigenvalues of 3.44 and 1.13 and together explained 65.46% of the total variance (PC1 = 49.28%; PC2 = 16.18%). Subsequent components (each with a eigenvalue less than 1.0) accounted for 12% of the variance, as shown in the table (Table 10.3), and were therefore not used for interpretation.

Parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalue	3.4497	1.1326	0.8339	0.6964	0.538	0.2692	0.08029
% of Variance	49.2811	16.1799	11.9122	9.9487	7.6858	3.8453	1.1471
Cumulative (%)	**49.2811**	**65.461**	77.3732	87.3218	95.0077	98.8529	100

Table 10.3 The histogram for the PCA results with the principal components with associated Eigenvalues. The first to the left (the red column) shows the PC1, the one with the highest value which covered 49.28% of the variance

The two principal components reflected the correlation between different elements (Table 10.4), each presenting distinctive patterns.

Variable	PC1	PC2
P	0.889479	0.120897
Cu	0.77711	-0.079052
Zn	0.922353	0.087927
As	0.719904	-0.162296
Cd	0.679971	0.260312
Sn	**0.089524**	**0.831063**
Pb	0.463406	-0.565003

Table 10.4 Component matrix table, showing element loading for the two components

PC1 captures nearly half of the total variance (49.28%) and represents the dominant geochemical axis in the dataset. This component is strongly associated with elevated concentrations of Cu, Zn, Cd, and As (Figure 10.5), indicating a coherent anthropological heavy-metal enrichment signal. These elements commonly co-occur in anthropogenic activity generally, including in metallurgical residues, slag-affected soils, and areas influenced by burning, and pyrometallurgical activity, particularly Cu and Zn (Ottaway and Matthews 1988; Bintliff and Degryse 2022).

PC2 explains an additional 16.18% of the variance and is primarily structured by positive loadings for P, Cd, and Sb, and strongly negative loadings for Pb, with weaker contributions from the remaining variables. Of particular interest is the relationship between tin and lead. This axis likely reflects a second dimension of metallurgical activity differentiation, one that is strongly influenced by Sb and may indicate the presence of a distinct Sb-rich subset of samples.

The PCA score plot shows the distribution of samples in the graph. Because of the number of samples, their overlap and the outliers which compressed the image and made it hard to

distinguish along with masking the vectors, the image presented in the results were generated without outliers, while the ones with outliers[12] are presented in the Appendix C.

The graph without outliers present below (Figure 10.5) shows a clear dispersion of samples along PC1, with heavy metal enriched contexts clustering toward the positive end of the axis. Several samples (e.g., PE1-3, PE1-8, PE1-9) exhibit extreme positive PC1 values, indicating pronounced heavy-metal loading. In contrast, many RA-series and CRB-series samples cluster toward the negative PC1 region, consistent with lower metal concentrations. Variation along PC2 is more moderate. A subset of samples (e.g., KZ1-5C, KZ1-5D, KZ1-5E) plots toward the negative end of PC2, while others (e.g., RAss97, RAss107) show strong positive PC2 values, reflecting elevated P and Cd.



Figure 10.5 PCA plot shows samples plotted on the two principal components. Outliers are not included in this plot

In summary samples with high positive PC1 scores therefore likely reflect contexts with intensified anthropological input, whereas strongly negative scores correspond to relatively

[12] The outlier samples excluded from the PCA include cases such as RA32, which was taken from directly beneath a bronze fragment and exhibited extremely high concentrations of copper, zinc and tin. The position of RA32 was placed long the y-axis, showing a positive PC1 score, strongly aligned with the heavy-metal enrichment axis, with a even higher value than RAss 107 (represented in the Table 10.5), but similar patterns.

uncontaminated or background soils. PC2 scores on the other hand appear to differentiate tin contaminated samples from the rest.

10.1.2.2 Ecological Assessment

The PCA results indicate that Cu, Zn, Pb, and As form a coherent geochemical group associated with metallurgical production and its residues. To evaluate the environmental significance of the concentration of these elements, ecological studies have developed a series of quantitative metrics that assess the degree of metal input and its potential impact. Among the most widely used are the Enrichment Factor (EF) and the Ecological Risk index (Er), both of which allow the magnitude of anthropogenic influence to be monitored across contexts and elements (Zhao et al. 2022). In this study, EF and Er were calculated for Cu, Zn, Pb, and As to assess their environmental loading. The Enrichment Factor is defined by the following equation:

$$EF = (M/Y)\ sample/(M/Y)\ background$$

In this equation, M represents the concentration of the target element, while Y denotes the concentration of the element selected for normalization (Spahić et al. 2018: 208; Zhao et al. 2022). In this study iron (Fe) was chosen as the normalizing element because of its relatively stable concentrations in the analyzed soils, in comparison with calcium. Once the values are calculated, the anthropogenic impact is assessed using established EF categories: values between 1–3 indicate minor enrichment; 3–5 moderate enrichment; 5–10 moderately severe enrichment; 10–25 severe enrichment; 25–50 very severe enrichment; and EF values greater than 50 represent extremely severe enrichment (Spahić et al. 2018).

The ecological-risk results indicate anthropogenic enrichment for Cu, Zn, and As, although none of the elements reached extreme risk levels (Er > 50). Copper shows the highest environmental impact, with values ranging from moderate to severe. The only case of severe ecological risk was the experimental sample collected in 2022 from directly beneath a bronze sheet (RA32) during excavations at Rabe Anka Siget. This sample contained more than 134 ppm of Cu, demonstrating that copper readily leaches from bronze objects into surrounding sediments and confirming that Cu is a key element for assessing metallurgical influence in these soils.

Zinc is the second element showing notable enrichment, with most samples falling within the moderate category and a smaller subset—primarily from Pecica—reaching moderately severe levels (for levels indications and results see Appendix C). Lead, by contrast, remains within the minor-enrichment range, and arsenic does not exhibit meaningful enrichment in the examined contexts.

For the Ecological Risk index (Er), the risk posed by a single element is calculated according to the following equation:

$$Eir = Tir * Cir$$

In this equation, Tir represents the biological toxicity factor of each metal, a constant predetermined value. For the elements examined in this study, the toxicity factors are: As = 10, Cu = 5, Pb = 5, and Zn = 1. This factor is multiplied by Cir, the pollution coefficient, which is calculated as the ratio between the concentration of the element in the sample and its concentration in the reference material—in this case, the sterile deposit.

Overall ecological risk was low across the dataset, with only the copper-rich sample (RA32), collected as an experiment, exhibiting a high-risk value (coefficients are presented in Appendix C).

10.2 Site-Level Analysis

The site-specific analyses presented in this chapter compare the results from teeth and soils across sites. At this point of the analysis the sites are not presented according to time period[13] period. The first section highlights contamination patterns and identifying outliers across all the sites examined in this dissertation. While the second portion presents results from teeth and soil from each individual site.

10.2.1 Lead in Teeth

While the broader patterns revealed taxonomic differences—likely reflecting variation in diet, and the environments in which animals were kept—the box-plot results presented here illustrate differences in enamel lead concentrations by taxon and by site (Figure 10.6).

[13] All sites apart from Crna Bara–Prkos contain a Bronze Age component, while Pecica Şanţul Mare is the only site with both the Copper Age (MBA) and Bronze Age components.

The general pattern of pigs exhibiting the highest Pb concentrations becomes more complex when analyzed across sites. Kiszombor Új Élet shows both the highest values and the widest spread in pigs, although its mean remains just below that of Klárafalva Hajdova. At Klárafalva, pig values form a tight cluster with a single outlier (KF 6), previously analyzed by LA-ICP-MS and shown to reflect episodic lead contamination (Tomažič 2025). Pigs from Rabe display a slightly broader, but lower values than those from Klárafalva, indicating relatively low Pb values. The one sample from Majdan 28, shows low Pb concentration, while no contamination was detected in pigs from Crna Bara–Prkos. The majority of pigs from Pecica Şanţul Mare present no detectable lead, while three outliers exhibit elevated concentrations—some comparable to those recorded at Rabe or Klárafalva.

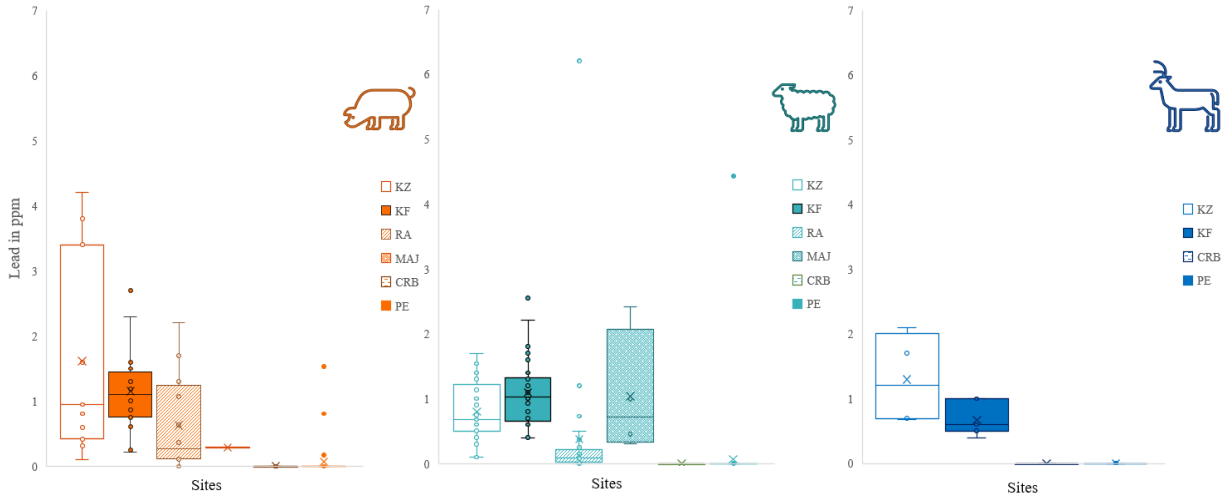


Figure 10.6 Box plots are separated by taxon—pigs on the left, caprids in the center, and deer on the right. Within each taxon, individual box plots represent the sites included in the analysis

The caprids present a different pattern from the pigs. While the highest lead concentration occurs in a caprid outlier from Rabe, sample RA36B, (a relatively young individual (approximately 15 months old) recovered from Test Unit 1a). The tooth was poorly preserved, which may explain the elevated value, as LA-ICP-MS analysis could not be performed due to its fragility. Majdan 28, with only four caprids, presented the largest spread. For example, sample number RA49-1223-0057 from Majdan 28, contained 2.42 mg/kg of Pb, while RA50-1223-0058 form the

same site measured 0.99 mg/kg of lead. Kiszombor and Klárafalva show relatively similar values, with Klárafalva slightly higher lead values for caprids, including one outlier.

Crna Bara and Pecica show no evidence of contamination in caprids, with the exception of a single Pecica specimen (PE93-0324-0125). This tooth was analyzed using LA-ICP-MS (Figure 10.7) and displays at least three major contamination events, visible as prominent Pb bands, along with several smaller episodes indicated by less intense bands.

The box plot for deer mirrors the general pattern observed in pigs, with Kiszombor samples showing both a wider spread and higher overall Pb concentrations. Klárafalva follows, as seen in the sample KF 1, which displays a slight, but not prominent increase in lead in the LA-ICP-MS trace-element map (Figure 10.8). In contrast, deer from Crna Bara and Pecica show no evidence of contamination. No deer teeth were recovered during the 2018–2022 excavation seasons at Rabe or Majdan 28.

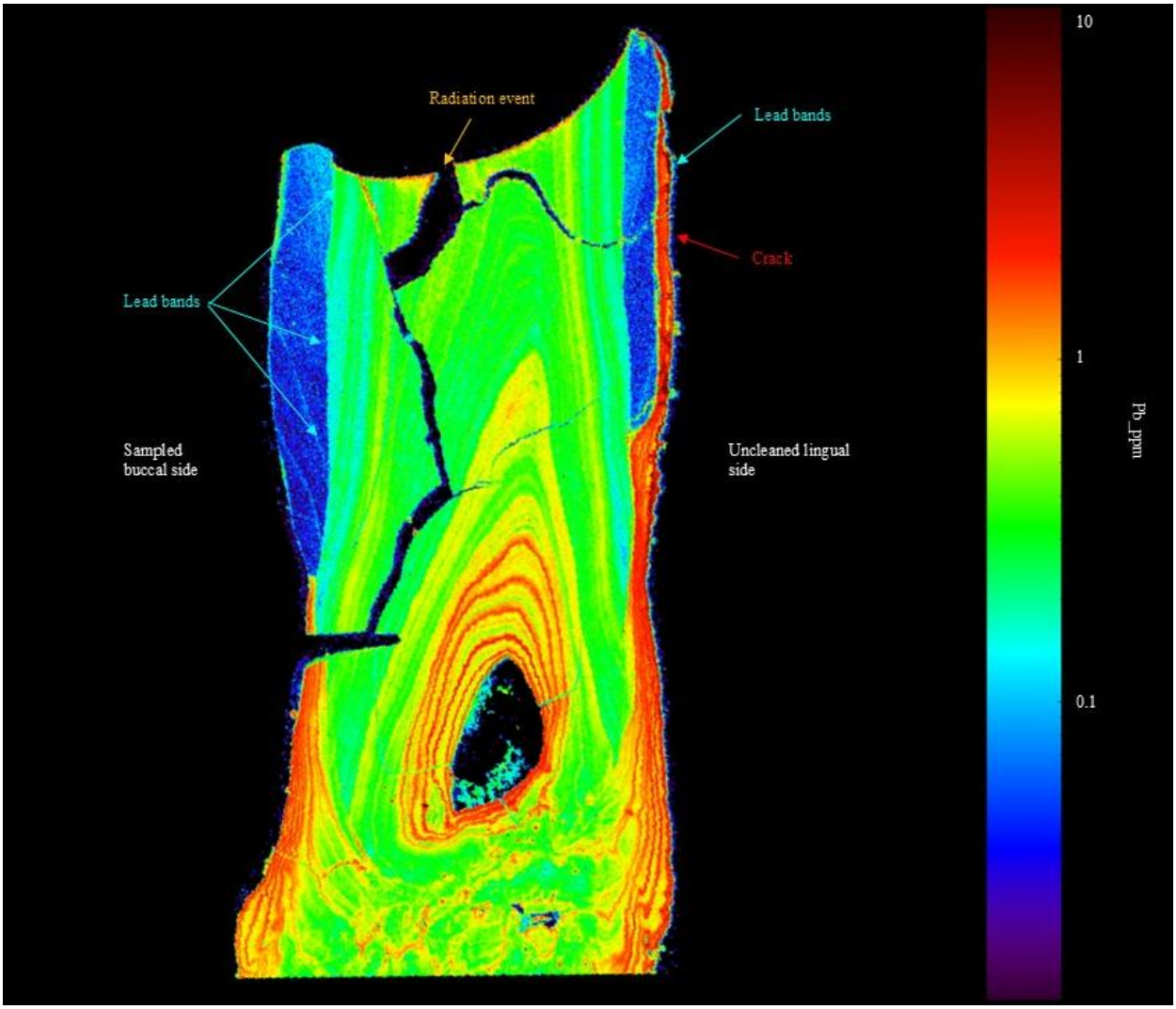


Figure 10.7 LA-ICP-MS trace-element map of the caprid tooth from Pecica Şanţul Mare. The image shows Pb concentrations normalized to Ca. The left side of the tooth surface displays evidence of mechanical cleaning, as well as the horizontal cut made during cleaning. This portion of the tooth has been embedded for ICP-MS analysis. Multiple cracks are visible, along the tooth with numerous layers of contamination within the root and dentin. Some of these layers are likely diagenetic in origin, as indicated by the absence of parallel or V-shaped growth-related patterns in the dentin and enamel, which normally appears with metabolic exposure. A distinct "radiation" type feature is also present on the crown, reflecting diagenetic alteration of the exposed dentin at the top of the tooth

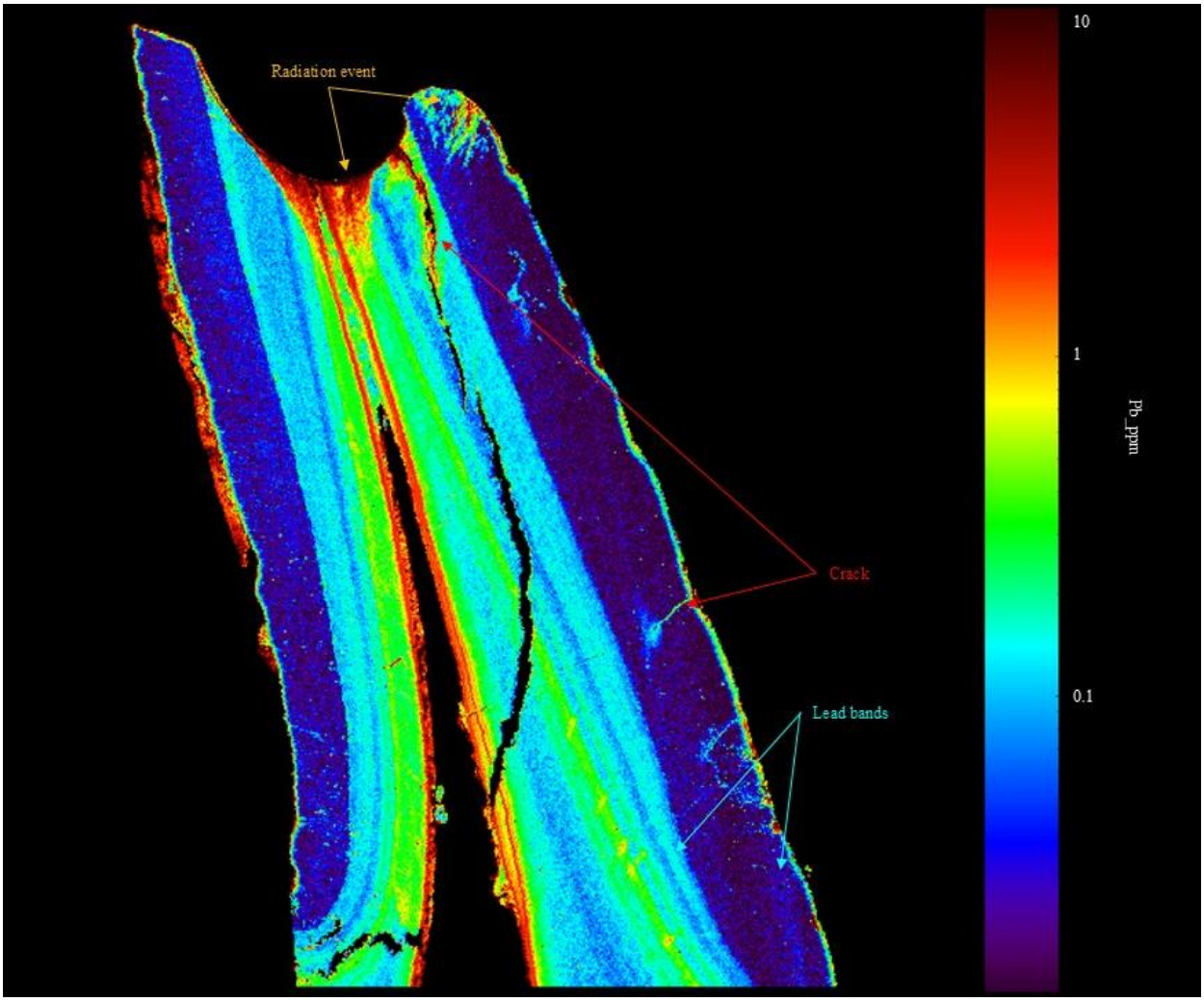


Figure 10.8 Trace-element map of sample KF 1. The specimen is RM2, and out of the entire tooth, only the right side of the tooth was analyzed. The map shows several radiation-type features, visible as orange areas, Pb-rich bands marked with blue V shaped patterns, along with minor cracking. The deer presents slight lead contamination toward the end of the enamel formation

10.2.2 Copper Concentrations in Archaeological Deposits

By comparing copper concentrations across archaeological contexts at all sites, it is possible to identify which sites exhibit the highest levels of Cu contamination and therefore provide the strongest evidence for metallurgical activity.

For soils, background Cu levels in sterile deposits are consistently low across all sites, typically ranging from 3–6 ppm. However, certain samples, such as RA32 from the Main Block at Rabe Anka Siget (excavated in 2022), contained exceptionally high copper concentrations. This

sample demonstrates that Cu can leach directly from metal objects into adjacent sediments, reinforcing the need to interpret copper enrichment relative to each site's local background.

When archaeological deposits across sites are compared, the results for copper align with expectations: as shown in the box-plot in Figure 10.9; Pecica Şanţul Mare far exceeds all other sites in copper concentrations. This outcome is consistent with decades of excavation and scholarship indicating that Pecica was one of the major centers of Bronze Age metallurgical production in the region (O'Shea 2005; O'Shea and Nicodemus 2019; Găvan 2015; Gogâltan and Găvan 2023).

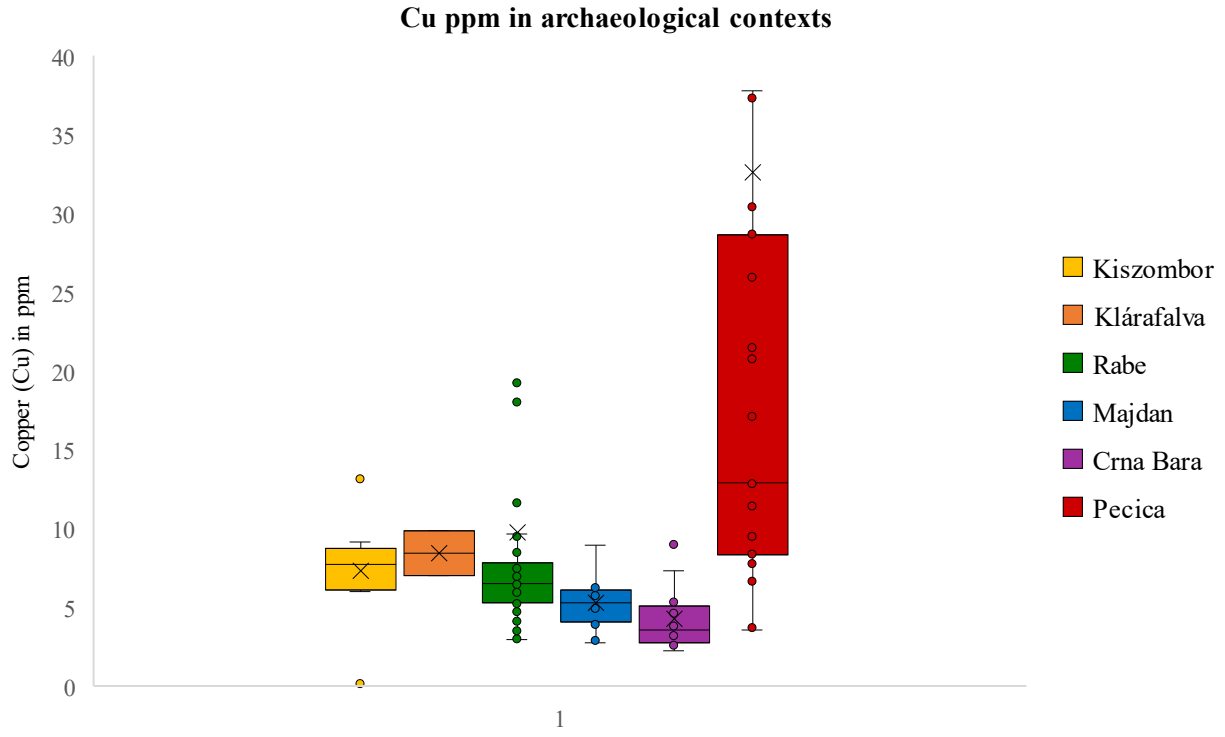


Figure 10.9 Box plot of copper concentrations from all soil samples taken from known archaeological contexts

The remaining sites show markedly lower copper concentrations, with values clustering tightly and with similar site averages and medians. Crna Bara exhibits the lowest Cu levels overall, with a single outlier originating from Step 9 of the profile - the last disturbed horizon before intact archaeological deposits. The large number of bullets in the upper centimeters of the profile

suggests that this outlier might reflect recent contamination and should therefore be interpreted with caution.

Klárafalva and Kiszombor rank second and third after Pecica in terms of Cu enrichment. Kiszombor displays two outliers: one elevated value from Trench 5, Layer B, and one unusually low value from Feature 11, which has been interpreted as the floor of a structure (O'Shea in press).

Rabe presents an interesting case, as copper concentrations indicate substantial differences between samples. The site also contains several outliers, the most notable being one sample from the Main Block (RAss34) and another from Test Unit 3 in the eastern portion of the site, originating from Layer F — lowest cultural deposit before sterile, approximately 1 m below the surface. The unit contained Feature 35—a circular 'clay ring' with a radius of 30 cm (see Test unit 3 report in Appendix A). The feature included two complete two-handled small jugs and three cattle horns filled with a dark, bitumen-like substance, although no further analyses of this material have yet been conducted. The elevated copper values in this context suggest that small-scale metallurgical activity may have taken place during the formation of this deposit.

Majdan 28 shows even lower levels of copper concentration. A single slag fragment recovered from the fill of Feature 42 (see site report for TU4 in the Appendix A) demonstrates that metallurgical processes were present in the area. The pit, Feature 42, was associated with a thermal feature and it likely represented a waste pit, where all the deposits from the thermal feature were placed.

10.2.3 Soil Contamination by Site

Enamel samples in this section will be compared for each to site, meaning all taxa will be grouped according to site. For soil samples the main element of analysis is copper. To evaluate whether copper migrated through different stratigraphic layers, one soil core from each site was selected (or in the case of Majdan 28, a stratigraphically ordered set of samples including both A horizon and sterile deposits). Copper mobility was assessed using the following formula, which quantifies anthropogenic enrichment above natural levels (Alloway 2013):

$$Cu\ excess\ =\ Cu\ sample\ -\ Cu\ background$$

Background Cu values in sterile deposits varied between sites. Ranging from a maximum of 2.1 ppm at Rabe Anka Siget to a minimum of 0.16 ppm at Crna Bara–Prkos. This variation likely reflects differences in the geochemical composition of loess derived sediments (Buggle et al. 2008; Muhs 2018; Rubinić et al. 2018; Fenn et al. 2025). While loess deposits cover the entire Carpathian Basin, thus encompassing all sites under analysis, the pedological properties of loess composition differs, due to age and type of accumulation, Fe-oxide accumulation, carbonate leaching, and hydrological conditions, which influence geochemical baselines even within a material often perceived as homogeneous (Pécsi 1990). Thus, copper values for the background are calculated for each site separately.

Excess copper was defined as values exceeding background by approximately +5 to +10 ppm, while values around 4–6 ppm were considered within the expected background range. Copper mobility is generally low in fine-textured soils such as clays and silts, and the results from all sites indicate very limited vertical movement, typically restricted to only a few centimeters. This limited mobility may be further explained by the strong presence of Fe oxides, which are known to bind copper effectively and reduce its vertical transport (Adriano 2001; McBride 1994; Sauvé et al. 2000).

In addition to copper, tin also leached from the experimental sample RA32. Although tin showed only a weak correlation in the PCA models, it remains archaeometallurgically significant as a temporal technological marker for the study region (Powell et al. 2018; Kiss 2020:320) and environmental pollutant (Liu et al. 2021). Nevertheless, tin concentrations in the dataset were low, with only a small number of samples registering values above zero (Appendix C). These occurrences will be discussed in detail on a site-by-site basis. For the next section, the results from all tested materials (teeth and soil) is combined to evaluate the overall level of contamination at each site.

10.2.3.1 Kiszombor Új Élet

The animals from Kiszombor show a wide-spread in values, particularly the pigs (Figure 10.10). Several outliers with high calcium likely reflect diagenetic alteration, as discussed in the general patterns section. Overall, both pigs and deer at Kiszombor form two distinct groups—one

with elevated lead contamination and one with low levels. The caprids present a similar, though less visually pronounced groupings.

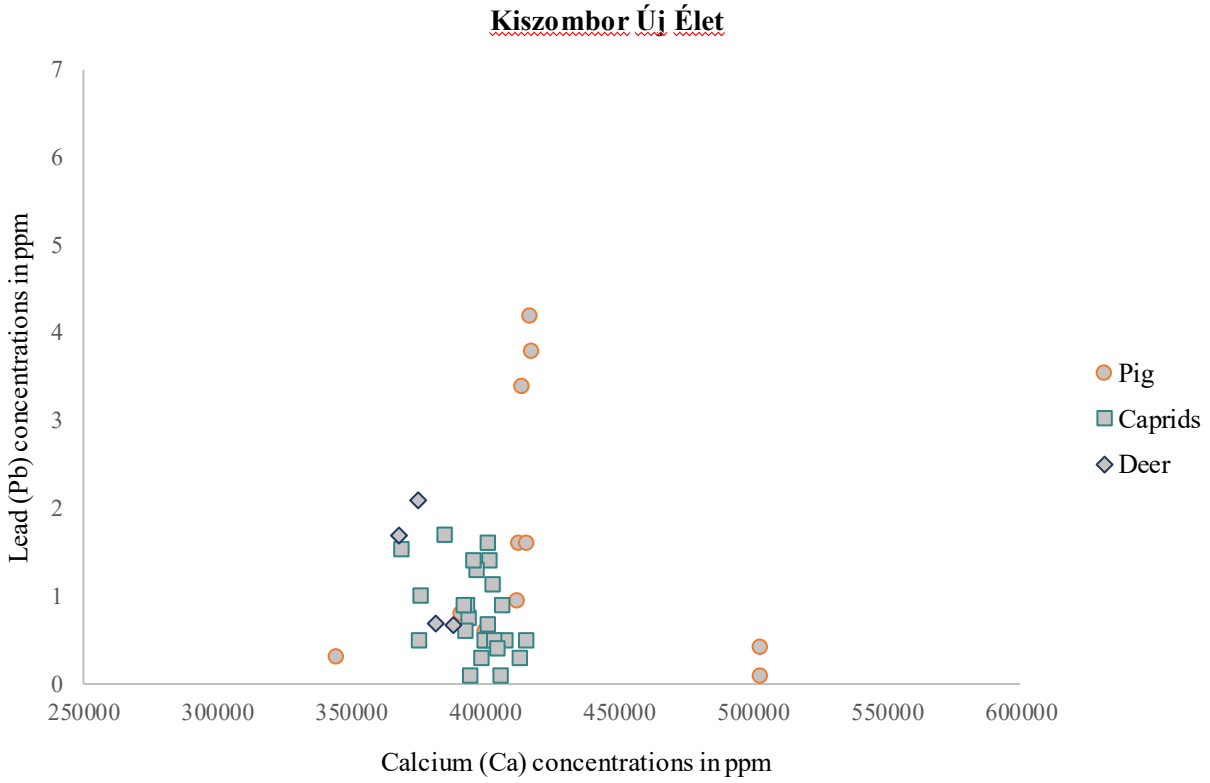


Figure 10.10 Scatter plot showing teeth samples from Kiszombor

The soil core analyzed from Kiszombor was taken from Trench 1 (Table 10.4). These samples come from an existing collection dated to 1989, and no primary sampling at the site was conducted within the scope of this study. For this reason, the results must be interpreted with caution. Even so, the pattern is informative: the core shows copper enrichment in the A horizon and in the deposit immediately beneath it, followed by a sharp decline in sample 5C. This distribution likely reflects agricultural disturbance rather than other forms of anthropogenic activity, with plowing mixing Cu-bearing sediments into the upper horizons and leaving deeper deposits relatively unaffected.

In contrast, archaeological soil samples from Kiszombor taken from multiple locations across the site show consistently elevated copper concentrations. Values range from a minimum of 0.13 mg/kg in the sample from Feature 11—the first layer of a house floor—to a maximum of

13.16 mg/kg in sample KZ5-54 from Trench 5, Layer B. The second-highest value, 9.14 mg/kg, comes from the ditch (sample KZD-64). Across all archaeological deposits at Kiszombor, the average Cu concentration is 7.3 mg/kg which shows the likely presence of some metallurgy.

Kiszombor Új Élet						
Sample lab ID	**Location**	**Depth of sample below surface**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
KZ1-5A	Tr. 1	/	Core in Tr. 1	A horizon	9.61	**7.24**
KZ1-5B	Tr. 1	/	Core in Tr. 1	cultural	8.48	**6.11**
KZ1-5C	Tr. 1	/	Core in Tr. 1	cultural	4.17	**1.80**
KZ1-5D	Tr. 1	/	Core in Tr. 1	cultural	3.10	**0.73**
KZ1-5E	Tr. 1	/	Core in Tr. 1	cultural/sterile?	2.37	**0.00**

Table 10.5 Table showing the details about the soil core from Kiszombor, along with the excess copper calculations

10.2.3.2 Klárafalva–Hajdova

The animals from Klárafalva show a pattern broadly similar to that observed at Kiszombor. Pigs again form two distinct groups—one with low lead concentrations and one with markedly higher values. Caprids display generally higher contamination levels and a wider spread, suggesting that they may also fall into comparable subgroups, although the division is less sharply defined than in pigs. Deer exhibit a similar two-group structure, but the contrast between low and high values is far more muted than in the domesticates (Figure 10.11).

Only two soil samples were available for sampling from Klárafalva. Similar to Kiszombor, all soils were subsampled as part of the museum collection, and both samples derive from archaeological contexts; consequently, no background or A horizon deposits were available for analysis, preventing the determination of copper excess for the site. The two samples show copper concentrations ranging from 7.04 to 9.87 mg/kg. These values closely match the archaeological soil concentrations observed at Kiszombor, suggesting comparable levels of Cu enrichment at both sites.

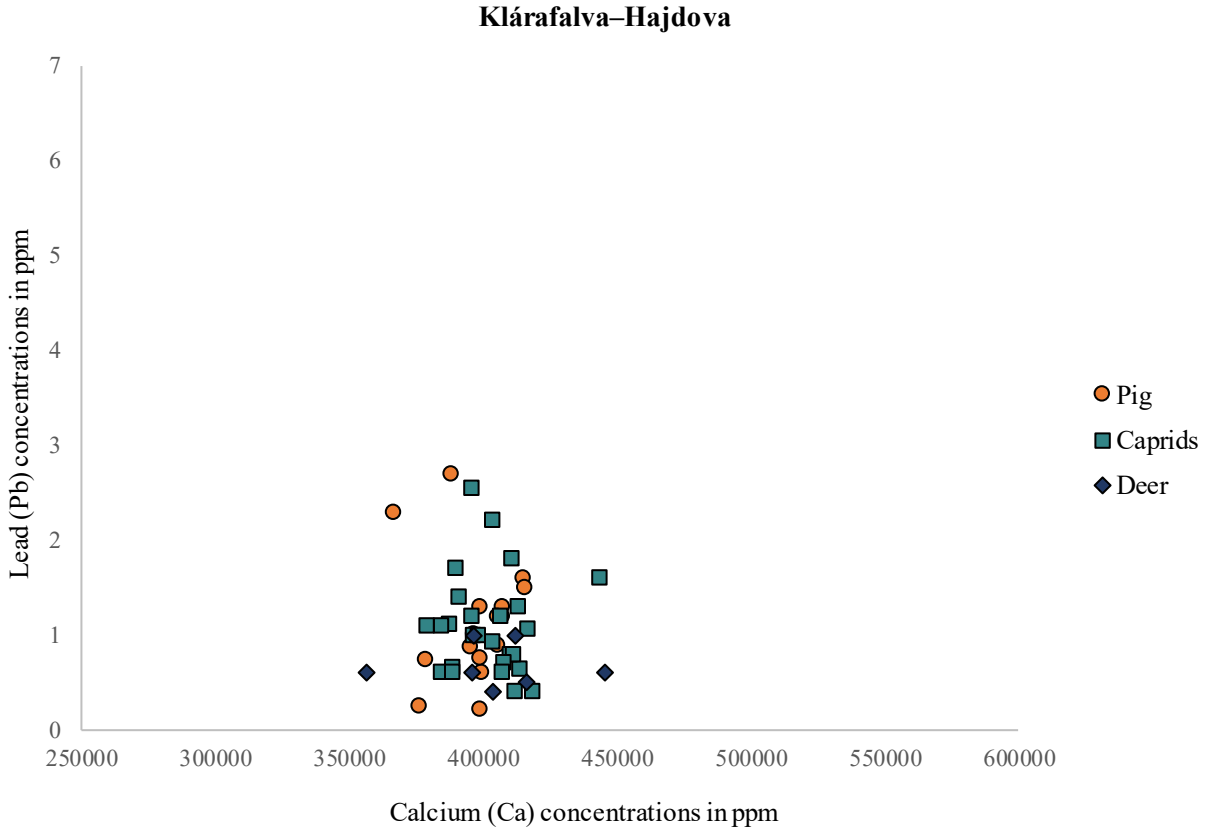


Figure 10.11 Scatter plot showing teeth samples from Klárafalva

10.2.3.3 Rabe Anka Siget

During the 2018 and 2022 excavation seasons, only a limited number of teeth suitable for sampling were recovered from Rabe Anka Siget. To increase the sample size—and because no deer were retrieved during these seasons—cattle teeth were used as a proxy for the environmental contamination. These individuals likely reflect the broader pasture-land baseline rather than conditions in the immediate site vicinity. The results showed consistently low lead concentrations in cattle.

Other domesticates—pigs and caprids—display a pattern similar to that observed at Kiszombor and Klárafalva. Pigs show generally elevated Pb values (average of 0.6 mg/kg), in comparison to caprids (average of 0.3mg/kg). However, caprids form notable outliers, some showing high levels of lead, including the sample RA36B with 6.2 mg/kg of lead; while others exhibit diagenetic signatures, with two individuals showing calcium concentrations exceeding 500

000 mg/kg (RA44-1123-0052 and RA37B), indicating post-depositional alteration rather than true biogenic uptake (Figure 10.12).

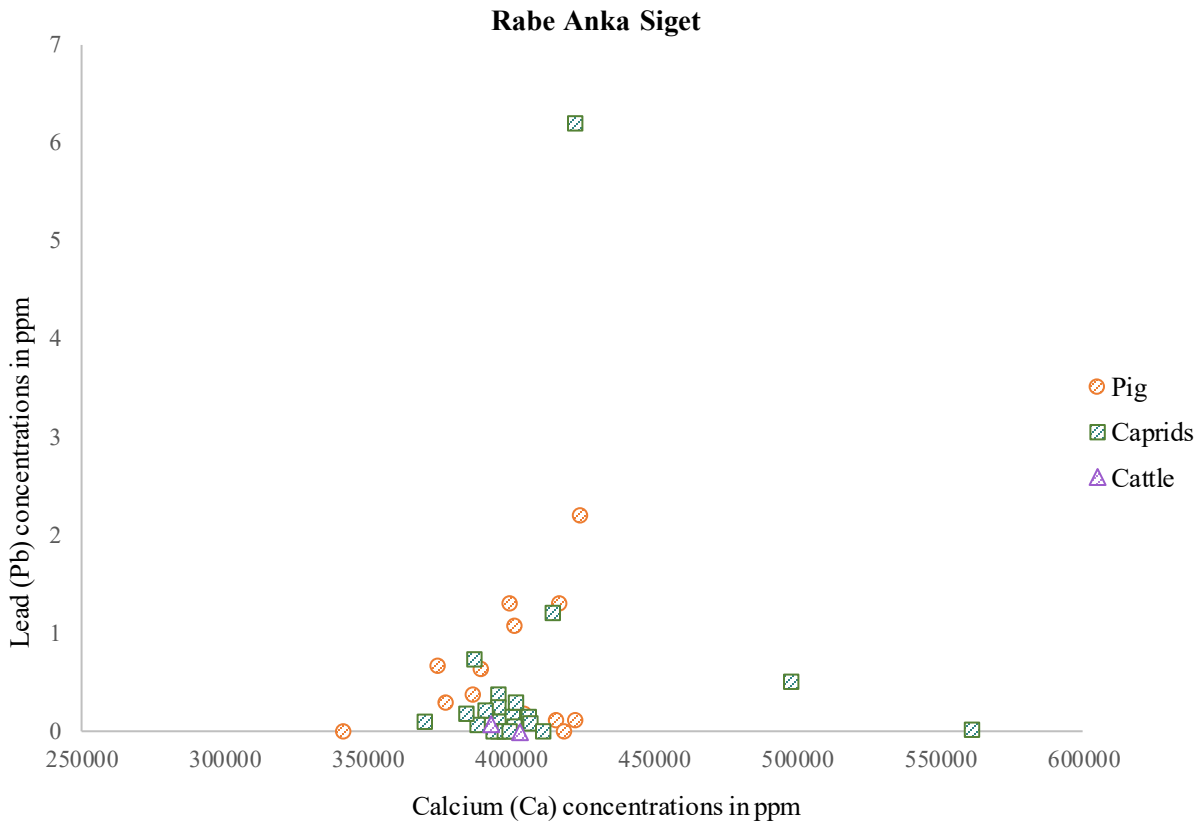


Figure 10.12 Scatter plot showing teeth samples from Rabe Anka Siget

A total of 32 soil cores were taken at Rabe Anka Siget. After the initial round of analyses, only selected samples were subjected to full geochemical testing. Across all sterile deposits, the combined average copper concentration is 3.16 mg/kg, with a standard deviation of 2.1 mg/kg. To assess copper mobility, Core 33—taken from the western tell in a forest gallery near the Main Block and close to the location of the experimental sample RA32—was selected for detailed examination. This core was intentionally selected to evaluate A horizon Cu levels in a forest gallery west from the Main Block site area, as the levels were ~4mg/kg lower than those in the disturbed zones elsewhere on the site.

Within Core 33, the results (Table 10.5) show some—but generally low—evidence of anthropogenic activity. The highest copper excess occurs in sample RA33-3, taken from a possible pit feature at a depth of 49 cm. Below this point, copper contamination decreases sharply. This pattern suggests a possible localized episode of activity associated with the pit feature rather than widespread copper excess across the profile.

Rabe Anka Siget						
Sample lab ID	**Location**	**Depth**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
RA 33-0	West tell - forest	20 cm	Core 33	A horizon	6.50	**3.31**
RA 33-3	West tell - forest	49 cm	Core 33	disturbance/pit?	8.28	**5.09**
RA 33-7	West tell - forest	82 cm	Core 33	cultural	6.31	**3.12**
RA 33-11	West tell - forest	118 cm	Core 33	disturbance/pit?	4.78	**1.59**
RA 33-13	West tell - forest	133 cm	Core 33	cultural	4.56	**1.37**
RA 33-17	West tell - forest	167 cm	Core 33	cultural	4.30	**1.11**
RA 33-18	West tell - forest	184 cm	Core 33	sterile	3.19	**0.00**
RA32	*West tell – Main Block*	*25 cm*	*Special sample*	*Underneath bronze fragment*	*134.83*	***131.64***

Table 10.6 Copper excess results calculated from the copper values analyzed from samples taken from core 33 from Rabe Anka Siget

Soil samples collected during the 2018 and 2022 excavation seasons at Rabe Anka Siget show elevated copper values, with the highest detected in the experimental sample RA32 with a copper excess of 131.64 mg/kg, which also contained elevated tin (1.23 mg/kg). Following by drastically lower values —around 20 mg/kg in samples RATU3-17 and RAss34. Copper and tin levels were also notable in sample RAss97 (7.27 mg/kg of copper and 7.6 mg/kg of tin) taken from Layer B of the main excavation unit beneath a 'fish plate.'

The remaining archaeological samples from Rabe average 9.7 mg/kg of copper. The lowest value, 2.98 mg/kg, comes from sample RATU3-6, taken from Layer F in TU3 in the eastern portion of the site. Notably, another sample from the same stratigraphic unit—RATU3-17, collected near burned Feature 35—shows a much higher Cu concentration of 19.31 mg/kg, with tin levels just above 0 (0.14mg/kg).

The results from Rabe demonstrate that the magnitude of copper leaching from metal objects into adjacent sediments provides a clear interpretive threshold: Cu concentrations exceeding approximately 5 ppm above background are likely to reflect anthropogenic inputs, most plausibly linked to metallurgical activity, as also indicated by the PCA model. Furthermore, across all sites examined, Rabe reports the highest tin concentrations in archaeological soils, particularly in samples from Layers A and B from the Main excavation block. It appears that the metallurgical activities at Rabe were localized, while adjacent sediments remained comparatively unaffected.

10.2.3.4 Majdan 28

Site of Majdan 28, located southwest of Rabe Anka Siget, and Rabe Anka Siget are due to their proximity likely related. Samples from Majdan 28 excavated during the 2022 field season were collected from TU4 (see Appendix A for TU4 reports). Animal remains were scarce, and even fewer teeth were suitable for geochemical analysis (n=5). While this number is insufficient to establish a site-based pattern, when considered alongside the trajectories observed at other sites, Majdan 28 appears to follow a similar trend determined at Kiszombor, Klárafalva and Rabe, showing two groups with caprids, one of which has comparatively higher lead values (2.24mg/kg of lead) (Figure 10.13).

Only a single pig was recovered, and the sole tooth available for sampling was an M1. This specimen shows a low lead signal, consistent with the expectation that first molars capture early-life exposure and may not reflect later contamination events.

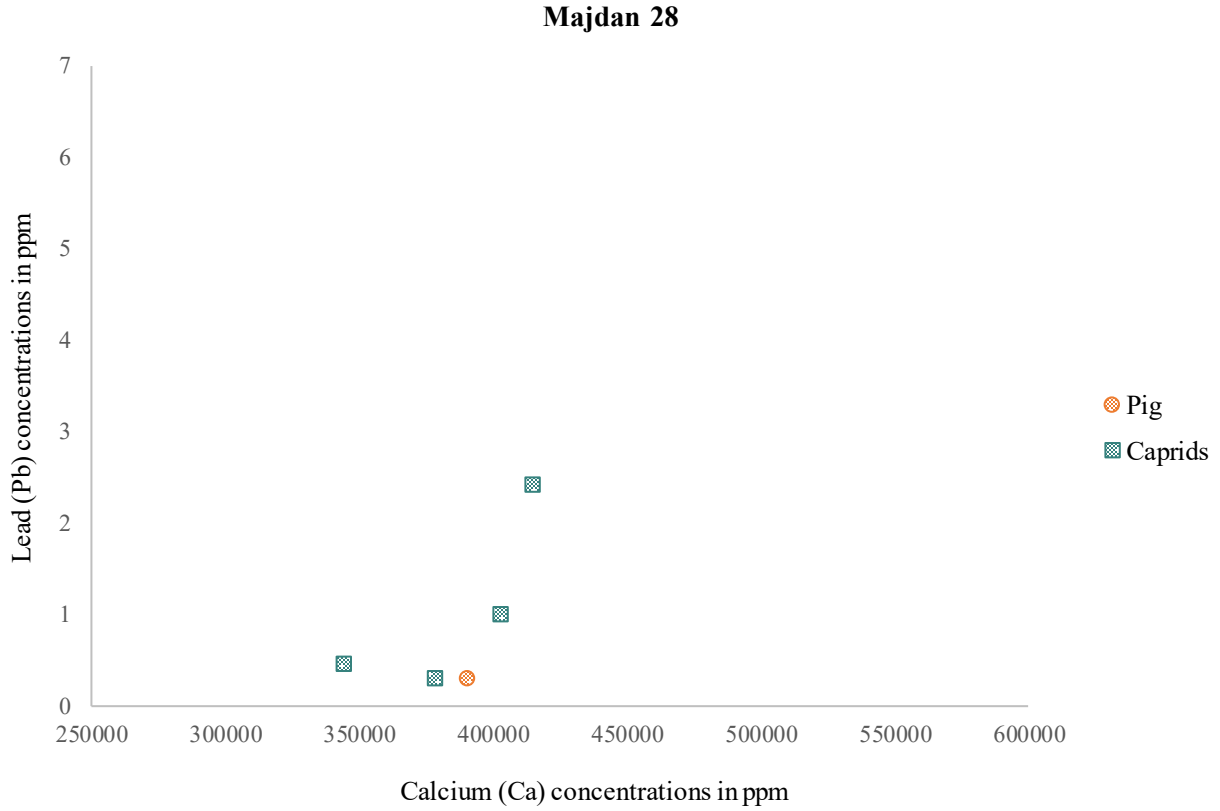


Figure 10.13 Scatter plot showing teeth samples from Majdan 28

Samples taken from the stratigraphic sequence in the test unit at Majdan 28 (Table 10.6) show very low copper excess throughout the profile. Most detectable contamination derives from the A horizon, which is consistent with agricultural disturbance rather than *in-situ* metallurgical activity.

Soil samples collected during excavation of the TU4 showed a minimum contamination of 2.71mg/kg of copper taken from pit fill feature 40 (sample Maj 125). This feature was a relatively shallow pit feature, which contained a large brazier.

The highest copper contamination was from the core 8 (Maj 8-1), with 9.66mg/kg (copper excess 3.58mg/kg) and 0.82mg/kg of tin. This sample came from Feature 42—a pit interpreted as a waste pit likely associated with the thermal feature in Layer A. While presenting a relatively small amount of contamination with copper, the detected tin represented the third-highest tin value across all sites, making Rabe and Majdan 28 the only sites with higher tin concentrations in soils.

Majdan 28						
Sample lab ID	**Location**	**Depth of sample below surface**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
Maj 1	TU4	20 cm	A horizon	A horizon	10.18	**4.10**
Maj 94	TU4	30cm	Layer A	cultural	2.90	**-3.18**
Maj 3	TU4	50 cm	Layer B	cultural	6.04	**-0.04**
Maj 100	TU4	55 cm	Layer C	cultural	5.19	**-0.89**
Maj 5	TU4	66cm	Layer D	cultural	3.95	**-2.13**
Maj 7	TU4	100 cm	sterile	sterile	6.08	**0.00**
Maj 8-1	*Core 8*	*64 cm*	*pit fill*	*cultural*	*9.66*	***3.58***

Table 10.7 Copper excess results calculated from the copper values analyzed from samples taken from TU4 from Majdan 28

10.2.3.5 Crna Bara–Prkos

Teeth from Crna Bara–Bara–Prkos were collected during the excavation of Test Units 1 and 2 and from the east-facing mound profile during the 2023 field season. None of the analyzed specimens showed evidence of lead contamination (Figure 10.14).

A total of nine cores were collected from the Crna Bara–Prkos site, while sterile deposits were reached only during the excavation of the test units and during the cleaning of the east-facing profile. To calculate the evidence for excess copper, samples were taken from Test Unit 1, located southeast of the mound (Table 10.7). Copper enrichment in this unit is very low overall, with the sterile deposit containing only 1.86 mg/kg Cu, and A horizon of 4.98mg/kg. The low contamination in the A horizon reflects the position of the test unit, located outside of the direct agricultural disturbance. In comparison, Test Unit 2, which was located closer to the disturbance area, showed elevated levels of 8.43mg/kg of copper, while the sterile remains low at 2.66mg/kg.

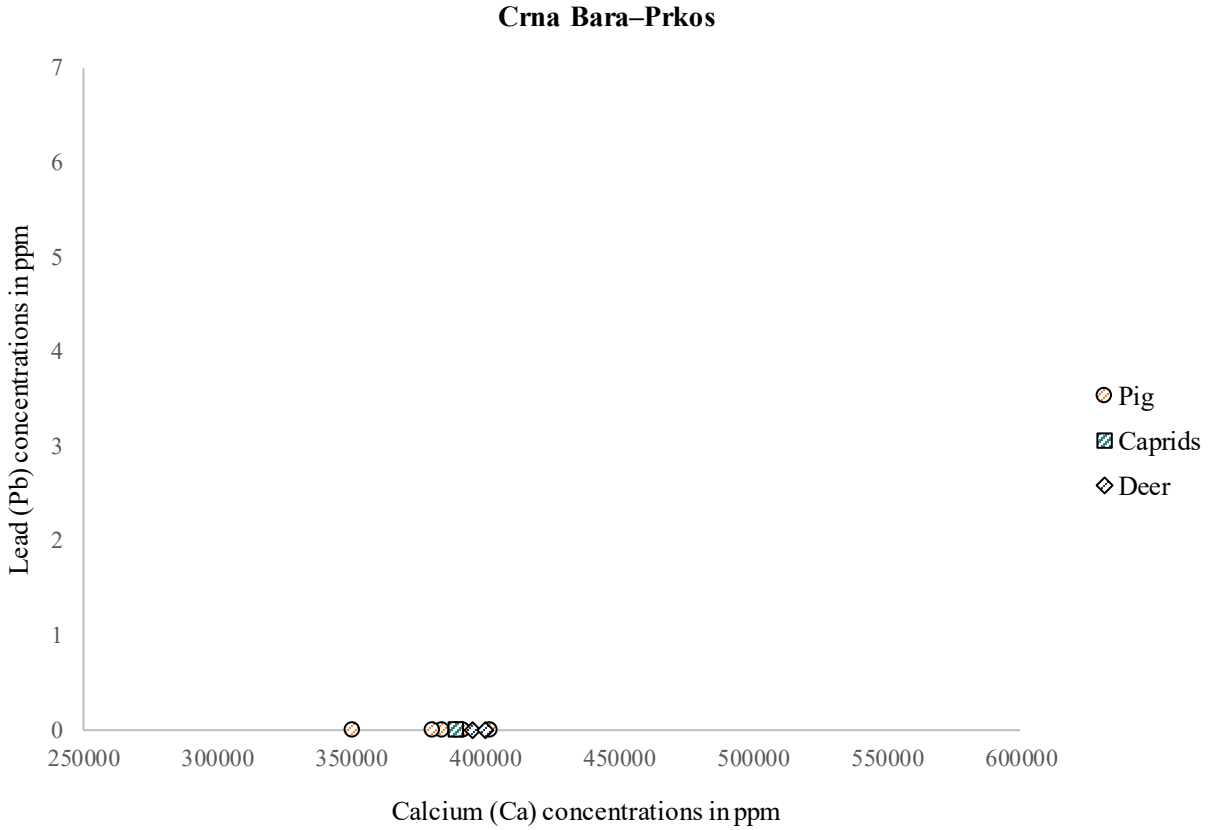


Figure 10.14 Scatter plot showing teeth samples from Crna Bara–Prkos

Within the cultural deposits at Crna Bara–Bara–Prkos, copper contamination remains low overall. The minimum value, 2.22 mg/kg, comes from Profile Step 11, Layer 5. The highest copper concentration (8.98 mg/kg) was recorded in Step 9, Layer 2. This elevated value is likely attributed to the fact that the upper two layers in this profile were redeposited and therefore not archaeologically in situ. Importantly, the first intact archaeological layer (Layer 3 in Step 10) also shows moderately elevated copper at 7.3 mg/kg, indicating that some Cu enrichment is present within the first undisturbed deposits, which then drastically drops to 2.61mg/kg within the sample taken from Step 10, under the house floor found in the east-facing profile.

Across all intact cultural layers, the average copper concentration is 4.25 mg/kg, with a standard deviation of 1.99 mg/kg. This relatively tight distribution suggests limited variability and supports the interpretation that copper inputs at Crna Bara–Prkos were low and spatially constricted to the disturbance across the site.

Crna Bara–Prkos						
Sample lab ID	**Location**	**Depth of sample below surface**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
CRB1-1	TU1	10 cm	TU1; Layer 1	A horizon	4.98	**3.12**
CRB1-2	TU1	30 cm	Layer 1	cultural	3.56	**1.70**
CRB1-3	TU1	57 cm	Layer 2	cultural	3.18	**1.32**
CRB1-4	TU1	77 cm	Layer 3	cultural	3.22	**1.36**
CRB1-5	TU1	111 cm	TU1	sterile	1.86	**0.00**

Table 10.8 Copper excess results calculated from the copper values analyzed from samples taken from TU1 at Crna Bara–Prkos

10.2.3.6 Pecica Şanţul Mare

The teeth samples from Pecica, incorporating both Copper and Bronze Age specimen, show generally low levels of lead contamination stored within the enamel. Only a few outliers in domesticates, particularly pigs, show elevated levels (Figure 10.15). The three pig outliers present elevated lead levels, with the highest exceeding 1mg/kg. One pig specimen also shows poor preservation, as indicated by unusually low calcium concentrations, which may affect the reliability of its Pb measurement. Among the caprids, only a single sample presents elevated lead levels; this is the specimen illustrated in Figure 10.7, analyzed using LA-ICP-MS.

A total of 18 cores were collected at Pecica and its immediate surroundings during the 2005-2006 field seasons by Dr. Sarah Sherwood [14], who provided the samples for subsampling.

For the present study, only selected samples—primarily from Cores 1–10—were analyzed. Among all sites examined, Pecica exhibits the highest copper concentrations, with the most pronounced contamination recorded in Core 8 (Table 10.8), taken from the main tell (O'Shea et al. 2005). This core shows a distinct peak in copper concentration between 125–142 cm, indicating a period of intense anthropogenic activity, followed by persistently elevated values down to approximately 240 cm.

[14] Dr. Sarah Sheerwood sent the samples to the University of Michigan and kindly authorized me to analyze these samples; thus all soil descriptions and depths derive from her field notes.

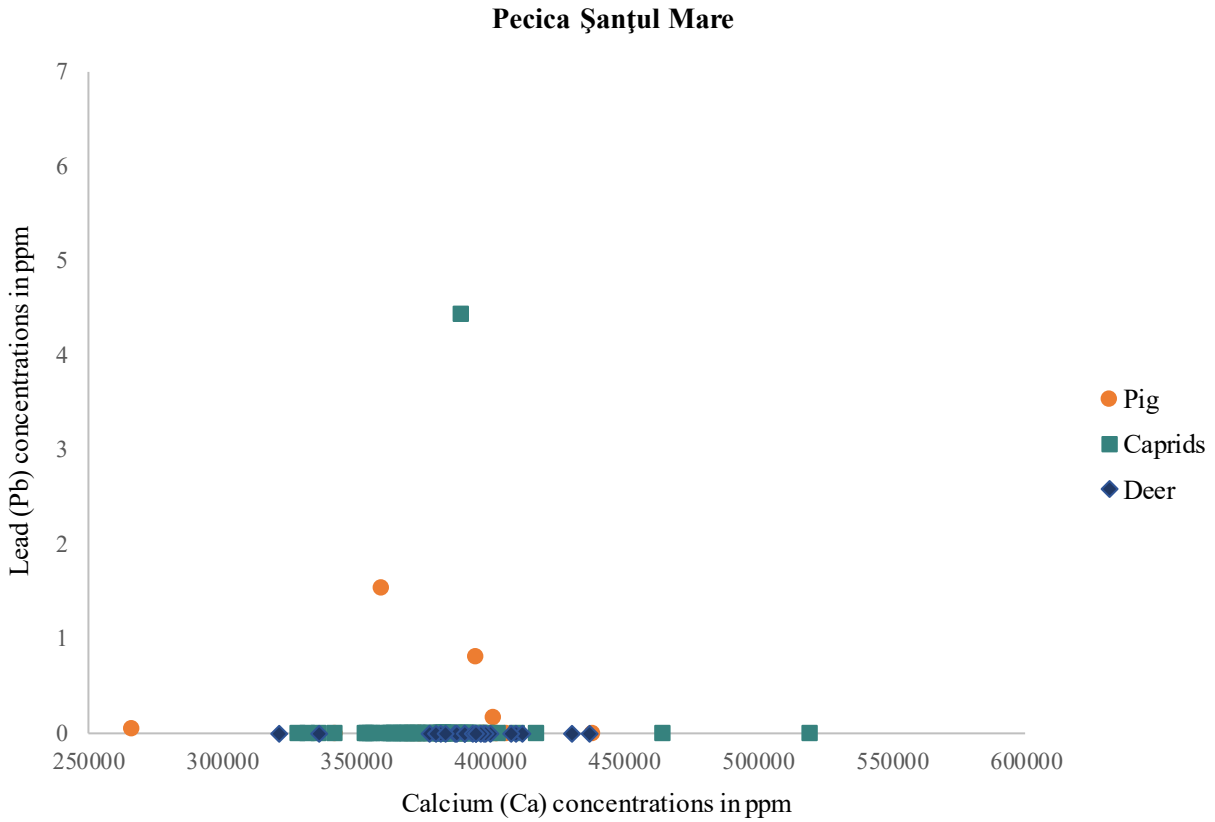


Figure 10.15 Scatter plot showing teeth samples from Pecica Şanţul Mare

Pecica Şanţul Mare						
Sample lab ID	**Location**	**Depth of sample below surface**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
PE2005-8-2	Main Block	20-40 cm	Core 8	A horizon	7.68	**4.01**
PE2005-8-6	Main Block	125-142 cm	Core 8	cultural	12.91	**9.24**
PE2005-8-9	Main Block	160-180 cm	Core 8	cultural	9.50	**5.83**
PE2005-8-11	Main Block	208-240 cm	Core 8	cultural	8.71	**5.04**
PE2005-8-13	Main Block	260-295 cm	Core 8	cultural	3.54	**0.00**
PE2005-8-17	Main Block	430-465 cm	Core 8	sterile	3.67	**0.00**

Table 10.9 Copper excess results calculated from the copper values analyzed from samples taken from core 8 from Pecica Şanţul Mare

To compare the spatial distribution of copper contamination, the same analysis was applied to another core from the same site, Core 3 (Table 10.9). This core was taken west from the main

tell during coring season 2005 (O'Shea et al. 2005). The results from this core indicated similar values in sterile deposits, to Core 8. However, the A horizon showed great differences, with the Core 3, showing almost three times the amount of copper, due to intensive modern agricultural practices around the site.

Despite differences in the upper disturbed layers, the archaeological deposits in Core 3 consistently show elevated copper levels. Sample PE2005-3-5, taken from 110-125cm below the surface, shows high anthropogenic activity at this depth, with an excess Cu of 8.43mg/kg. Elevated values, which continued even past 150 cm (6.26mg/kg Cu excess), then decreased sharply around 320 cm, likely indicating a transitional deposit before the sterile.

Even at larger depth, Cu values remain high: the maximum contamination reaches 13.86 mg/kg, the minimum is 8.34 mg/kg, and the average is 10.47 mg/kg. These values are by far the highest recorded across all sites in the study, underscoring Pecica's role as the most metallurgically intensive settlement in the region. Evidence for tin at the site is minimal, with concentrations barely above detection limits and a maximum of only 0.29 mg/kg.

Pecica Şanţul Mare						
Sample lab ID	**Location**	**Depth of sample below surface**	**Context**	**Soil context**	**Cu**	**Excess Cu (ppm)**
PE2005-3-1	Core 3	0-20 cm	/	A horizon	16.04	**12.88**
PE2005-3-5	Core 3	110-125 cm	/	cultural	11.59	**8.43**
PE2005-3-6	Core 3	150 cm	/	cultural	9.42	**6.26**
PE2005-3-8	Core 3	320 cm	/	cultural	4.49	**1.33**
PE2005-3-10	Core 3	380 cm	/	sterile	3.16	**0.00**

Table 10.10 Copper excess results calculated from the copper values analyzed from samples taken from core 3 from Pecica Şanţul Mare

In summary across all sites, some degree of anthropogenic copper enrichment is present, but it appears in different strata and reflects distinct formation processes. At Crna Bara–Prkos, Cu enrichment is largely confined to disturbed zones, where recent mixing and bioturbation associated with agricultural activity have introduced or redistributed copper. At Majdan 28, copper enrichment is even more limited, occurring only within the pit fill of Feature 42, where a slag fragment and ash-rich sediment indicate low-intensity metallurgical waste deposition.

Rabe Anka Siget, Klárafalva–Hajdova, and Kiszombor Új Élet show somewhat higher levels of copper enrichment, consistent with small-scale, domestic metallurgical activity. At Kiszombor and Rabe, this enrichment appears spread across multiple contexts, whereas at Klárafalva it is more modest but still detectable in archaeological deposits.

Pecica Şanţul Mare stands apart from all other sites. Here, copper concentrations are consistently higher—even in deep cultural layers—reflecting intensive and long-term metallurgical activity centered on the main tell. However, copper contamination was also found in the surrounding areas, likely indicating metallurgical activity in areas surrounding the tell.

10.3 Period-Level Analysis

The period examined in this dissertation spans from 4500-1500 BCE, a timeframe that encompasses multiple cultural and technological changes (for details, see Chapter 5). Each of the sites included in this study present distinct occupational phases, some of which do overlap. To enable meaningful comparison across the full temporal range, I created a chronological sequence that broadly overlaps with site phases outlined by the excavators (O'Shea in press; O'Shea and Nicodemus 2019; Nicodemus et al. 2015; Mirković-Marić et al. 2025) and phases outlined in Kiss et al. (2019) (Table 10.10).

Temporal division	Cultural affiliation	Temporal divide used in this work	Cal. years BCE	Number of years
Middle Bronze Age	Late Maros (1950-1500 BCE)	**MBA 3**	1690-1550	140 years
		MBA 2	1825-1690	135 years
		MBA 1	2000-1825	175 years
Early Bronze Age	Early Maros (2700-1950 BCE)	**EBA 2**	2175-2000	175 years
		EBA 1	2715-2175	540 years
Late Copper Age	/	**/**	/	/
Middle Copper Age	Hunyadihalom (4000-3600 BCE)	**MCA**	4000-3700	~300 years
Early Copper Age	Tiszapolgár and Bodrogkeresztúr (4500-3800 BCE)*	**ECA**	4500-4000	~500 years

Table 10.11 Broader temporal divisions between 4500-1500 BCE and the artificial temporal divisions used in this work, adapted for the sites under study

10.3.1 Copper Age Results

Due to the limited sample size, the Early and Middle Copper Age teeth and soil data were combined. The sites representing these periods were Crna Bara–Prkos (Early Copper Age) and Pecica Şanţul Mare (Middle Copper Age). Across all taxa, samples show no evidence of contamination during this period (Figure 10.16).

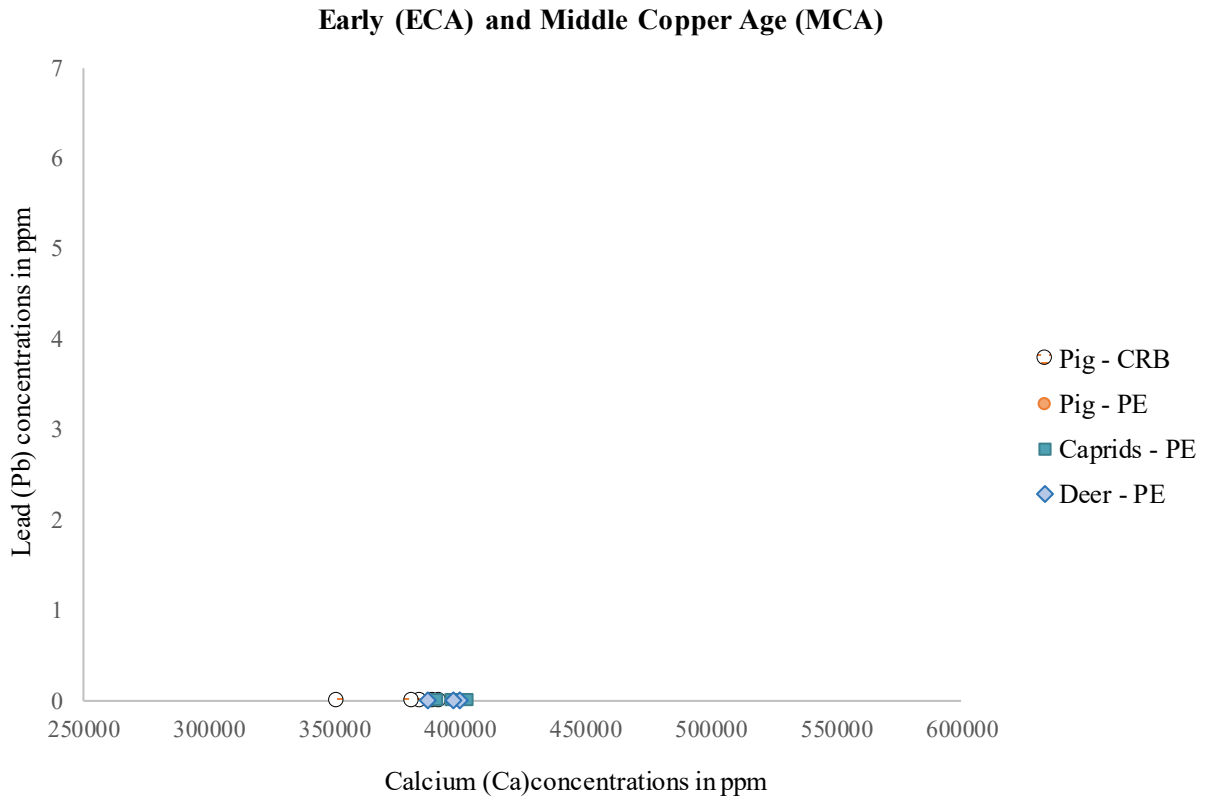


Figure 10.16 Scatter plot showing the amount of lead in teeth enamel from animals dating to the Early and Middle Copper Age

Soil samples, on the other hand, show some copper enrichment, but the overall levels remain low (Figure 10.17). To further illustrate the lack of change over form the Late Neolithic to the Early Copper Age, I also included soil samples from the Late Neolithic at Crna Bara, which show low to negligible Cu contamination.

At Pecica Şanţul Mare, the soil samples show clear evidence of copper contamination. As discussed above, Pecica exhibits the highest Cu concentrations across sites. The copper-migration model derived from the soil cores indicates minimal vertical movement of Cu through the

stratigraphy, with no tailing into the sterile deposits. This pattern demonstrates that the observed enrichment reflects in situ activity rather than post-depositional processes. Although no direct evidence of metallurgy has been identified at Pecica for the Middle Copper Age, the geochemical signal suggests that low-level metallurgical activity was likely taking place at the site. This interpretation aligns with broader regional patterns: copper metallurgy is documented in the area from the Early Copper Age onward, even if unequivocal evidence for local production remains rare.

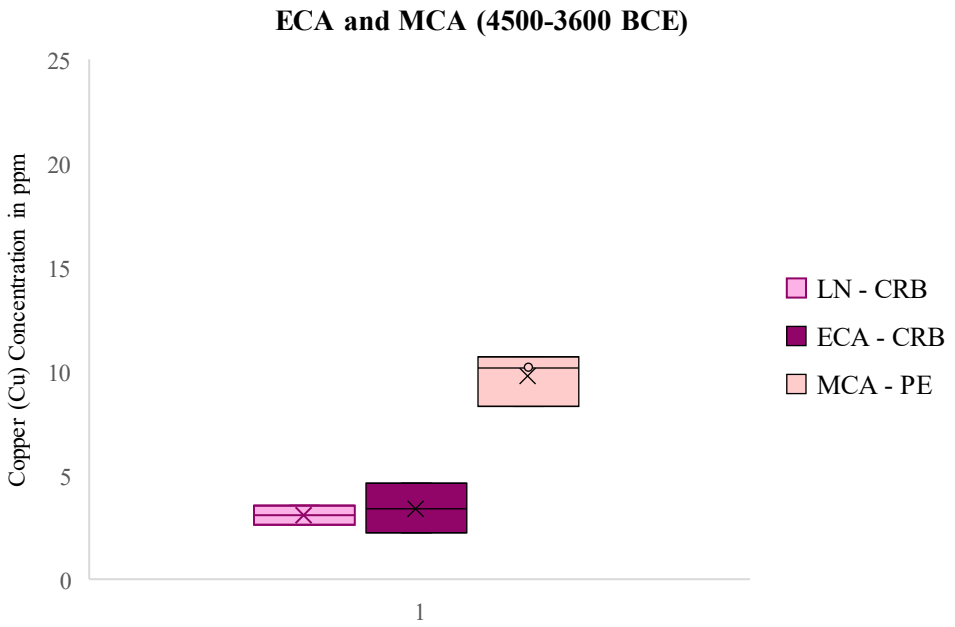


Figure 10.17 Box plot showing copper concentrations from Early and Middle Copper Age archaeological deposit from the sites of Crna Bara–Prkos (CRB) and Pecica Şanţul Mare (PE)

10.3.2 Bronze Age Results

The Bronze Age is the first period in which clear material evidence for local metallurgical production appears in the Tisza–Maros region. The period is divided into EBA 1, EBA 2 and EBA 3, covering the period until 1500 BCE.

10.3.2.1 Early Bronze Age

The Early Bronze Age results from teeth and soil are divided into EBA 1 and EBA 2, both represented by data from the site of Kiszombor Új Élet (Figure 10.18). The enamel data show no

meaningful temporal differences within the Early Bronze Age sequence; instead, variation appears to be primarily taxonomic. As noted in the general patterns section, pigs are particularly informative, forming two distinct groups that likely reflect differences in exposure, time of exposure, or husbandry practices. Caprids show some variation in contamination levels, although these differences are far less pronounced than those observed in pigs. Deer, by contrast, show very little evidence of lead contamination at Kiszombor. This pattern indicates metallurgical activity within the site's boundaries, likely within domestic spaces.

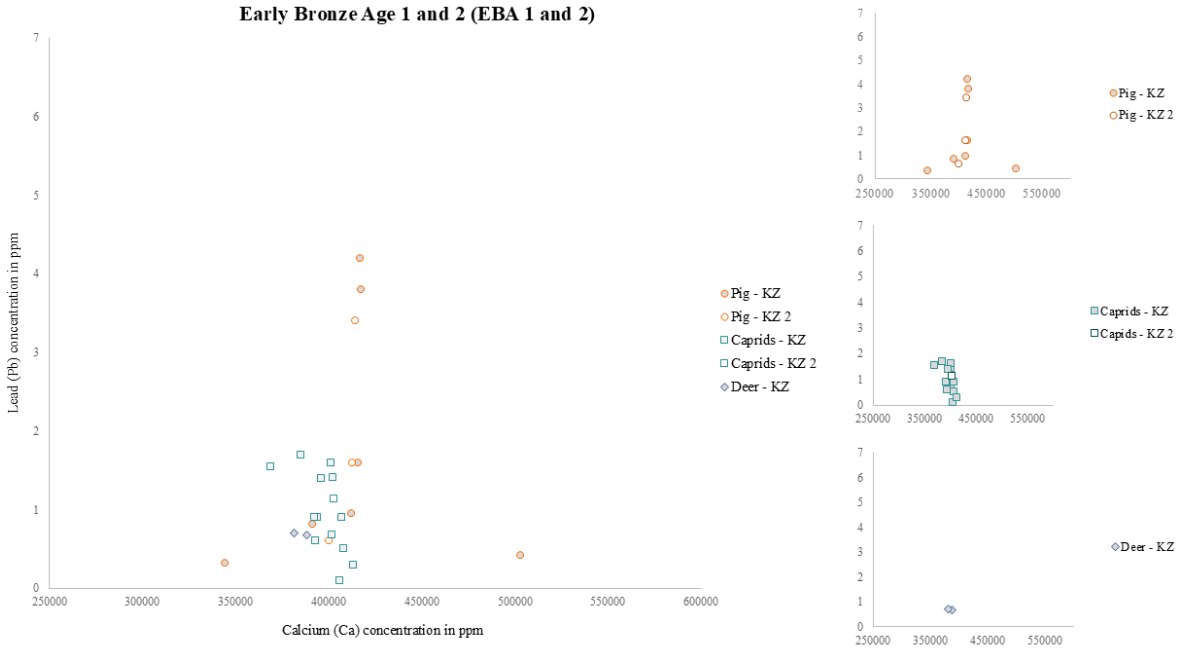


Figure 10.18 Scatter plot showing the amount of lead in teeth enamel from animals dating to the Early Bronze Age (EBA 1 and 2)

The soil samples analyzed for this period also belong to Kiszombor, specifically from Trenches 3 and 5. Although no spatial differences in copper contamination were identified across the excavated areas (Tomažič in print), the results do reveal temporal variation at the site (Figure 10.19). In EBA 1, the box plot shows a noticeably wider spread of Cu concentrations, indicating greater variability and suggesting that episodes of higher-intensity contamination occurred during this earlier phase. In contrast, the EBA 2 samples display a much tighter distribution. While the

average Cu concentration is similar between the two phases, the reduced spread in EBA 2 likely reflects fewer or less intense contamination events than in EBA 1.

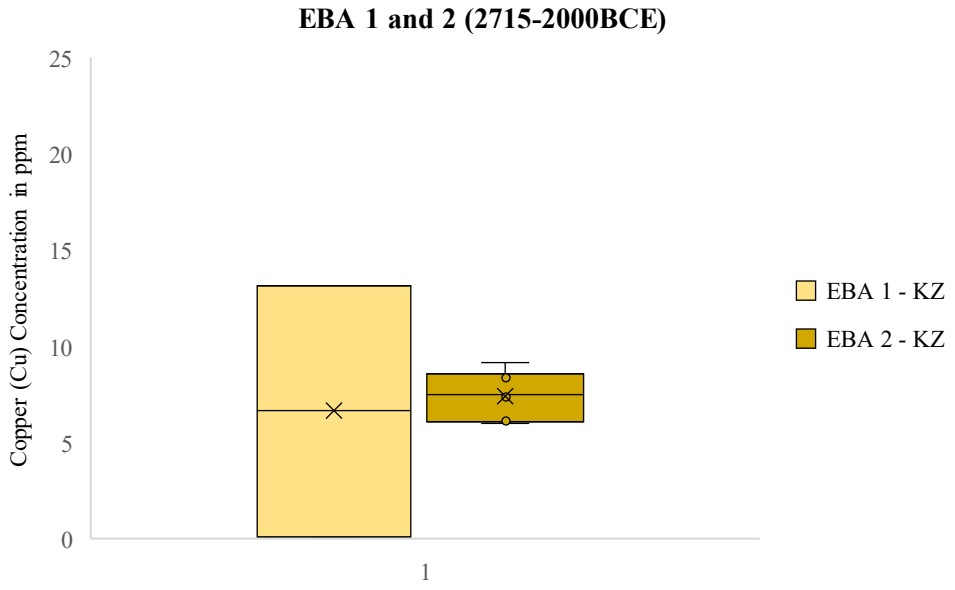


Figure 10.19 Box plot showing copper concentrations from Early Bronze Age (EBA 1 and EBA2) archaeological deposit from the site of Kiszombor (KZ)

10.3.2.2 Middle Bronze Age

The Middle Bronze Age period is divided into EBA 2/MBA 1 transition, MBA 2 and MBA 3. Because several samples—particularly those from Klárafalva Hajdova—span a broad temporal range (2175–1825 BCE) and overlap both the EBA 2 and MBA 1 periods, it was not possible to assign individual samples confidently to a narrower chronological window. For this reason, I treat the teeth samples from this interval together. The sites represented in this category include Pecica Şanţul Mare (PE 1 presents samples from MBA 1), Klárafalva Hajdova (KF 2/1, spanning EBA 2–MBA 1), Rabe Anka Siget (RA 1 falls under MBA 1), and Kiszombor Új Élet (KZ samples dating to MBA 1) (Figure 10.20).

During the EBA2/MBA 1 period, the evidence generally indicates higher contamination levels in animals—both pigs and caprids—particularly at Klárafalva and Kiszombor. At Pecica, caprids and deer show no contamination, whereas pigs display a more variable pattern. Klárafalva pigs exhibit consistently elevated Pb values, while those from Rabe and Pecica remain low. The

Pecica pigs from this period are especially noteworthy: some individuals show elevated Pb concentrations while others remain low, mirroring the groupings observed at Kiszombor during EBA 1 and EBA 2.

This variability may reflect differences in herding practices, proximity, and/or the timing of metallurgical activity, with some animals exposed during the final phase of enamel formation of their M2 teeth, while others were not. The absence of contamination in deer from the same contexts at Pecica further supports the interpretation that exposure was localized and not site-wide.

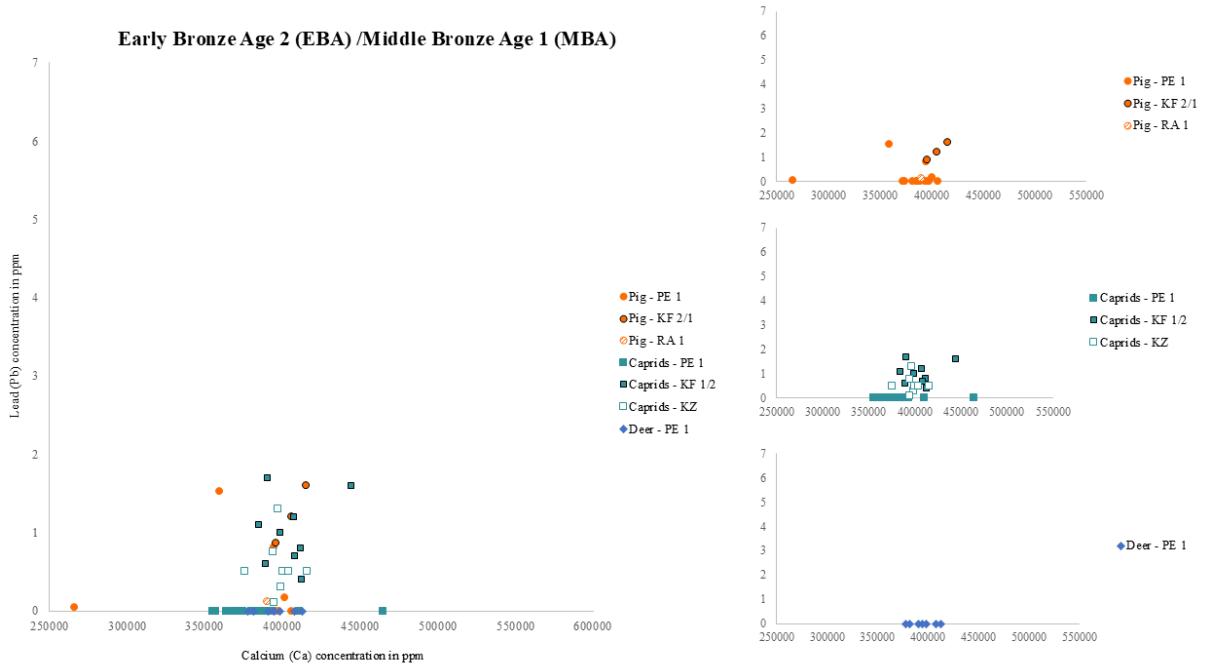


Figure 10.20 Scatter plot showing the amount of lead in teeth enamel from animals dating to the EBA 2 and MBA 1

The soil results dating to this period come from Rabe Anka Siget and Pecica Şanţul Mare (Figure 10.21). Interestingly, Rabe exhibits far greater variability in copper contamination than Pecica. However, the average Cu concentration at Rabe is approximately 5 ppm lower than that of Pecica. This pattern suggests that copper contamination at Rabe occurred at fluctuating intensities during the MBA 1 period, whereas at Pecica the overall level of contamination constant or less

pronounced. Tin concentrations were generally low in this period, ranging between 0-0.27mg/kg, with the highest end detected in Pecica.

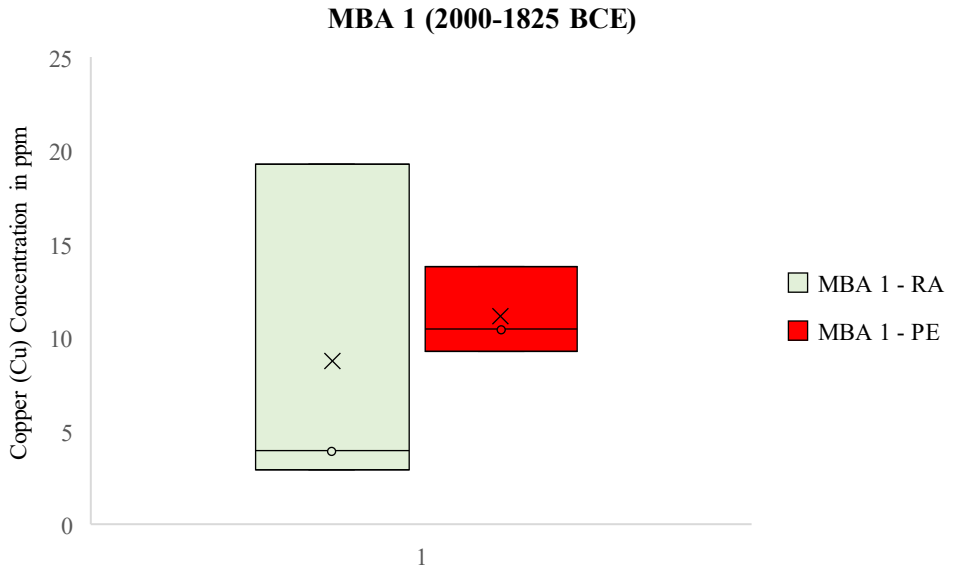


Figure 10.21 Box plot showing copper concentrations from MBA 1 archaeological deposit from Rabe Anka Siget (RA) and Pecica Şanţul Mare (PE)

The samples dating to the MBA 2 period (1825–1690 BCE) come from Pecica, Klárafalva, Rabe and Majdan 28 (Figure 10.22). The faunal evidence from these sites shows a pattern broadly consistent with that observed in MBA 1: overall higher levels of lead contamination in animals, accompanied by clear taxon-specific differences. Pigs continue to exhibit the highest and most variable Pb concentrations, while caprids show a more moderate but still elevated range.

As in MBA 1, the strongest contrasts during MBA 2 emerge between sites rather than between taxa or time periods. Pigs from Rabe display markedly higher Pb concentrations than those from Klárafalva and Pecica, indicating more intense or more frequent exposure at Rabe. A similar pattern is evident among caprids: the highest Pb value comes from a caprid from the Middle Tell at Rabe, with the second-highest from Majdan 28. These elevated values suggest that some sheep and goats were kept in close proximity to metallurgical or other anthropogenic Pb sources for at least part of their lives, as also reflected in the LA-ICP-MS profile of sample PE93-0324-0125 (Figure 10.9).

To reinforce the site-specific pattern, with cattle from Rabe and deer from Pecica, both showing no evidence of Pb contamination. In contrast, the Klárafalva deer exhibit slightly elevated Pb levels, a pattern also visible in the LA-ICP-MS sample from this site (Figure 10.10).

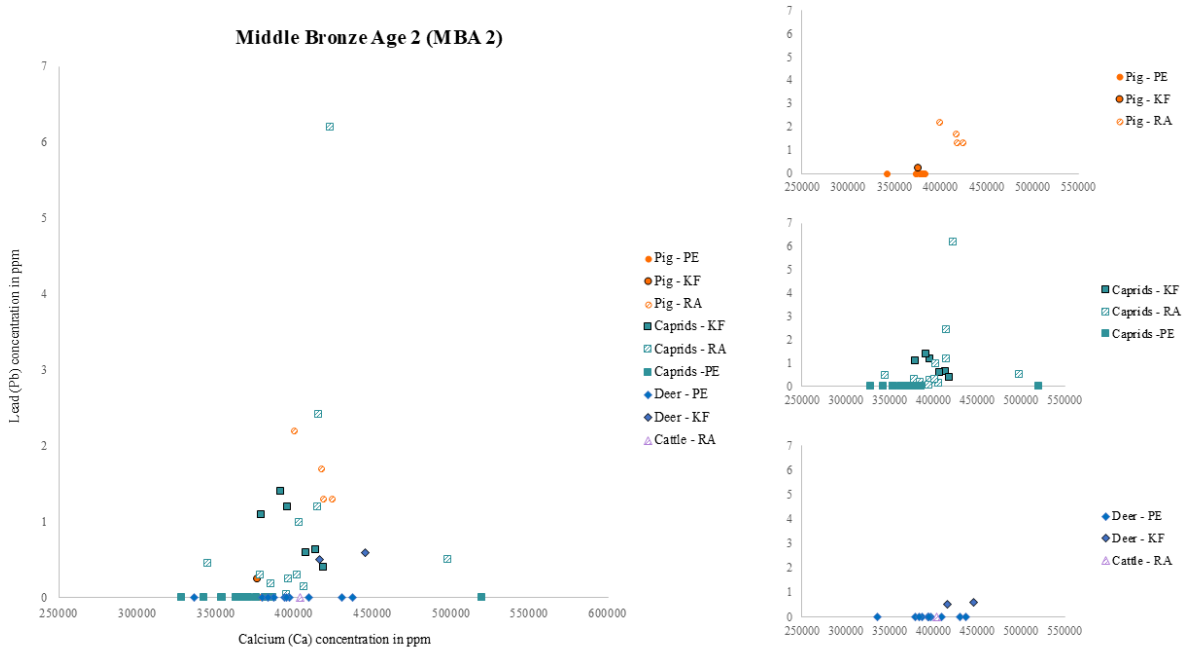


Figure 10.22 Scatter plot showing the amount of lead in teeth enamel from animals dating to the MBA 2

Soil samples dating to MBA 2 period come from Klárafalva, Rabe, and Majdan 28 (Figure 10.23). Among the three sites, Klárafalva exhibits the highest copper contamination during this period, with values that clearly exceed those recorded at both Rabe and Majdan 28. This pattern suggests that localized metallurgical or domestic-scale activities at Klárafalva left a more pronounced geochemical signature in the soils than at the other two sites, which show a similar distribution.

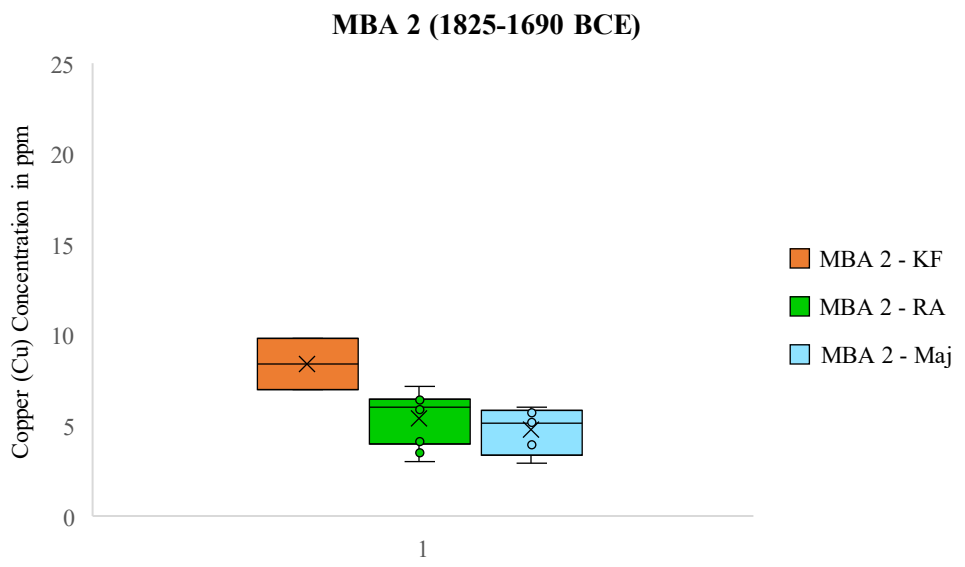


Figure 10.23 Box plot showing copper concentrations from MBA 2 archaeological deposit from Klárafalva (KF), Rabe (RA) and Majdan 28 (Maj)

It is noteworthy that some Rabe and Majdan samples present low levels of detectable tin, with the highest of the group being RATU3-4, form the eastern part of the site, (1.23mg/kg).

The final period under analysis is MBA 3 (1690–1550 BCE). For most Maros sites, this phase represents the last major occupation horizon. The faunal data for this period come from Pecica, Klárafalva, Rabe, and Majdan 28 (Figure 10.24). Together, these assemblages provide the final snapshot of lead exposure patterns before the abandonment or transformation of these settlements.

While all species follow the already recognized pattern throughout the Bronze Age — animal groups, some with higher levels of contamination than others. However, out of all periods under analysis, the MBA 3 shows the most defined difference between animals within the same taxonomic group, and for the first time, even in deer. While elevated levels and grouping in pigs have been observe in earlier periods, such difference is now more pronounced in caprids, which show higher lead contamination, particularly for Klárafalva and Pecica. Compared with the MBA 2, the caprids from Rabe appear to have lower contamination.

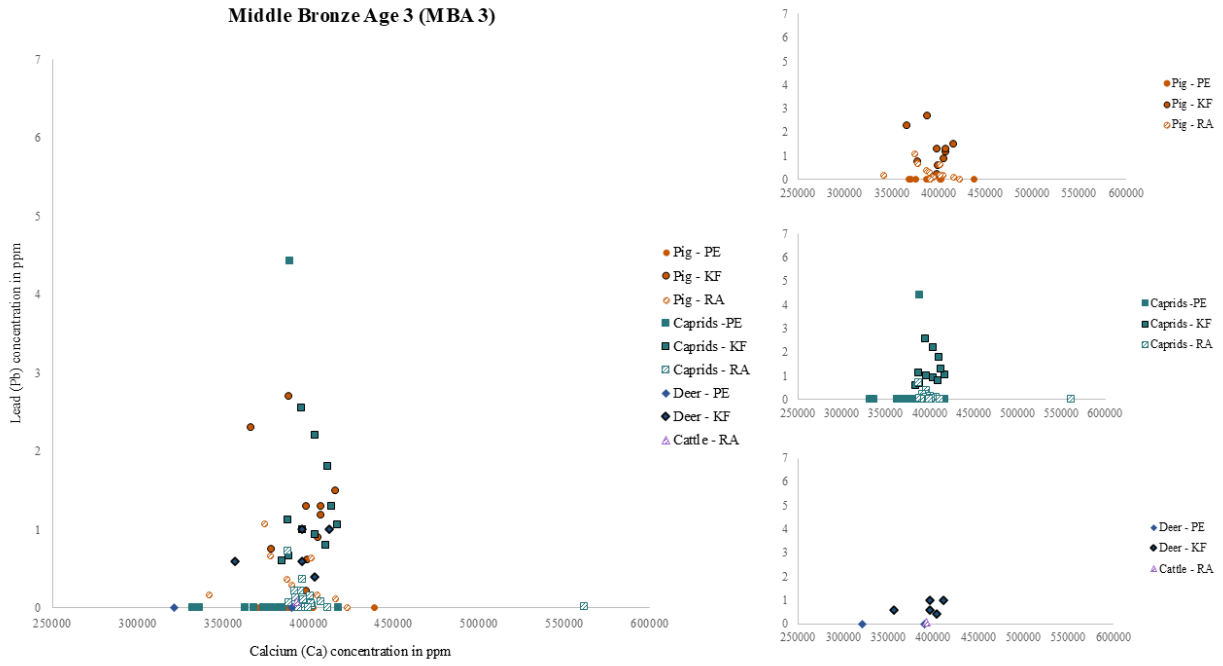


Figure 10.24 Scatter plot showing the amount of lead in teeth enamel from animals dating to the MBA 3.

Soils dating to the MBA 3 came from Rabe, Majdan and Pecica (Figure 10.25). Out of the three, Pecica shows the largest amount and tightest spread of contamination, followed by Rabe, which has the most variable samples out of the three, with one outlier — RAss34, which was a soil sample taken from feature 30, which was a thermal feature within a structure in the Main excavation block. The sample was collected close to a bronze fragment during excavation in 2022.

Furthermore, samples from all sites show detectable levels of tin, with Rabe and Majdan presenting a significant amount of tin during this period. Rabe soil samples show the highest range, from 0 to 7.6mg/kg, detected in sample RAss97, with an average of 0.44 mg/kg. Majdan on the other hand shows a much lower amount, with the highest value of 0.82mg/kg form sample MA8-1, from the pit fill, and an average of 0.07mg/kg. Pecica's levels were barely above detection limit.

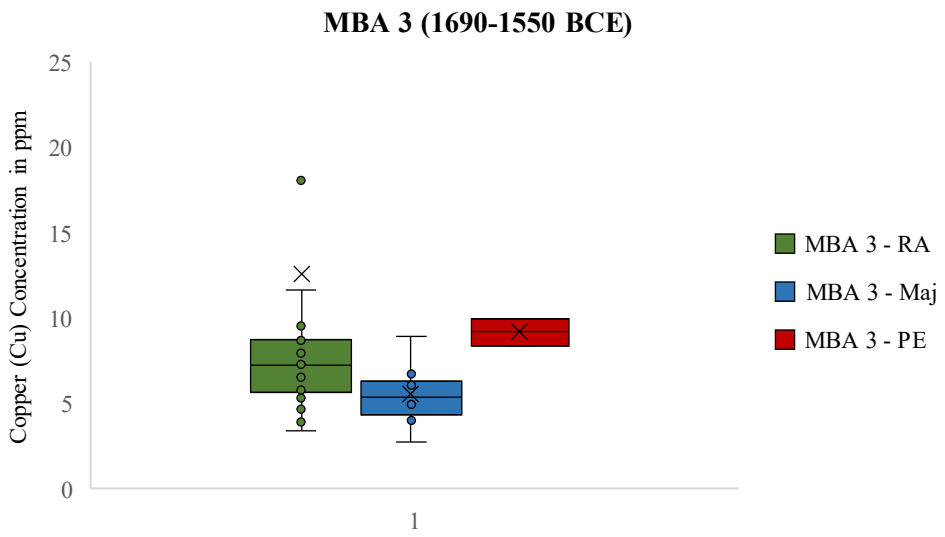


Figure 10.25 Box plot showing copper concentrations from MBA 3 archaeological deposits

10.4 Summary

The results obtained from the second and third molars of pigs, caprids, and deer, together with soil samples from cores and archaeologically dated deposits, reveal clear species-specific, site-specific, and temporal distinctions. These patterns demonstrate that lead and copper exposure across the study region was shaped not only by differences in animal behavior and husbandry practices that presented site-to-site differences, but also broader chronological developments.

First, contamination differs between species. The Ba/Ca ratios provide an important interpretive anchor, possibly reflecting dietary differences, husbandry practices, track the age of the animal and the degree of enamel mineralization. Together, these lines of evidence indicate that several samples were likely affected by diagenetic processes. The general patterns for soils indicate differences between samples with greater heavy metal contamination and those with higher organic content. The heavy metal contamination in some samples shows anthropogenic enrichment, particularly for copper. Furthermore, in some cases, the elevated levels of heavy metals, in this case zinc, copper, and cadmium, appear to present a moderate ecological risk, according to modern ecological models.

Second, and perhaps the most notable result (discussed further in Chapter 11) is that the level of contamination is site dependent. In fact, both lead contamination in teeth and copper contamination in soils, including sterile deposits, appear to be variable between sites. This emphasizes individual and variable site histories of contamination.

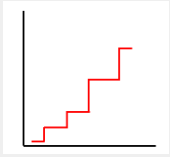
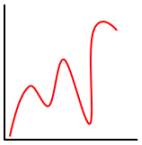
Finally, differences appear to be temporal as well. There are stark differences in both teeth and soils between the Copper and Bronze Ages. **In the Copper Age, levels of contamination were significantly lower than in the Bronze Age.** Levels seem to rise gradually from the Early Copper Age onward, with a regional peak seen only in soils from Pecica in the Middle Copper Age. However, differences emerged particularly in the Bronze Age. In fact, changes in contamination levels within the same animal group emerged. This feature was first observed in pigs from the Early Bronze Age; it later became more prominent in other species. For caprids, these groupings appear during the Middle Bronze Age; for deer, only in MBA 3, the final period of the Middle Bronze Age. Similarly, for soils, copper contamination appears to have varied between sites and time period, emphasizing the site-specific intensification process, tin levels appear far more prominent in the MBA 3, while the earliest appearance goes back to MBA 2 and it was particularly prominent at the site of Rabe Anka Siget.

In the next chapter — Chapter 11 — I will contextualize the outlined results within the environmental and archaeological knowledge discussed in Chapters 5 and 6.

Chapter 11 Testing Expectations: Comparing the Results Against Hypotheses

Chapter 11 brings together the metallurgical and contamination data to address the research questions that frame this dissertation, as outlined in Chapter 7. These questions examine two dimensions of intensification: the long-term shift in metallurgical activity between 4500 and 1500 BCE, and the ways in which intensification was expressed across different Bronze Age communities.

From these guiding questions, a series of hypotheses was developed to outline scenarios and expected outcomes (Table 11.1). This chapter evaluates those hypotheses and identifies the interpretations most strongly supported by the data presented in the Results chapter (Chapter 10).

Hypothesis		Production expectation	Environmental expectation
Intensification patterns over time	*Ia. Linear increase in production* 	Steady, uninterrupted increase of production from Copper to the Bronze Age	Contamination will accumulate over time, with the highest signature in the Bronze Age
	I.b Stepped increase in production 	A general increase in production overtime, with intervals of rapid development	Longer periods of similar contamination levels
	I.c Non-monothetic 	Production is changing magnitudes overtime, presenting a low and high level of production, with the highest in the Bronze Age	Levels of contamination are variable - both in abundance and chemical signature

Community responses to intensification	*II.a Similar expression of intensification*	All communities will perform the same type of metallurgical activity, with the same technology, in the same location, and same scale	Contamination will be the same in all analyzed settlements
	II.b Differential expression of intensification	Communities show differential production, including activities, technologies, scales, and location	Sites with greater production will have a higher signature

Table 11.1 Hypothesis and expectations detected in production and environmental aspects of the research

11.1 Change of Intensification Through Time

The first question in this dissertation examines temporal changes in metallurgical intensification across the period 4500–1500 BCE, with particular emphasis on developments during the Bronze Age. It proposed that increases in metallurgical production, reflected in technological shifts (see Chapter 5 for details) and changing uses of space, could follow one of several trajectories: a linear progression, a stepped or episodic increase, or a non-monothetic pattern characterized by uneven intensity of technological developments. The hypotheses were evaluated by comparing their expected patterns of production and environmental impact over the 3000 years.

Of the three hypotheses, the third, which describes the change as non-monothetic, appears to best fit the results. The hypothesis states: *"Hypothesis 1c- The intensification of metallurgical production detected during the Bronze Age results from the non-monotonic increase of activity that varied in magnitude from the Copper Age onward."*

In this hypothesis, the metallurgical production was expected to show changing magnitudes of intensification over time, with the highest peak in the Bronze Age. As outlined in Chapter 5, the archaeological literature indicates that Early Copper Age metallurgical activity is most visible at settlements located near ore sources, even as metal artifacts circulated widely across Southeastern and Central Europe, thus representing the first peak in metallurgical production (Heeb 2011; Jovanović 1971, 1990; Makkay 1996; Muhly 1988; Renfrew 1969; Virág 2003).

Across the wider Carpathian Basin, the large number of recovered tools, associated with the Tiszapolgár and Bodrogkeresztúr cultural complexes, has enabled detailed typological analyses

of artefacts (particularly axes) (Sava 2015). However, despite the large number of objects, direct traces of metallurgical manufacture are largely absent. These patterns may reflect the limited number of identified settlements and issues related to the identification of metallurgical installations within settlements, due to their ephemeral nature. Alternatively, it is possible that the lack of metallurgical evidence is due to metals not being produced at the site, or at least not within the sampled areas. Instead, the metals might have been brought to settlements, whether by the communities themselves or through broader exchange networks.

The evidence from the Tisza-Maros region reinforces the wider regional patterns; as at Crna Bara–Prkos (Mirković-Marić et al. 2025), no metallurgical installations, tools or contamination evidence in soils or animals have been recovered. However, the nearby cemetery of Podlokanj Nove Bašte attributed to this period has yielded several metallurgical tools—including a copper axe, a chisel, and multiple gold ornaments—demonstrating that metalworking was practiced within the broader community (Grčki-Stanimirov and Stanimirov-Grčki 2025).

Following the Early Copper Age peak, the Middle Copper Age presents far more limited metallurgical evidence, although copper continued to circulate regionally (see Chapter 5 for details). In the study area, this phase corresponds to the Hunyadihalom cultural group. A settlement attributed to this group is documented in the lower deposits of Pecica Şanţul Mare.

At Pecica, analyzed animal teeth indicate that neither domestic animals nor deer were exposed to metallurgical activity, yet soils from this period show sporadic and slightly elevated copper concentrations. This is a noteworthy result: despite the absence of metallurgical debris in the archaeological record, the geochemical signal points to localized, low-level metallurgical activity. This finding underscores the principle that the absence of material evidence is not evidence of absence. It is entirely plausible that small-scale metalworking—likely household-level production—occurred at the site, perhaps within domestic installations as previously noted for Vinča groups by Radivojević et al. (2021). This kind of production would leave very limited amount of contamination and would result in small amount of metallurgical debris, especially if the utilized ores were oxide ores which leave little residue.

During the Late Copper Age, bronze metallurgy appears across the wider region; however, scholars note that evidence for metallurgical production is limited and remains uneven and difficult to document (Makkay 1996; Bondár 2018). At the sites examined in this study, no evidence of Late Copper Age occupation has been recovered.

The next major occupation horizon corresponds to the Early Bronze Age, marked by the occupation of Maros communities. With the Maros, the intensity of metallurgical production increases noticeably.

The evidence from both soils and teeth dating to this period showed a marked rise in contamination and were attributed to Kiszombor Új Élet. This environmental signal indicates that metallurgical activity was occurring on a small scale in different areas within the settlement, likely still at a domestic level. At the same time, it cannot be excluded that the location or timing of these activities shifted at a finer temporal resolution than is visible in the current dataset.

Despite the increase of metallurgical production during the Early Bronze Age, the peak is associated with the Middle Bronze Age. While none of the examined sites focused on the 'ore scouting and preparation' stage, rather it appears that ore, ingots, and possibly finished objects were brought into the settlements. However, all sites show some evidence of 'ore transformation' and 'object-making' stages, inferred by the presence of casting remains and waste material such as slags, droplets, and other production residues. At most sites, apart from Pecica, this intensification occurs despite the apparent absence of dedicated metallurgical facilities, with the notable implication that production was embedded within domestic or multipurpose activity areas rather than formal workshops.

Evidence for intensification is also visible in the environmental footprint. Contamination signals in both animal teeth and soils indicate an increased production, however it was only during the MBA 2 (1825-1690 BCE) that production became more consistent, widely spread and more frequent than in preceding periods. During MBA 2, tin also appears in the soils, indicating changes in local metallurgical practices of production or network systems. By the end of the Middle Bronze Age, however, there is already a visible decline in metallurgical and contamination evidence, with sites generally showing a less consistent production pattern.

In summary, when comparing the intensification of metallurgical activity, the overall trajectory is non-monotonic—both when the Copper Age is included and when the Bronze Age is considered on its own. Production peaks have been identified during the Early Copper Age, if metal objects are considered, however no evidence has been spotted in the soils. In contrast, in the archaeological record, it appears that production declines slightly in the Middle Copper Age and it also marks the first evidence in soils. Because no evidence for Late Copper Age occupation at sites, its developmental pattern cannot be assessed. Metallurgical production, visible both in remains and soil, increases substantially in the Early Bronze Age and becomes markedly intensified during MBA 2, after which it appears to decline in MBA 3.

11.2 Expression of Metallurgical Intensification

The second question tested whether the expression of metallurgical intensification—particularly among Maros communities—was (a) similar or (b) different across sites. The results support the second option, indicating that: Hypothesis 2b – Bronze Age communities living in the Tisza-Maros region expressed metallurgical intensification differently.

When examining the excavated metallurgical evidence retrieved from the sites (Table 11.2) [15], it becomes clear that different types and quantities of objects were retrieved from each settlement. This pattern suggests that not all sites participated in the full *chaîne opératoire*; rather, they were likely integrated into a broader exchange-network system in which some sites took precedence in the activity, during specific periods of time, while others remained on a domestic level of activity. For example, metalworking features here are represented primarily by thermal installations around which slag or other debris was present. In most sites, these features are multipurpose thermal features, rather than specialized, with the exception of Pecica, for which evidence suggests the presence of metallurgical workshops, due to several superimposed thermal features associated with the amount of molds and debris found at the site (O'Shea et al. 2005; Nicodemus et al. 2015; Găvan 2015)

[15] The site of Crna Bara-Bara–Prkos is not represented in this table, as it did not show in-situ Bronze Age occupation.

When comparing all lines of evidence—metallurgical remains, faunal contamination, and soil chemistry—distinct patterns emerge across the different sites. While metallurgical debris is not always present at sites, when present it directly reflects the presence and intensity of contamination in soils, whereas contamination in animals captures how production intersected with domestic space, herding practices, and the broader settlement environment.

	Metalworking features	Casting artifacts	Metallic objects	Metalworking debris
Kiszombor-Új-Élet	X	X	X	X
Klárafalva Hajdova	X	X	X	X
Pecica Şanţul Mare	XXX	XXX	XX	XXX
Rabe Anka Siget	X	X	X	
Majdan 28	X			X

Table 11.2 The type and amount of metalworking production evidence dating to the Bronze Age, as of currently known, from the analyzed sites

Among all sites, Pecica presents the strongest evidence for metallurgical production and the highest levels of soil contamination (see Chapter 10). Yet the faunal remains from Pecica show no consistent contamination, suggesting that animals were generally kept or pastured away from metallurgical activity. Only occasional exposure is visible, as indicated by the three pig outliers during MBA 1 and the single contaminated caprid in MBA 3. This pattern implies that while metallurgical activity was intense, certain portions were mostly spatially segregated from areas where animals were kept or herded, with animals encountering contamination only intermittently.

In comparison, the widest spread contamination is observed at Kiszombor. This is most clearly visible in the pig remains, followed by deer and then caprids. Soil data show a similarly broad distribution of contamination, particularly during the EBA 1 period. Such widespread signatures likely reflect the pattern already noted for this site: metallurgical activity was probably conducted in multiple areas of the settlement at different times, producing variable intensities of exposure across both space and species.

Klárafalva presents a stark contrast. Here, all analyzed animals—including deer—show evidence of contamination, with pigs again exhibiting the highest levels. Soil samples, although limited in number, also show elevated contamination. Given Klárafalva's proximity to the river (approximately 350 m) and being surrounded wetlands, it is likely that metallurgical activity was concentrated within the settlement core, with possible occasional shifts to peripheral areas during dry periods. Such shifts could explain the elevated contamination observed in deer, which would have been more exposed to activity occurring on the outskirts.

At Rabe and Majdan 28, intensification appears to be primarily temporal rather than spatial. Teeth and soil samples from Rabe show elevated contamination only during MBA 2 (1825-1690 BCE), the period in which the site reached its greatest extent and likely incorporated Majdan 28. Metallurgical activity at Rabe increased from MBA 1 to MBA 2 but declined during MBA 3. Between 1825 and 1690 BCE, Rabe and Majdan 28 exhibit similar contamination levels, while both show a marked decrease in activity after that, as seen by the evidence dating to the MBA 3 (1690-1550 BCE).

However, while these two questions have been answered, the hypotheses themselves do not fully capture the nuance revealed by the data. The patterns observed across communities, species, and environmental contexts are more complex than the proposed structure of the hypotheses. These subtleties are essential for understanding the cultural implications of metallurgical production, its spatial organization, and its social embeddedness and ultimately change overtime. The interpretive nuances that emerge from this dataset are therefore explored in greater depth in the next and final chapter of this dissertation (Chapter 12).

Chapter 12 Discussion and Conclusion

The questions and hypotheses (Chapter 7 and Chapter 11) set forth in this work provided a strong foundation to discuss the impacts of intensification. However, the findings uncovered a far more complex picture than initially anticipated. In this chapter, I will consider this complex picture by highlighting the nuances uncovered in three major sections: intensification levels, implications for future work, and conclusions.

In the first part of the chapter, I discuss the nuances of metallurgical intensification that have been revealed in this analysis. Here, I show that the apparent character of intensification is not uniform but varies depending on the scale at which it occurred and is observed. The variability in metallurgical intensification in the Tisza-Maros region, can be differentiated at individual site and regional levels.

The site-level reveals community decisions reflected in subtle patterns of animal husbandry and activity locations, highlighting distinct settlement histories. Once these site-specific patterns are compared and integrated into the Tisza-Maros region, a new picture emerges, revealing cultural aspects, strategies, and likely connections between sites. In this regard, local settlement histories are overlain by larger regional dynamics of intensification of metallurgical production, which appears more as a response to broader socio-environmental dynamics than a process integrated within individual settlement histories. The regional level also reveals the scope of metallurgical production, which can be aimed at satisfying local or supralocal needs. I conclude this section by discussing the role of wetlands and land availability in the process of metallurgical intensification.

The second part of the chapter discusses the implications of this research. The multiscale, multiple lines of evidence, and multidisciplinary approach employed in this work highlights the different dimensions of archaeological data. This discussion emphasizes the discipline's potential and its contributions to debates on contamination, pollution, and perspectives on environmental

change. The chapter concludes with a consideration of future research directions and the strengths and limitations of the present study.

12.1 Intensification Levels: Site and Regional Perspectives

As discussed in Chapter 2, the term intensification has often been an ambiguous umbrella term, rather than approached through context-specific outcomes. Morrison (1994) emphasizes that intensification must be contextualized within specific social and environmental settings to understand individual trajectories and then compared to one another to reveal similarities and differences in the process. Only through such comparison can we begin to understand what intensification looks like across communities and how its expression changes over time, an approach taken in this dissertation.

As demonstrated in Chapter 11, the Tisza–Maros communities, especially the Bronze Age Maros communities, express metallurgical intensification in distinct ways, despite belonging to the same broader cultural group. These differences highlight the importance of scale, context, and local histories in unfolding the evidence of intensification.

12.1.1 Site-Based Intensification

Site-based patterns of intensification reveal the distinct histories of individual communities. On the site level, we can begin to understand when metallurgy was adopted, how production changed over time, and how these shifts intersected with broader aspects of community life. At Pecica Şanţul Mare, for example, the evidence suggests two episodes of intensification: one in the Middle Copper Age Hunyadihalom strata and another in the Middle Bronze Age Maros deposits. Preliminary results from metal fragments from the site conducted by Orfanou indicate that during the early phase of the Maros occupation (MBA 1), metallurgical activity focused primarily on production with unalloyed copper, which presented traces of arsenic (As). Tin (Sn) bronze metallurgy appears during the MBA 2, but becomes dominant toward the site's later phases (Orfanou, personal communication, January 28, 2026).

When the elemental evidence from Pecica's metal fragments is considered alongside the contamination data from soil, the combined results closely align. The first spike in

contamination—visible in both faunal remains and soils—occurs during MBA 1, while the highest peak occurred during MBA 2.

The analysis of metal fragments dating to MBA 2 also showed variable As/Sn ratios, with some showing lower arsenic and higher tin, likely indicating a wide range of resources available at the site at this time. However, while the archaeological, soil, and metal fragment evidence point toward high contamination, there is no evidence of contamination in the animals from Pecica during this period (Figure12.1). This pattern suggests that livestock, particularly during periods of high metallurgical production, were kept away from the primary zones of metallurgical activity and were likely brought closer to the site only before slaughter. The highest peak in production was followed by the site's decline by MBA 3, when As/Sn variability in metal samples diminished, and most artifacts displayed a similar range of As/Sn ratios. Similarly, the soil evidence shows lower contamination during this period, while a small group of animals appears to have been kept closer to the metallurgical activity.

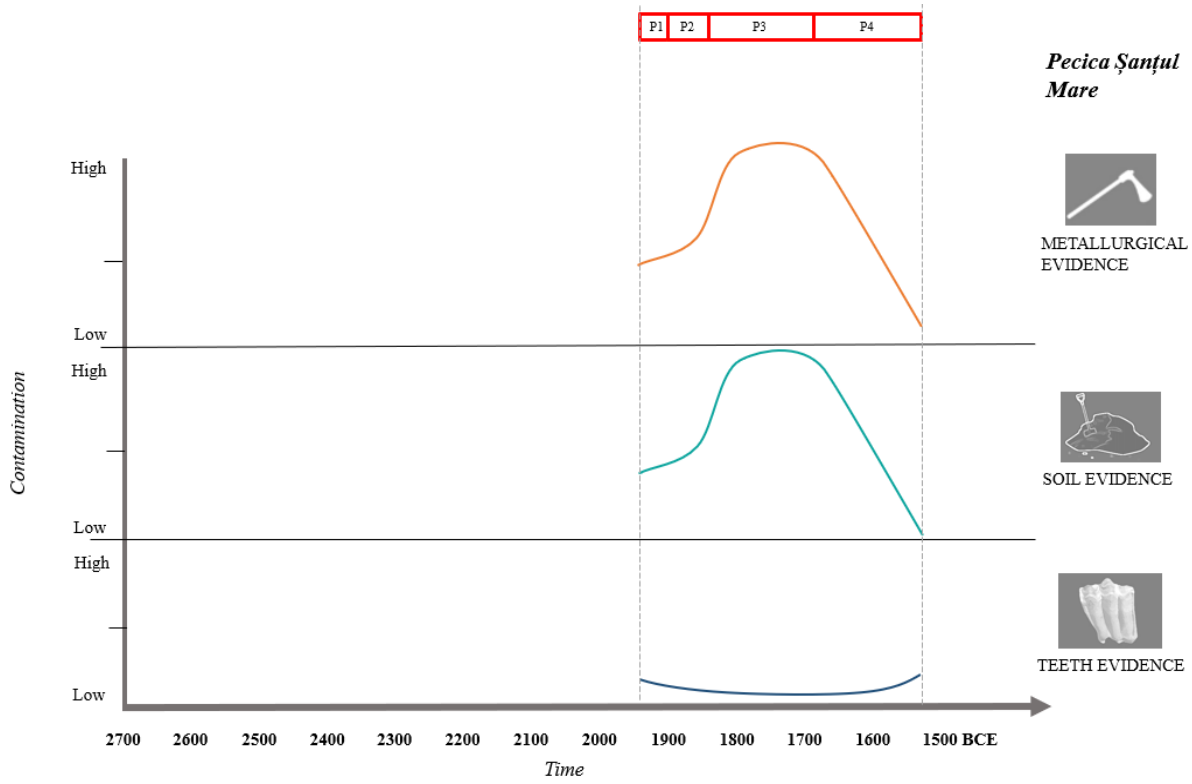


Figure 12.1 Graph showing trends of different lines of evidence from Pecica Şanţul Mare

In contrast, the site of Rabe shows the most diverse soil contamination during MBA 1, with periods of high and low contamination. Results from animal teeth dating to the same period exhibit low levels of contamination (Figure 12.2). During MBA 2 —the phase of the site's largest expansion, likely incorporating Majdan 28 and possibly additional nearby locations (presented by Trifunović survey 2012) —contamination levels on average increase but become less variable, with both Rabe and Majdan exhibiting broadly similar signatures in soils. During this period, contamination represented by animals, primarily pigs, at Rabe also rises. During MBA 3, soil contamination increases, with a higher amount of tin also detected in the samples. Contamination in both pigs and caprids is comparable, although notably lower for pigs detected during the MBA 2. A similar image is reflected at Majdan 28. MBA 3 shows elevated levels of tin in soils, particularly those taken right underneath the metal fragments. While the signal in soils is strong and undoubtedly reflects the leaching of tin and copper from the fragment, archaeometallurgical analysis would reveal technological and production nuances of this period. At this time, archaeometallurgical analysis awaits.

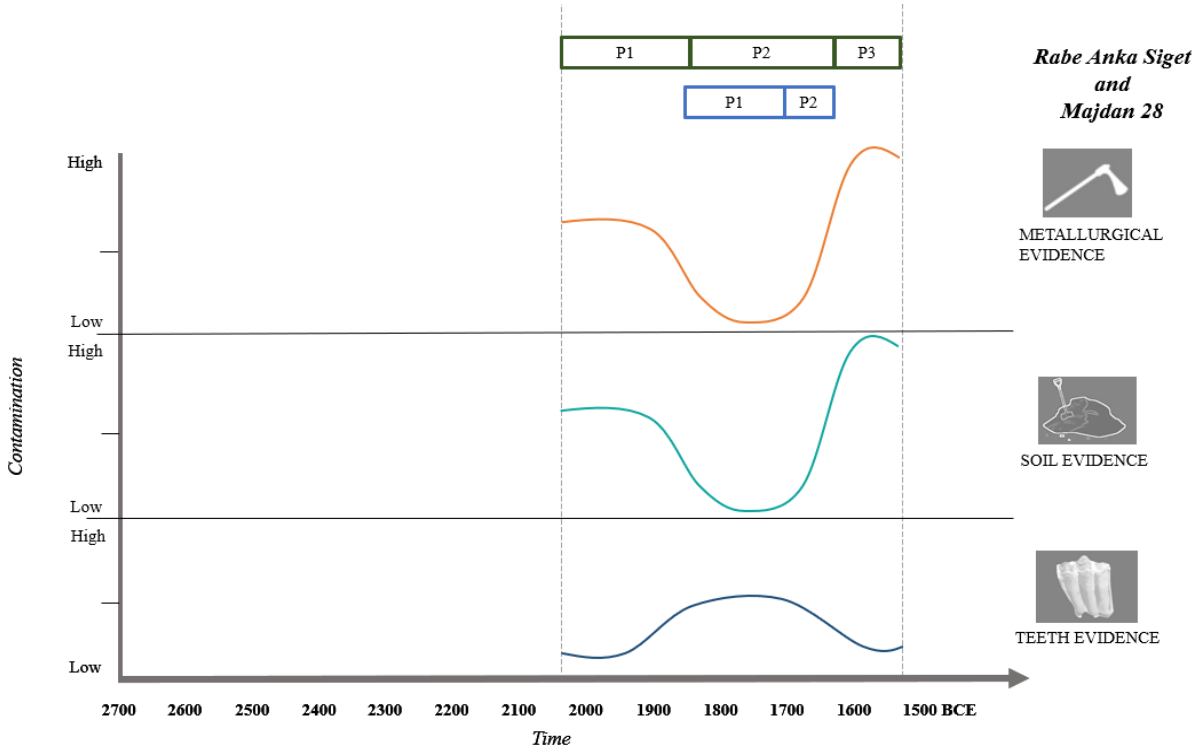


Figure 12.2 Graph showing trends of different lines of evidence from Rabe Anka Siget and Majdan 28

Kiszombor, by contrast, shows generally higher levels of contamination in animals, with relatively little change over the site's occupation. The only notable difference is in caprids, which display lower average contamination during MBA 1 than in earlier periods. The soil data from the deposits dated to EBA 1 show a wider range of contamination levels than those from EBA 2. Unfortunately, no soils dating to MBA 1 were available for sampling. The archaeometallurgical analysis of slags conducted by Papalas (2008), however, suggests a likely technological temporal progression from the gehlenite to the fayalite group at the site, along with likely smelting activity, deduced from the wide range of raw materials retrieved from the site. Furthermore, the Papalas's EDS compositional analysis of metal prills shows a higher arsenic content than tin throughout the occupation (2008), a pattern comparable to that of the Pecica metal fragments detected by Orfanau.

One of the most striking patterns at Kiszombor, however, appears in the contamination evidence, where two distinct contamination groups in the animals—particularly pigs—show clearly separated high- and low-contamination values (Chapter 10, figure 10.11). While neither group can be attributed to a specific settlement location, this does not preclude the possibility that particular activity areas, distinct episodes of production, or both were present at the site. However, determining which of these scenarios is more likely would require finer-grained chronological resolution and additional targeted research.

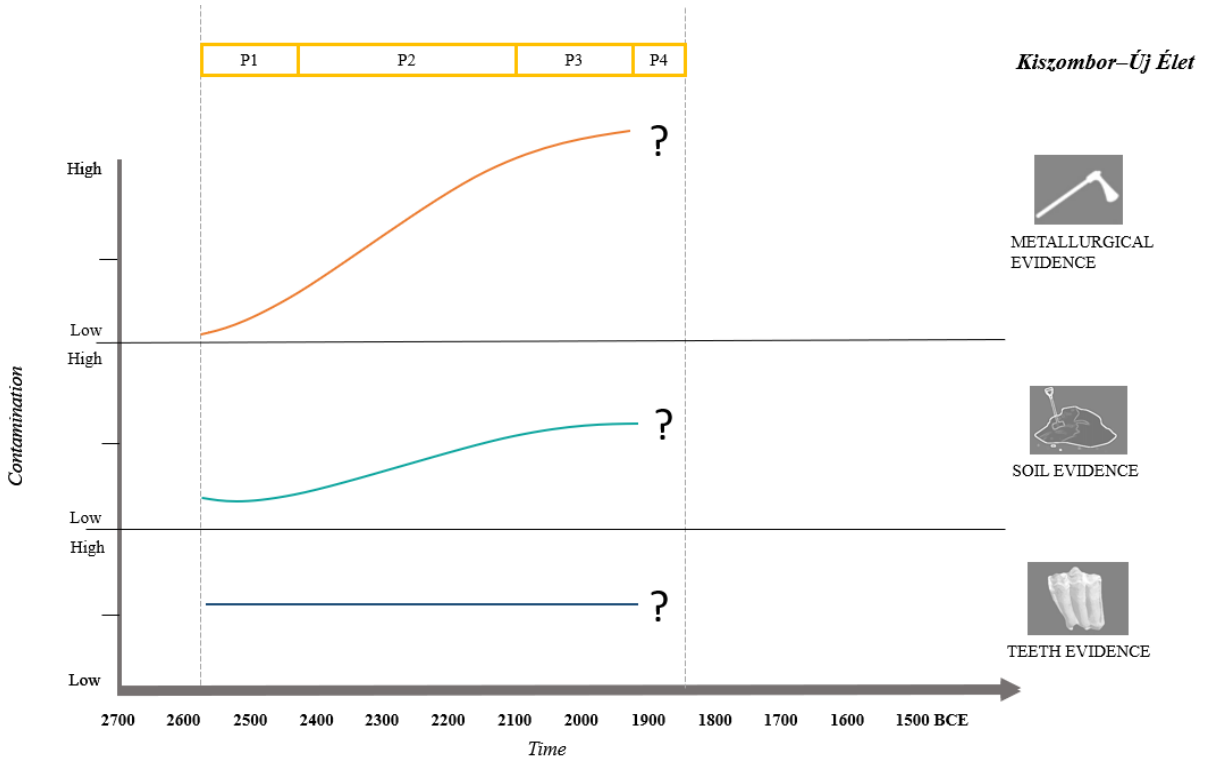


Figure 12.3 Graph showing trends of different lines of evidence from Kiszombor Új Élet

Klárafalva, by contrast, shows contamination in domestic animals during the EBA 2/MBA 1 period, followed by a decline in MBA 2 and then a renewed increase in MBA 3. Klárafalva is also the first site to show clear groups of highly contaminated and less-contaminated areas across all animal species by the MBA 3. Soil contamination results from soils dating to the MBA 2 show moderate contamination levels, comparable in both intensity and spread to the EBA 2 soils from Kiszombor.

The results of the analysis of slags by Papalas (2008) indicate either pre-smelted provisioned material or very pure ore, suggesting that, particularly during the MBA 3, Klárafalva's metallurgical activity was focused on casting, rather than smelting. Furthermore, the EDS compositional analysis of metal prills, conducted by the Papalas in the same work, shows a change in elemental composition in slags through time; with slags dating to the earlier periods containing more arsenic than tin, while the opposite is true in the late phases of the site (Papalas 2008), particularly during MBA 3. Unfortunately, no soils dating to this period were available for sampling to further discuss the contamination signature of the site.

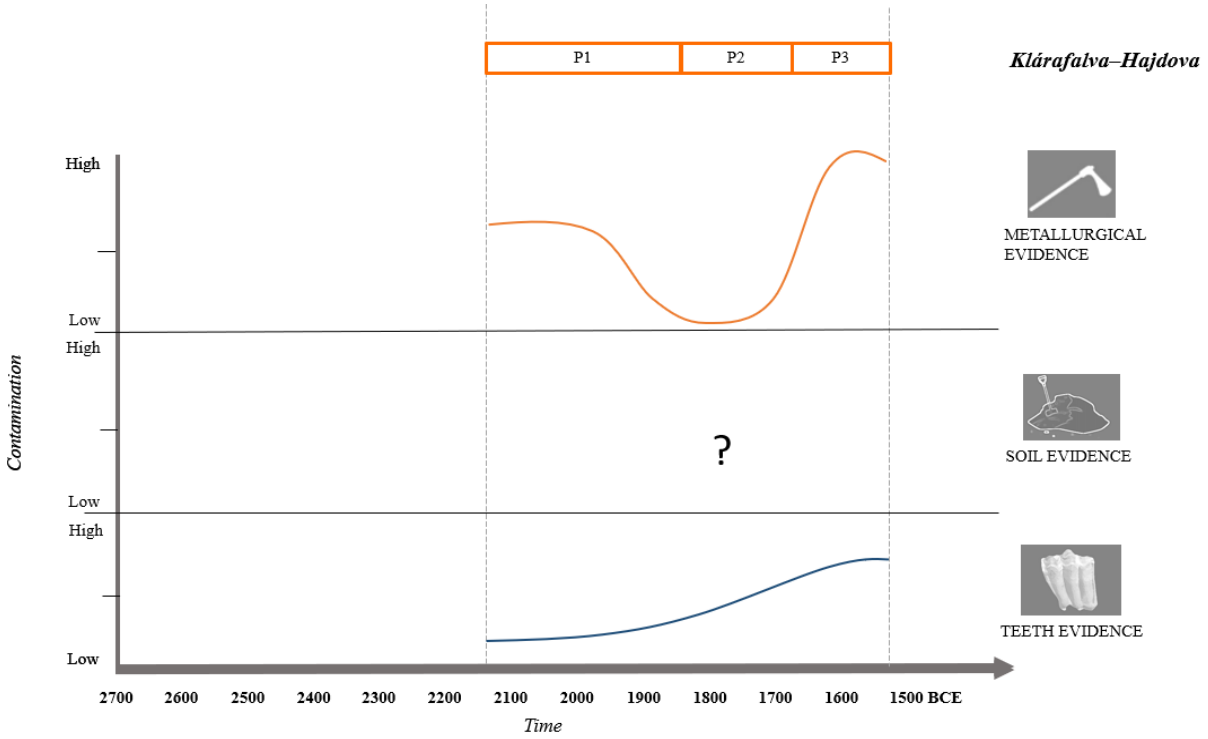


Figure 12.4 Graph showing trends of different lines of evidence from Klárafalva Hajdova

12.1.2 Regional Level of Intensification

At the site level, intensification reveals distinct settlement histories of metallurgical activity, showing that each community experienced its own oscillations in production intensity over time. The identified variations in production intensity, however, are likely reflecting responses to changes in regional socio-economic trajectories, technological developments or trends, environmental or ecological pressures, and shifting cultural dynamics. All these regional aspects have likely influenced the production strategies of individual communities. However, when these individual community strategies are viewed at the **regional-level**, collective responses to widespread changes, stressors, or opportunities become visible.

O'Shea and Nicodemus (2019) distinguish Maros settlements according to their position along the Maros River. Sites located closer to the Tisza–Maros confluence are classified as part of the lower Maros region—a group that includes all sites analyzed in this dissertation except Pecica, which lies farther upstream. In his synthesis, O'Shea (in press) sees these locational differences and the settlement's proximity to wetlands as contributing factors to different regional settlement

forms, tied to settlement density. For example, Pecica is located on a bluff top at the edge of the wetland zone and thus surrounded by dry lands, represents the classic tell-type settlement with dense vertical occupation, with occupational areas surrounding the tell at the time of its largest extent. Whereas the lower Maros sites—Kiszombor, Klárafalva, and Rabe—are also considered as tell-type settlements, but out of the three, Kiszombor is marked by less densely packed ocupation. Among the lower Maros sites, Rabe most closely resembles the Pecica model.

Across regional contamination patterns, it is possible to distinguish two broad levels of metallurgical production intensity that reflect the scope of metallurgical production: **household-scale** and **workshop-scale**. Household-scale production reflects metallurgical activity undertaken primarily to meet the local community's needs, with limited investment. In the archaeological record, this can be recognized through fewer production remains, less infrastructure, reduced surplus generation, and greater contamination. Workshop-scale production, by contrast, implies a level of investment that exceeds community consumption, suggesting more formalized and standardized production, greater specialization, spatial segregation, and likely community participation and wider exchange networks.

Within the dataset presented here, Pecica is the only site that clearly meets the criteria for workshop-scale production. The magnitude of contamination detected in soils and the scale of metallurgical debris point toward a production system operating beyond the settlements' needs. However, while the evidence from Pecica overwhelmingly points to larger-scale production, a finer-grained examination shows that this shift occurs in MBA 1, with detected evidence of possible workshop structures (Nicodemus et al. 2015) and reaches its peak production intensity during MBA 2. During the MBA 2 (1825-1690 BCE), Pecica reached its largest spatial extent (O'Shea and Nicodemus 2019). It is during this same period that Orfanau (personal communication) noted that chemical evidence from the metal fragments (As/Sn ratios) showed the greatest variability, likely reflecting the influx of numerous resources into the settlement.

Although no soils dating to the MBA 2 were available for sampling from Pecica, soils dating to the MBA 1 show the highest contamination levels across all sites. In contrast, as discussed above, particularly during MBA 2, none of the animals analyzed in this period exhibited

contamination. This likely further reflects the husbandry practice of pasturing animals in the extensive drylands surrounding the site, effectively shielding them from metallurgical contamination. Alternatively, the animal remains found on the tell represent provisions from nearby areas with lower metallurgical activity. All this evidence combined reflects the community's increased investment in securing metallurgical production.

The workshop-level at Pecica, however, does not last very long. In fact, by the MBA 3, the site size decreases and with it also the metallurgical production, scaling back to its Early Bronze Age footprint (O'Shea and Nicodemus 2019). With the site's decline, metallurgical production scales back to community-level production, which becomes more consistent, with tin bronze dominating the assemblage (Orfanou, personal communication, January 28, 2026), along with lower soil signatures and presence of contamination in some animals. The presence of animals closer to the activity could also signify that the activity was not conducted as frequently as before, thus the separation of space was likely deemed less important.

The only site that exhibits contamination patterns remotely comparable to Pecica is Rabe. Both Rabe and Pecica show low faunal contamination during periods when metallurgical activity and soil contamination were at their highest, suggesting strategies to keep animals away from production areas. At Pecica, this pattern emerges earlier and more intensely, whereas at Rabe (according to the current evidence) it becomes visible only during MBA 3. Nonetheless, the evidence presented at Rabe suggests a degree of settlement reorganization during the MBA 3 — both in the internal settlement layout and herding practices, that accommodated the increased metallurgical activity.

A spike in production during the MBA 3, coinciding with the decline at Pecica, is also observed at Klárafalva. While at the late stage of Rabe the contamination pattern seen in animals and soils reminds of the one at Pecica, Klárafalva presents a different picture. Here, the increased metallurgical production and its associated level of contamination was detected across all taxa — including deer. This pattern suggests Klárafalva's broader footprint of metallurgical activity. This signature could be the result of the extension of settlement activities into the drier areas surrounding the site, or an overall drier period that allowed wild game to come closer to the site.

Kiszombor, like other lower Maros sites, maintained a community-level of metallurgical activity throughout its occupation, though with varying intensity. While at Klárafalva the highest contamination was observed during MBA 3, at Kiszombor the higher spread of contamination occurred much earlier in the Maros sequence. As the earliest analyzed Maros sites, O'Shea (in press) and Papalas (2008) show differences between the early and later stages of the sites, which coincide with the contamination detected in this work. While animal contamination shows similar patterns and intensities throughout its occupation, soil evidence becomes a less variable signal during the later phase of the site, dated to EBA 2. No significant spatial differentiation has been identified in animals. On the contrary, soils show the highest contamination evidence from the area of the ditch that surrounded the site, possibly implying that the activity could have been conducted in its surroundings. However, this interpretation is worth taking with a grain of salt, as O'Shea (in press), reports that the core of the site has not been excavated, so any other temporal or spatial patterns might be obfuscated by this excavation bias.

However, despite the patterns presented, including reorganization efforts, none of the sites, apart from Pecica, ever reached workshop-level metallurgical production. Nevertheless, the emerging patterns not only highlight similarities and differences in contamination across the lower Maros region, but also likely imply forms of inter-community collaboration, which could be related to their proximity to the wetlands.

12.1.2.1 Maros Metallurgical Production and Prehistoric Land Use

In their analysis of the Maros settlement systems, O'Shea and Nicodemus (2019) stressed the differences in settlement size between the lower and upper Maros regions. Undoubtedly, one of the confounding factors in settlement size is proximity to wetlands and the availability of dry land around each site (Figure 12.5).

Based on the reconstructed watershed from the 19th-century Austro-Hungarian maps (Duffy et al. 2022), all sites in the lower Maros region appear to have been situated within the wetland zone. In addition to constraining the community's ability to expand its territory, wetlands also provided a rich, predictable environment, yet one more susceptible to climatic fluctuations.

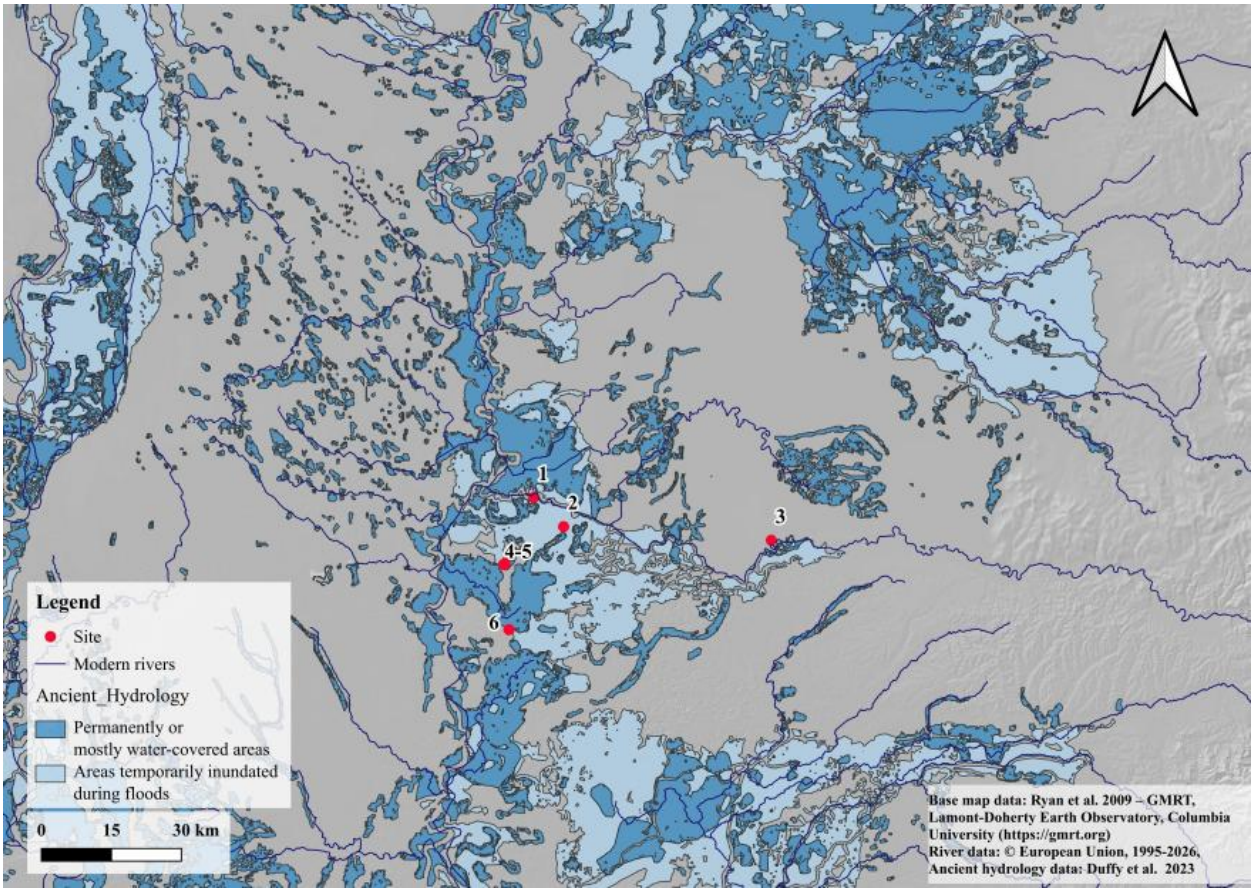


Figure 12.5 Map showing reconstructed watersheds based on a 19th-century historical map. Red dots indicate the sites analyzed: 1 – Klárafalva Hajdova, 2 – Kiszombor Új Élet, 3 – Pecica Şanţul Mare, 4 – Rabe Anka Siget, 5 – Majdan 28, and 6 – Crna Bara–Prkos. Watershed boundaries were refined using supplementary data from Duffy et al. (2023). Map by Györgyi Parditka.

Climatic reconstructions presented in Chapter 5, point to a colder and drier climate during the MBA 2. This colder and drier climate likely affected communities in the wetlands more strongly than those on the margins, such as Pecica (Figure 12.6). The lower contamination levels and reduced metallurgical production at all sites except Pecica during this period suggest a possible correlation between settlement reorganization and environmental changes within the wetlands. Although climate was certainly not the sole factor, the prolonged colder and drier conditions may have contributed to shifts in the social landscape and in the organization of settlement labor, particularly if this period saw a contraction of wetland areas. The drying of seasonal wetlands, and thus lessening of seasonal flooding, would have created both new opportunities and new challenges, potentially prompting communities to broaden or adjust their subsistence strategies.

This pattern is perhaps most visible at Klárafalva, located only 350 m from the Maros River. During MBA 2—the middle phase of the site's occupation (dated to 1825–1689 BCE)—the community appears to have focused more heavily on fishing activities and on smaller livestock (Nicodemus, in press). At Rabe, MBA 2 corresponds to a period of significant expansion (similar to Pecica), during which the settlement likely extended its territory, which coincides with the first phase of occupation at Majdan 28. Along with the expansion of the settlement and decrease in metallurgical contamination relative to MBA 1, it is possible that the community at Rabe shifted its priorities to focus on subsistence security. Although still subject to further investigation, evidence dating to the MBA 2 found in the middle tell indicates an increased presence of food remains and storage features at both sites from this period (Nicodemus 2018; see Majdan 28 report in Appendix A).

From the evidence presented above, a possible correlation between settlement reorganization and environmental change appears within the wetland zone. The notably lower contamination levels and reduced metallurgical production during MBA 2 at all sites except Pecica suggest a broader reorganization of regional roles. Pecica appears to have held a near-monopoly on metallurgical production during this period, while other communities may have invested more heavily in complementary activities or in alternative subsistence strategies, reflecting an adaptive response to both environmental and social change.

The drying of seasonal wetlands would have created both new opportunities and challenges for communities accustomed to predictable seasonal inundations. It is likely that sectors such as agriculture would have been among the most affected, potentially forcing communities to broaden their diet or adjust their subsistence strategies.

In a recent study (Tomažič et al. 2026) examining the Maros diet between 2100 and 1500 BCE using carbon and nitrogen stable isotopes from humans and animals the cemeteries of Mokrin and Ostojićevo, we identified a subtle dietary shift beginning in MBA 2. Prior to this period, communities exhibited broadly similar diets based on livestock, wild animals, and C3 plants. After ca. 1800 BCE, however, the isotopic values show a slight broadening of both carbon and nitrogen signatures. Although these differences are small, they may reflect the incorporation of additional foods or changes in food processing within the broader subsistence strategy.

While this interpretation was not explored in the original publication, the dietary changes may relate to the dynamics outlined in this study. Environmental fluctuations during MBA 2—particularly within the wetland zone—may have prompted a reorganization of resources and subsistence practices, especially among communities whose livelihoods were closely tied to wetland ecologies.

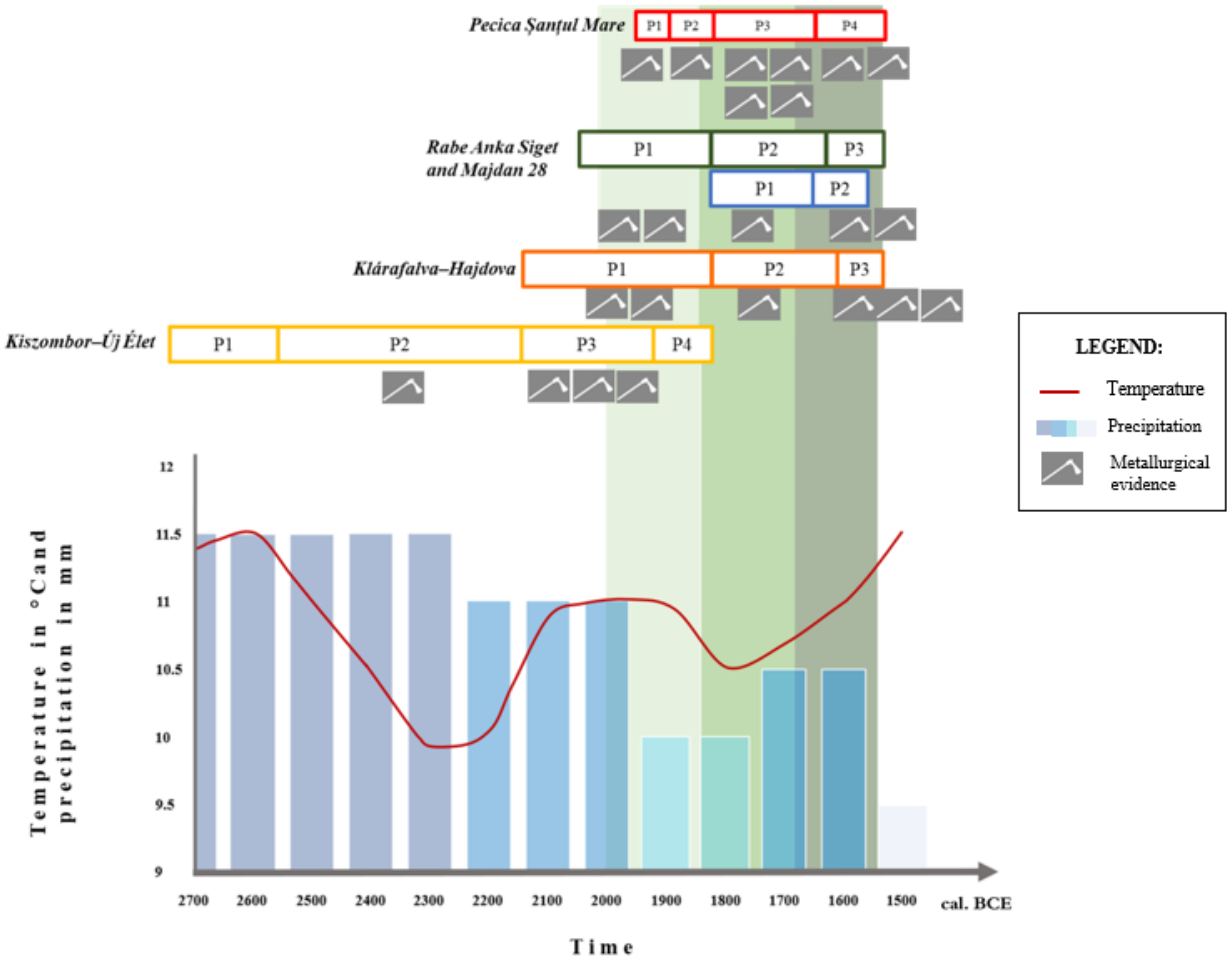


Figure 12.6 Climatic reconstruction from 2700–1500 BCE, derived from larger regional environmental datasets (Drăguşin et al. 2014; Demény et al. 2019; Molloy et al. 2023), illustrates average precipitation and temperature trends over time in relation in relation to the site phases (P) and their associated metallurgical evidence and intensity (indicated by the grey box marked with an axe symbol)

MBA 3 (1690–1550 BCE), by contrast, presents environmentally a markedly different picture, with increasing temperatures and precipitation. At the settlement level, this period is characterized by a decrease in settlement size and metallurgical production at Pecica, while production increases at both Rabe and Klárafalva. With Pecica reverting to a pattern more

reminiscent of its Early Bronze Age state, it is possible that metal circulation was reorganized along the Maros River or that a new exchange network emerged. This interpretation is supported by the surge in tin signatures in soils from the western tell at Rabe, suggesting a shift in production intensity during this phase.

Another instance of correlation between environmental conditions in the wetlands and labor organization can be observed between 2100 and 1900 BCE, corresponding to EBA 2 and MBA 1. This period reflects higher temperatures and increased wetness, during which all sites show elevated contamination levels and higher metallurgical signatures. Conversely, around 1500 BCE—when precipitation declines—the drop in wetness coincides with the abandonment of the Maros region and the collapse of other polities across the eastern Carpathian basin.

In summary, periods of low precipitation would have placed particular pressure on communities living within the wetlands, forcing them to adjust their resources and priorities. In such conditions, communities may have shifted their focus toward securing subsistence and broadening their management practices to buffer against increased environmental uncertainty. Perhaps communities placed greater emphasis on differential food processing, including practices such as drying, fermentation, and storage.

It is also possible that after some attempts (as a last resort or as a result of persuasion), communities unable to adapt to these changes joined larger settlements, which could explain the expansion of sites such as Rabe and Pecica during MBA 2. At Pecica in particular, the influx of people may have contributed to the rise in metallurgical production, which in turn could have supported and sustained the growing population. Similarly, high climatic variability may have strained these communities, contributing to the overall collapse of communities, not just Maros, around 1500 BCE.

Nevertheless, the periods of increased metallurgical production, visible at both the site and regional scales, not only resulted from socio-environmental dynamics but also affected local environments by altering soil chemical signatures and impacting humans and animals alike.

Furthermore, these levels also contributed to the global patterns of contamination dated to the Bronze Age that environmental scientists have detected (Longman et al. 2018).

12.1.2.2 The Impact of Maros Metallurgy and Implications of This Work

Three major heavy-metal contamination peaks have been detected throughout human history, aside from the modern-day spike (Longman et al. 2018). While these peaks are globally averaged signals, it is important to emphasize that they represent the cumulative contributions of many regional societies, including the Maros.

When we compare these global curves with the archaeological evidence for metallurgical production in Europe outlined in Chapter 5, it becomes clear that the Bronze Age peak most closely corresponds to the Middle Bronze Age in the study region. However, several smaller regional surges—such as the one detected in the Early Copper Age—likely contributed to the overall accumulated signal detected in the Bronze Age.

It is fair to assume that communities in the Tisza–Maros region contributed to these global contamination levels. Although Maros communities—aside from Pecica—did not show large evidence of metalworking in the archaeological record, all of the communities contributed to the global rise in contamination detected by environmental scientists. However, the way they contributed to global contamination levels is highlighted in this research. Maros' contribution to global contamination was not uniform, neither through time nor between settlements; rather, it varied and depended on a range of factors to which communities responded.

A particularly interesting implication of this work is the community's reaction to the intensification of metallurgical production. Maros communities appear to reorganize their settlements to separate animals from production areas. This may reflect an awareness of the hazards associated with metallurgical work—such as increased fire risk, strong odors, or the practical desire to keep waste away from domestic or work spaces. O'Shea (in press) already notes that Maros house floors are typically clean and uncluttered, and there is no evidence that livestock were kept inside houses, unlike what is seen in many Neolithic (Whittle and Cummings 2007; Mlekuž 2015) or Iron Age contexts across Europe (Løken 2020:58). Instead, animals were likely housed elsewhere, possibly in sheds or designated areas within the settlement. The PCA soil results

support this interpretation: soils from the sites cluster either as metallurgical-related deposits or as deposits with high tin content. However high levels of P and Zn also indicate organic rich deposits. The latter plausibly representing areas where animals were kept or dung was deposited.

It is also possible that the separation of space during intensified activity may have had more abstract motivations as well, such as beliefs surrounding metallurgical production. Whatever the underlying reason, the deliberate spatial separation of activities represents an active societal choice—one that left clear, traceable signatures in the archaeological record.

The ability to trace contamination levels was made possible by a structured, multilayered methodological approach, which is another key implication of this work. The sampling strategy employed here enabled a broad, comparative perspective across multiple lines of evidence and allowed differences through time to be clearly identified. The choice of sampling materials—particularly teeth and soils—proved especially productive. Although originally intended as redundant datasets, they revealed distinct and complementary aspects of the relationship between communities and metallurgical activity: animal teeth reflected the domestic and dietary dimensions of this relationship, while soils captured the spatial and technological signatures of metallurgical production.

The methodological approach of this work can be seen as another means of monitoring metallurgical activities and their intensities in the absence of, or in the extreme scarcity of, associated archaeological material, such as slag and kilns. Such methodology can thereby be used as a tool in reshaping our understanding of metallurgical organization both at the settlement and regional level. In the present case, this work demonstrates that different communities not only practiced metallurgy in varying intensities but also adjusted their husbandry strategies accordingly—adjustments that were closely tied to the availability of surrounding land at any given time. These patterns speak to the communities' detailed knowledge of their environments and to the management strategies they employed in response to changing conditions.

For communities situated closer to the wetlands, environmental and ecological changes would have had a particularly strong impact on their ability to pasture animals—especially larger livestock such as cattle or horses.

Another important takeaway from this research is the result from the LA-ICP-MS. With this technique, I was able not only to determine the presence or absence of contamination in the teeth but also to locate its source (diagenetic or metabolic) and to identify episodic contamination events rather than constant exposure.

The results from the LA-ICP-MS are supported by the Ba/Ca values, presented in Chapter 10. The results suggest that all animals, including pigs, may have been pastured in nearby woodland areas, as their values overlap with those of deer. Alternatively, the location where animals were kept may have shifted, and fodder collected from these forested zones may have been brought back and fed to them. These nuances present another avenue for research, which will be explored in greater detail in future work.

Once all evidence is combined, broader patterns suggest a possible correlation between wetter periods and heightened metallurgical activity. I use the word possible deliberately, as the environmental reconstructions for this region remain relatively coarse and should be interpreted with caution. However, the fact that all analyzed communities exhibit similar trajectories suggests that broader factors are at play, and whether environmental conditions and the timing of metallurgical production may have contributed to the observed patterns is worth exploring in the future. While environmental change was almost certainly not the sole factor contributing to shifts in social networks and the intensity of metallurgical production, it is one factor worth considering when examining settlement or regional changes and patterns.

The implications of this work also extend into broader theoretical perspectives, highlighting the strengths of archaeology when multiple lines of evidence and multidisciplinary approaches are combined. This research demonstrates that archaeology can meaningfully contribute to debates on past contamination and pollution, standing alongside other scientific fields. Indeed, I would argue that archaeology offers uniquely detailed insights: our ability to reconstruct patterns of behavior within individual communities, across regions, and through time, without encountering the constraints faced by many other sciences. Although archaeological interpretations always carry the risk of over-generalization, it is important to recognize archaeology as a valuable contributor to global conversations. Rather than focusing solely on gaps

or limitations, we should confidently demonstrate what archaeology can reveal about human–environment interactions and the long-term consequences of human activity.

12.2 Conclusion

In shaping the *Dangerous Technology Project,* my aim was to examine how metallurgical intensity changed over time and how this activity impacted societies. While the results were interesting, they revealed a much more complex picture that highlighted some limitations of the project, which are shaping the directions of future work.

While the broad temporal span showed interesting variation in intensity, one limitation concerns the coarse temporal resolution for the Copper Age assemblages and the need for larger sample sizes, particularly soils from controlled excavations. This is especially significant due to the discovery of contamination in Copper Age deposits in Pecica, which might indicate some of the first local metallurgical productions despite the lack of metallurgical production evidence in these deposits.

A larger sample size might have highlighted temporal changes in metallurgical production during the entire Copper Age, illuminating how these earlier dynamics influenced the networks established in the Bronze Age. Furthermore, adding evidence from other Bronze Age societies located outside the wetland zone would show whether the identified variations were culturally specific, environmentally driven, or general patterns shared across communities.

A way forward for this methodology is to refine it to reduce costs and increase efficiency. This includes micro-sampling across the entire enamel–dentine junction and incorporating histological analyses. Together, these approaches would provide a finer temporal resolution of individual animal exposure and may allow the identification of more detailed patterns of contamination.

Finally, it has been argued that societies thrived in wetlands environments, including in this region long before the Maros (Sava 2015). By comparing lives of wetland communities across regions and time periods, we can begin to change the modern stigma of wetland environments and inhabitable ecologies. Proven by the archaeological record, wetlands provide a buffer against food insecurity during periods of instability. Thus by analyzing the life of past wetland communities,

we can parse the behaviors required not only to survive but also to thrive in these environments. This provides a great opportunity for technological and substance sustainability in the Anthropocene. For the Tisza-Maros region however, a more precise environmental reconstruction of the region would greatly enhance our understanding of how wetland communities interacted with their surroundings over more than three millennia.

Finally, the present work, while reinforcing existing archaeological interpretations about metallurgical production, also reveals nuances in the relationship between humans, technology, and the environment. These nuances underscore the deep interconnectedness of past societies and how they changed over time, in turn shaping long-term human–environment dynamics. Metallurgy did, in fact, change human societies by not only altering their socio-economic dynamics but also their subsistence strategies and biological systems.

Appendices

Appendix A: Rabe Anka Siget and Majdan 28 Fieldwork Report

This appendix provides the reports from fieldwork at Rabe Anka Siget and Majdan 28. It summarized the coring season 2021 and the excavation season in 2022.

The work at Rabe Anka Siget started as part of the RASAP project, a project co-lead by the University of Wisconsin, University of Michigan and the Balkan institute of Serbia.

a) Coring at Rabe Anka Siget and Majdan 28

At Rabe Anka Siget, three types of fields were sampled: agricultural fields under a rotation of onions, sunflowers, wheat, and corn; pastureland; and woodland. In the western portion of the tell, two cores were taken—one in the pasture (Core 32), located at the highest point of the mound where sterile soil was reached at 1.80 m, and one in the adjacent forested area (Core 33). The forest core was included to establish a background signature for comparison with agricultural areas, as this portion of the site has remained undisturbed for at least a century (Table A.1).

Coring was conducted in 2021 with an auger corer and AMS core. The coring was done to assess the depth of the sites in various locations, collecting stratified samples and to gain material for dating with AMS core. In 2021 I conducted an extensive coring season with 33 cores spread throughout the site (see Chapter 8). For the summer season of coring, I used the auger corer with a special sampling protocol (details outlined under the soils section in Chapter 8). In fall 2021, we returned to the site to conduct three more cores, this time with an AMS core, which allowed us to reach sterile of each area.

Core	Collection season	Corer type	Number of collected samples	Location of the core	Depth reached	Cult Depth
1	Summer 2021	Auger	9	Ditch	90 cm	< 90 cm
2	Summer 2021	Auger	10	Ditch	90 cm	< 90 cm
3	Summer 2021	Auger	9	East area	90 cm	< 90 cm
4	Summer 2021	Auger	10	East area	90 cm	< 90 cm
5	Summer 2021	Auger	9	East area	90 cm	< 90 cm
6	Summer 2021	Auger	12	East area	90 cm	< 90 cm
7	Summer 2021	Auger	7	East area	90 cm	< 90 cm
8	Summer 2021	Auger	9	East area	90 cm	< 90 cm
9	Summer 2021	Auger	9	East area	90 cm	< 90 cm
10	Summer 2021	Auger	10	East area	90 cm	< 90 cm
11	Summer 2021	Auger	8	East area	90 cm	< 90 cm
12	Summer 2021	Auger	8	East area	90 cm	83 cm
13	Summer 2021	Auger	9	East area	90 cm	< 90 cm
14	Summer 2021	Auger	10	East area	90 cm	< 90 cm
15	Summer 2021	Auger	9	East area	90 cm	< 90 cm
16	Summer 2021	Auger	10	East area	90 cm	< 90 cm
17	Summer 2021	Auger	10	East area	90 cm	75 cm
20	Summer 2021	Auger	10	Middle tell	90 cm	< 90 cm
21	Summer 2021	Auger	8	West tell	90 cm	< 90 cm
22/23	Summer 2021	Auger	8	Outside East	90 cm	< 90 cm
24	Summer 2021	Auger	8	Northern marshes	90 cm	73 cm
25	Summer 2021	Auger	8	East area	90 cm	81 cm
26	Summer 2021	Auger	12	West tell	90 cm	< 90 cm
27	Summer 2021	Auger	11	Middle tell	90 cm	< 90 cm
28	Summer 2021	Auger	11	Middle tell	90 cm	< 90 cm
29	Summer 2021	Auger	11	East area	90 cm	< 90 cm
30	November 2021	AMS	22	West tell	278 cm	~240 cm
31	November 2021	AMS	31	Middle tell	220 cm	200 cm
32	November 2021	AMS	15	East area	150 cm	100 cm
33	November 2021	AMS	17	West - forest	184 cm	~ 85-110 cm

Table A.1 Core information, including number of samples collected

Most cores were placed in the far eastern portion of the site, an area hypothesized to have been an activity zone. These cores revealed numerous pits and substantial quantities of daub, with sterile soil reaching approximately 1 m depth. In contrast, cores from the middle (core 31)

and western (core 32 and 33) portions of the tell required much deeper sampling; sterile was only reached around 2m using the AMS corer in November 2021.

b) Excavation

Excavation of Test Unit 3 (eastern portion of the Rabe Anka Siget tell) and Test Unit 4 at Majdan 28, were conducted in the summer of 2022. Strata was hand excavated by natural/cultural layers. Features were half-sectioned to examine the internal layer structure of features and were recorded separately. All excavated sediment was measured by volume and 10% of sediment within each discrete context was screened to recover a sample of small artifacts. From each deposit a a sample of maximum 100g was taken for trace element analysis, while the rest (maximum volume 10 liters) was also for flotation to obtain a 100% subsample of deposit materials, including botanicals.

Each stratum and feature were documented on field forms. All strata and features were photographed, hand and digitally mapped with a Sokkia Total Station.

Diagnostic artifacts (ceramic rims, handles, bases, decorated body sherds, lithics, metals, worked bone, etc.) and samples were plotted in 3D with the total station to provide precise locational information.

All hand-collected artifacts were washed, sorted, counted, and weighed by a discrete collection unit (lot). Diagnostic artifacts were photographed, while a sample of these diagnostics was drawn. Artifacts are curated at the Kikinda National Museum. Teeth and soils samples were collected for ICP-MS analysis following the procedure outlined in Chapter 8.

Test Unit 3 – Rabe Anka Siget

Test Unit 3 was located in the eastern part of the site, an area referred to as the "outer mound" in the 2018 report (Nicodemus 2018). Work in this area was carried out between 2017 and 2021.

The unit placed at the site during summer 2022, measured 2 × 2 m, and sterile soil was reached at 1.23 m. Excavation revealed a sequence of superimposed pits, confirming the high level of disturbance suggested by the geomagnetic survey.

These pits emerged immediately below the ground surface, filled with pottery, bone, and other materials, including a shell. The pits were concentrated primarily in the southern portion of the

unit. Intact layers were limited and restricted to the northwest corner. No structural deposits were identified, aside from general architectural debris.

Artifact composition was dominated by non-diagnostic pottery sherds, which accounted for 79.4% of all finds. Bone and shell formed the second-largest category, with bone comprising 23.13% of the assemblage. Two slag fragments were also recovered, although no direct evidence of metallurgical activity was identified in this unit. Artifact density varied across layers and features, with an almost equal distribution between the two in TU3 (Figure A.1).

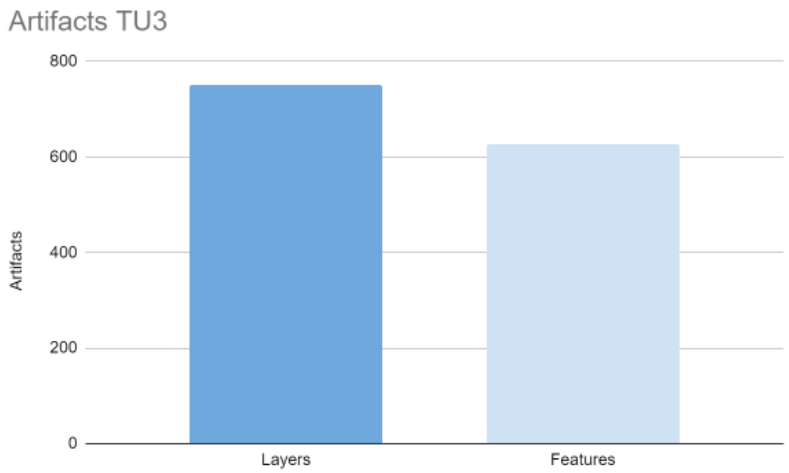


Figure A.1 General artifact distribution and comparison of density between layers and features from TU3

A horizon

The A horizon is a highly disturbed stratum averaging 27 cm in depth. The uppermost part of the A horizon is very loose and filled with fresh wheat roots. The soil is black (2.5Y 2/1) silty clay with heavy bioturbation. The consistency of the deposit changed deeper, going from loose to extremely compact toward the bottom.

The recovered artifact density was medium compared to other strata. Artifacts mostly include ceramics, bones, one shell, two grinder stones, and a few fragments of medieval ceramics. The material are Bronze Age, which the vast majority belonging to the Maros culture, evidence of Belegiš and Vatin were also present.

Layer A

Layer A is the first semi-intact cultural stratum underneath the A-horizon. It averages 14 cm in depth and comprises dark brown (7.5YR 3/3) silty-clay. Although Layer A is an extremely compact deposit, resulting from agricultural activities and unusually dry weather conditions months prior to excavation. Layer A presents a small amount of architectural rubble with medium artifact density, primarily pottery, bone, and clay. A small amount of diagnostic pottery was recovered from this deposit. The deposit extended over the entire unit, except the southern part, which was cut by feature 26.

Layer B

Layer B consisted of an intact deposit, exposed to high temperatures and located underneath layer A. Approximately 7.5 cm thick on the western portion of the test unit and decreased toward the east, this friable deposit consisted of burned clay - yellowish red (5YR 5/6) and unburned clay - pale brown (2.5Y 7/3) silty clay deposit.

The artifact density was medium, presenting some ornamented and burnished pottery and bones. The deposit was disturbed by animal barrows, particularly prominent on the western portion of the test unit, a layer identified as Feature 31. The southern portion of the layer was cut by Feature 26.

Layer C

Layer C is a 25.5 cm thick deposit that lies underneath layer B. This silty clay greyish brown (2.5Y 5/2) deposit was filled with charcoal flakes and presented a high density of artifacts, including ceramics and animal bones. Layer C was cut by Feature 34 on the east side, Feature 31 on the west side, and Feature 26 on the southern portion of the deposit. From layer C onward, the test unit was half-sectioned.

Layer D

Layer D, uncovered only in the western portion of the test unit, was a highly disturbed deposit from animal burrows. Located underneath layer C, this deposit was approximately 6cm thick. This greyish brown (2.5Y 3/2) deposit was compact and more organic, clayier layer.

Presenting low artifact density (rusticated pottery fragment found in this layer) (Figure A.2) compared to other layers, this deposit resembles a walking surface.



Figure A.2 Diagnostic pottery from Layer D from the TU3. Courtesy of Amy Nicodemus

Layer E

Layer E extended through the entire western portion of the test unit and was roughly 31cm thick. The layer was a very dark grey (10YR 3/1) deposit. The deposit had a silty clay consistency, but it was more coarse and <10% and presented low artifact density and less rodent disturbance in comparison to layer D.

Layer F

Layer F underlies layer E and is approximately 23cm thick in the middle of the sondage and thins toward the west. The layer was a light yellowish brown (2.5 Y 6/3) silty clay layer with low artifact density - small shells and daub flakes. The layer was sloping south and was cut by feature 35; under layer F, there was a sterile layer - that reached 123 cm.

Feature 26

The feature pit, located in the southern portion of the test unit, appears at the base of the A-horizon. The feature was cut in half by the test unit, which excavated dimensions were 150x81x30 cm. The feature is a late medieval pit, with mixed Sarmatian, Bronze Age, and Medieval material, including burned bones and shells. The concave shape of the pit was disturbed by numerous animal barrows, particularly in internal layer 2, which was a much looser deposit. The material from the layers did not change. The feature cut through layers A-C.

Feature 27

Feature 27 was a pit identified in the southwestern corner of the unit, of the approximate size of 60x30x59cm. The pit cuts layer F and is cut by features 31 and 35. The overall shape of the pit is hard to determine, but it presented a concave base. The feature was full of dark burned soil, architectural debris, pottery, bone and shell.

Feature 31

Feature 31 was a pit that appeared to be sealed by the very compact layer A. The feature dimensions were 50x40x76cm and extended through almost half of the test unit. The pit cut layers from B through E, cut features 27 and 35. The relationship between Feature 26 (the medieval pit) and Feature 31 cannot be determined. The pit presented straight edges and a concave base and appeared to be filled in numerous episodes and presented five distinct internal layers. The pit was disturbed by animal borrow but presented a high artifact density, including a large Vatin pot (Fig A.3), a complete single-handle Maros jar, and a high density of architectural debris. The pit contained few bones but no shell.



Figure A.3 The large Vatin pot recovered from Feature 31. Figure showing the placement of the sherds during excavation, along with a large amount of sprouted seeds (on the left) and the reconstructed pot (on the right)

Feature 34

Feature 34 was a pit identified in layer C on the eastern past of the test unit. Presenting a relatively shallow pit (80x20x20 cm), the pit had a concave base. Upper layers might have disturbed the pit, as it showed a brown fill and only one pinched fillet body sherd.

Feature 35

Feature 35 was a pit cut in layers D-F, and feature 27 was but by feature 31. The feature is a concave pit with two layers. IL 1 was filled with burned architectural debris, soil, high density of artifacts in the upper layer. Within the feature 35 fill, there was Belegiš pottery found, which could have been brought into the deposit through either feature 31 or the animal barrow located on the northern edge of the pit.

While the IL2 presented the remains of a clay ring. In the middle of the ring there was whole two-handle small jar and three cattle horns with possible bitumen (?) remains on the inside of each horn and their surrounding.

It appears that Feature 31, damaged Feature 35, thus they present distinct chronological distinct episodes.

The final stratigraphical drawing was done on the last day of excavation (Figure A.4). The drawing shows a continuing stratigraphy of the test unit, starting at the south-west corner.

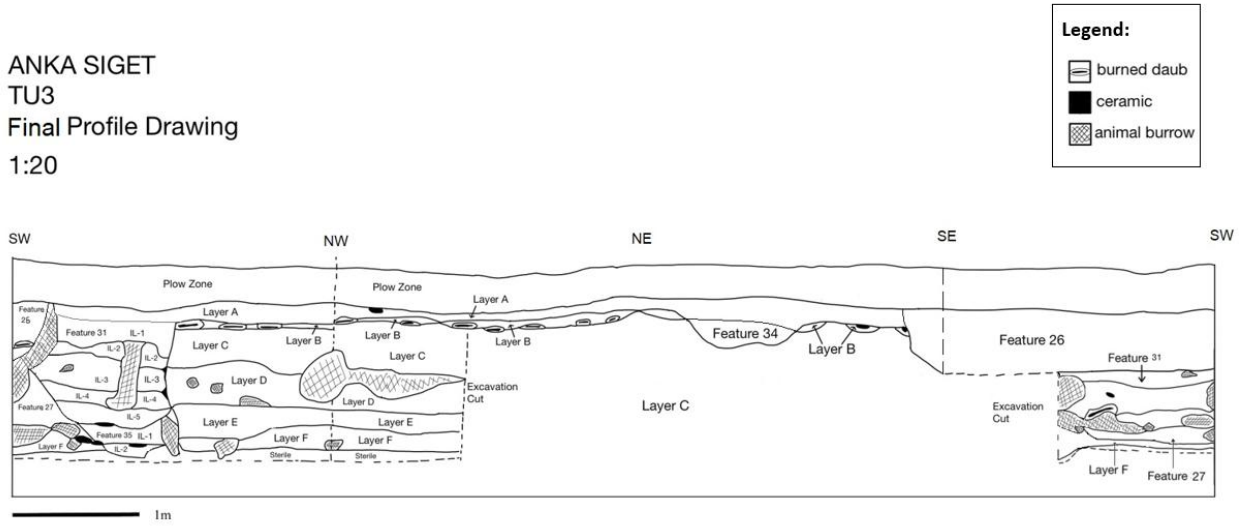


Figure A.4 Drawing of the stratigraphy of the TU3. Digitalized by Sila Duzgun

In December 2024, the results of the radiocarbon dates were received from The University of Georgia, Center for Applied Isotope Studies (Table A.2). The results confirm that Feature 31 was much later than the bottom deposits of the test unit.

Site	Context	Lab ID Sample	Material	Median Probability	14C years, BP	±	1σ Range
Rabe	TU3, F31	RA57-1223-0068	tooth	1674 BCE	3390	25	1732-1631
Rabe	TU3, Layer D	RA56-1223-0067	tooth	1909 BCE	3560	25	1947-1882

Table A.2 Radiocarbon dating results from Rabe Anka Siget TU3

In summary, while test unit 3 shows an area with dense occupation that spanned a longer period of time, no house debris was found. From the limited excavation of test unit 3, it's possible to conclude that the eastern portion of the site was most likely a multipurpose activity area, rather than specialized, composed by pits filled with refuse debris, walking surfaces, which were intentionally sealed and burned, seen by layer B.

However, the area continued to be occupied after this event, seen by Vatin material from the large pit (Feature 31) which cut the Maros deposits, and even later during the Medieval period, visible by Feature 26.

Test Unit 4 – Majdan 28

Majdan 28, first identified by Trifunović (2012) and later surveyed by Daković (2023), is located southwest of the western mound of Rabe Anka Siget, across the system of channels. Pedestrian survey, coring, and geophysical prospections were conducted at the site. These investigations revealed evidence of Bronze Age, Medieval, and nineteenth-century occupation. Coring carried out in 2021 confirmed the presence of Bronze Age (Maros-period) deposits (core number 8). Chemical analysis of sediment using ICP-MS showed notably elevated tin concentrations compared to other sampled areas.

The Test Unit 4 excavation followed the test unit strategy of 2018, with a 2x2 m2 test unit, in which corners were recorded with the total station. The excavation, recording, material collection and flotation sample-taking followed the strategy outlined in the methodology. Additional sediment samples were collected for ecological chemical analysis with ICP-MS.

The site was visibly damaged by deep plowing. No structural deposits were found, but the very bottom of a thermal feature was recovered.

The density of artifacts in TU4 was much lower than TU3. In which the highest number of artifacts were the non-diagnostic sherds (56.36%). The second highest are bone and shell, in which 86.01% is bone. Within all artifacts there was also found ten slags. In terms of layers and features artifact distribution, the layers had a much higher artifact amount (Figure A.5).

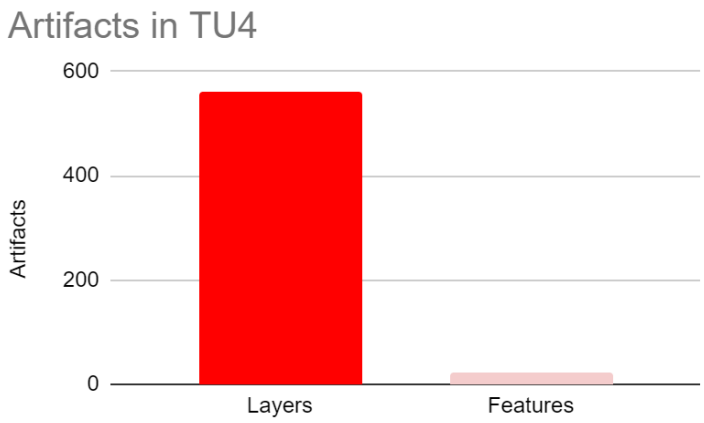


Figure A.5 General artifact distribution and comparison of density between layers and features from TU4

A-horizon

The A-horizon is a highly disturbed stratum averaging 40 cm in depth. The uppermost part of the A-horizon is friable and loose but gets more compact toward the bottom. The very dark grey deposit (10YR 3/1) layer was filled with sunflower roots and presented medium artifact density, with some pottery (primarily Maros), bones, and modern debris (modern glass and brick). The plow scars ran very deep, visible even in layer A.

Layer A

Layer A covers the entire unit and was roughly 14cm deep. Presenting still evidence of plow scars, this very dark greyish brown deposit (10YR 3/2) was a silty, more organic soil with high density of burned daub fragments and relatively high pottery density. The pottery was covered in calcination, which turned out to be concentrated and assigned as feature 37.

Layer B

Layer B stretches though the entire unit and is roughly 33cm thick. This brown deposit (10YR 3/3) presented almost no visible difference compared to layer A, except a drastic difference in artifact density. Layer B presents low artifact density and was cut by feature 40 located on the western portion of the test unit.

Layer C

With layer C the unit was half sectioned and extended over the eastern portion of the unit. The roughly 23 cm thick deposit was a clayier, more organic and compact brown (10YR 3/3) deposit, filled with small pieces of burned bone and presenting low pottery density. Animal activity was prominent in this deposit.

Layer D

Layer D sloped toward the south from 10 to 2 cm thickness. Identified only in the eastern portion of the unit, this brown (10YR 4/3) silty clay layer presented low artifact density.

Layer E

Layer E was located under layer D and was approximately 30cm thick. Presenting a brown layer (10YR 4/3), the deposit was lighter in color (going from brown to dark olive brown - 2.5Y 3/3) and more compact toward the bottom. This layer was majorly disturbed by animal activity and presented low artifact density. Under layer E there was the sterile deposit - reached at 94 cm.

Feature 37

Feature 37 was identified as a pottery concentration within Layer A. The feature measured approximately 100 × 100 × 5 cm and appeared roughly circular, forming a shallow, flat-bottomed basin (Figure A.6). It most likely represents the very base of a lined thermal feature. The deposit consisted of flat-lying sherds from two vessels (one cooking pot and one fine ware jug, neither complete) along with fragments of daub. Much of the pottery was covered with concretion. The feature had been disturbed by ploughing and agricultural activity, as evidenced by the spread of sherds across the test unit.



Figure A.6 Remains of thermal feature (Feature 37) from TU4 destroyed by ploughing

Feature 40

Feature 40 was a pit located in the western portion of the test unit which was cut in layer B and sealed by layer A. The pit was a circular pit with concave sides and flat base. The fill or the pit was filled with small daub flakes and became looser closer to the bottom. Within the fill there was a large brazier (Figure A.7), some vitrified material (slag?) and pottery fragments.



Figure A.7 Fragment of the large brazier found in Feature 40 in the TU4. Photo by Gyögyi Parditka

Feature 42

Feature 42 was a pit feature, 70x50x60 cm located on the southwest corner of the test unit. The feature was overlaid by layer A and cut into layer B. Showing a circular shape, with vertical walls and a flat bottom. The fill of the pit was a hard grey, extremely silty, ashy, almost powdery-like deposit. This deposit was sampled in 2022 through Core 8, which presented evidence of tin. The fill presented charcoal pieces, higher artifact density, including fine ware, a high concentration of fish bones, slags. The deposit closer to the bottom of the pit changed and consisted primarily of rubble and pottery. The density of artifacts decreased toward the bottom of the pit.



Figure A.8 Southern part of TU4 showing the half-section of Feature 42 along with the south profile

In summary, Test Unit 4 at Majdan 28 suggests a shorter or more episodic occupation compared to TU3 at Rabe. The high degree of disturbance—visible in the straight, uniform base of the A-horizon and in deep cuts reaching up to 60 cm—indicates that later occupation layers may have been completely removed. Based on the limited excavations, this portion of the site may have functioned as a multipurpose cooking or activity area. This interpretation is supported by the mixed assemblage recovered across the unit, including the base of a thermal feature (Feature 37), a large brazier from Feature 40, and the substantial quantity of fish bones recovered from Feature 42 (Figure A.9). The presence of slag, ash, and pottery further suggests that Feature 42 may have served as a refuse pit associated with nearby activities, potentially including limited metallurgical processing.

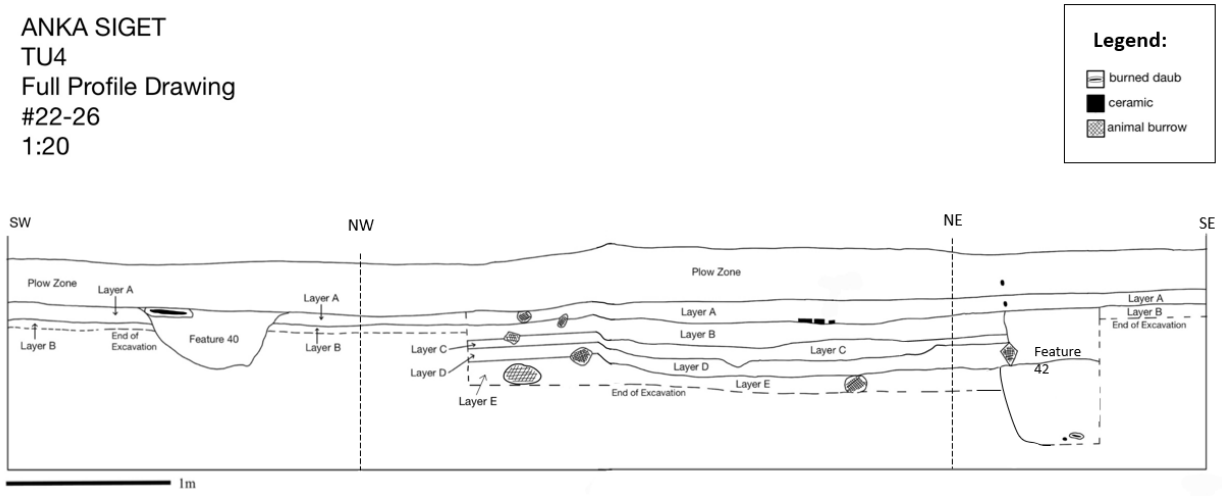


Figure A.9 TU4 profile unit drawing, showing the stratigraphy throughout the entire test unit. Drawing digitalized by Sila Duzgun

The relative dating of the site was hard to establish due to the lack of diagnostic chronologically significant sherds. Absolute dating, conducted at The University of Georgia (same as samples from TU3), however showed that the site dater between ca. 1800-1645 BCE (Table A.3).

Site	Context	Lab ID Sample	Material	Median Probability	14C years, BP	±	1σ Range
Majdan	TU4, Layer A	RA52-1223-0060	tooth	1746 BCE	3440	25	1868-1850
Majdan	TU4, Layer D	RA49-1223-0057	tooth	1780 BCE	3460	25	1873-1846
Majdan	TU4, F42	22-426	bone	1645 BCE	3360	25	1730-1723

Table A.3 Radiocarbon dating results from TU4

Appendix B: Animal Teeth Samples Results

Appendix B presents the tooth evidence analyzed in this dissertation. This section primarily contains tables detailing information about individual tooth samples, including all available contextual and recording information. Three major tables are provided: (1) basic information about each sampled tooth (Table B.1), (2) detailed metadata for individual samples (Table B.2), and (3) the results of ICP-MS analysis (Table B.3). Together, these tables offer a comprehensive overview of the dental dataset used in this study.

Site	***Sample #***		***Tooth information***			***Context***
	On the bag	*Lab ID*	**Taxon**	**Common name**	**Tooth sampled**	
Klárafalva Hajdova	KF72-21	KF21-1023-0001	*Ovicapridae*	Sheep/goat	LM3	B1
Klárafalva Hajdova	KF123-23	KF23-1123-0002	*Ovicapridae*	Sheep/goat	LM3	E1
Klárafalva Hajdova	KF824-28	KF28-1123-0003	*Ovicapridae*	Sheep/goat	RM2	C1; F44/IL1
Klárafalva Hajdova	KF763-29	KF29-1123-0004	*Ovicapridae*	Sheep/goat	LM3	E1
Klárafalva Hajdova	KF237-25b	KF25B-1123-0005	*Ovicapridae*	Sheep/goat	LM3	A2
Kiszombor Új-Élet	KZ570-18	KZ18-1123-0006	*Ovicapridae*	Sheep/goat	LUM2	Tr. 1; unit 2; F16
Kiszombor Új-Élet	KZ587-14	KZ14-1123-0007	*Ovicapridae*	Sheep/goat	RM2	Tr. 1; unit 2; 2
Kiszombor Új-Élet	KZ292-13b	KZ13-1123-0008	*Ovicapridae*	Sheep/goat	LM3	Tr. 5; unit 3; F2
Klárafalva Hajdova	KF200-34	KF34-1123-0009	*Ovicapridae*	Sheep/goat	RM2	A1
Klárafalva Hajdova	KF200-34	KF34-1123-0010	*Ovicapridae*	Sheep/goat	RM3	A1
Kiszombor Új-Élet	KZ587-14	KZ14-1123-0011	*Ovicapridae*	Sheep/goat	RM3	Tr. 1; unit 2;

Klárafalva Hajdova	KF29-18	KF18-1123-0012	*Ovicapridae*	Sheep/goat		A2
Klárafalva Hajdova	KF331-26	KF26-1123-0013	*Ovicapridae*	Sheep/goat	LM2	A2; F22, IL1
Kiszombor Új-Élet	KZ399-1	KZ1-1123-0014	*Capreolus capreolus*	Roe Deer	LM2	unit 2; tr 5, feat 5b
Klárafalva Hajdova	KF213-17	KF17-1123-0015	*Sus scrofa*	Domestic pig	RM2	A2
Kiszombor Új-Élet	KZ399-1	KZ1-1123-0016	*Capreolus capreolus*	Roe Deer	LM3	unit 2; tr 5, F5b
Klárafalva Hajdova	KF48-6a	KF6A-1123-0017	*Sus scrofa*	Domestic pig	LM2	A2
Klárafalva Hajdova	KF48-6b	KF6B-1123-0018	*Sus scrofa*	Domestic pig	LM2	A2
Klárafalva Hajdova	KF500-16	KF16-1123-0019	*Sus scrofa*	Domestic pig	LM2	G1
Kiszombor Új-Élet	KZ479-3	KZ3-1123-0020	*Sus scrofa*	Domestic pig	RM2	unit 1, tr 1
Kiszombor Új-Élet	KZ170-8	KZ8-1123-0021	*Sus scrofa*	Domestic pig	RUM2	unit 1, tr 5
Kiszombor Új-Élet	KZ141-10	KZ10-1123-0022	*Sus scrofa*	Domestic pig	LM2	/
Kiszombor Új-Élet	KZ405-11	KZ11-1123-0023	*Sus scrofa*	Domestic pig	LUM3	unit 1, tr 5, F5b
Klárafalva Hajdova	KF-13	KF13-1123-0024	*Sus scrofa*	Domestic pig	RM2	/
Klárafalva Hajdova	KF-13	KF13-1123-0025	*Sus scrofa*	Domestic pig	RM3	/
Kiszombor Új-Élet	KZ638-20	KZ20-1123-0026	*Ovicapridae*	Sheep/goat	LM2	unit 5, tr 1
Kiszombor Új-Élet	KZ505-12	KZ12-1123-0027	*Sus scrofa*	Domestic pig	LM3	unit 1, tr 1
Klárafalva Hajdova	KF998-32	KF32-1123-0028	*Ovicapridae*	Sheep/goat	LM2	unit 1
Klárafalva Hajdova	KF379-4	KF4-1123-0029	*Sus scrofa*	Domestic pig	RM3	unit 4
Klárafalva Hajdova	KF1002-12	KF12-1123-0030	*Sus scrofa*	Domestic pig	LM2	I1
Rabe Anka Siget	RA173-22	RA22-1123-0031	*Ovicapridae*	Sheep/goat	RM3	TU1a; A
Rabe Anka Siget	RA189-23	RA23-1123-0032	*Ovicapridae*	Sheep/goat	RM2	TU1A; B
Rabe Anka Siget	RA198-24	RA24-1123-0033	*Ovicapridae*	Sheep/goat	RM2	TU1a; B
Rabe Anka Siget	RA168-25	RA25-1123-0034	*Ovicapridae*	Sheep/goat	RM3	TU1; C
Rabe Anka Siget	RA168-26	RA26-1123-0035	*Ovicapridae*	Sheep/goat	LM2	TU1; C

Rabe Anka Siget	RA168-26	RA26-1123-0036	*Ovicapridae*	Sheep/goat	LM3	TU1; C
Rabe Anka Siget	RA160-27	RA27-1123-0037	*Ovicapridae*	Sheep/goat	LM3	TU2a
Rabe Anka Siget	RA198-24	RA24-1123-0038	*Ovicapridae*	Sheep/goat	RM3	TU1a; B
Rabe Anka Siget	RA189-23	RA23-1123-0039	*Ovicapridae*	Sheep/goat	RM3	TU1A
Rabe Anka Siget	RA259-29	RA29-1123-0040	*Ovicapridae*	Sheep/goat	LM1/2	Main block 1; F25 S1/2
Rabe Anka Siget	RA267-30	RA30-1123-0041	*Bos taurus*	Cattle	UM3	Main block 1; F79 E1/2
Rabe Anka Siget	RA311-31	RA31-1123-0042	*Ovicapridae*	Sheep/goat	UM1/2	Main block 1; F18 N1/2
Rabe Anka Siget	RA316-32	RA32-1123-0043	*Ovicapridae*	Sheep/goat	maxilla M2	Main block 1; F15 IL-1; F18 IL1
Rabe Anka Siget	RA324-33	RA33-1123-0044	*Sus scrofa*	Domestic pig	UM2	Main block; F19 IL-3
Rabe Anka Siget	RA334-34	RA34-1123-0045	*Sus scrofa*	Domestic pig	UM3	Main block; F18 IL-2
Rabe Anka Siget	RA371-35	RA35-1123-0046	*Ovicapridae*	Sheep/goat	LM2	Main block; N1 E1 Str. 5 IL-1
Rabe Anka Siget	RA425-36	RA36-1123-0047	*Sus scrofa*	Domestic pig	LM1-2	Main block; base PZ
Rabe Anka Siget	RA452-1-40	RA40-1123-0048	*Ovicapridae*	Sheep/goat	M2	Main block; N2 E6; B
Rabe Anka Siget	RA452-2-41	RA41-1123-0049	*Sus scrofa*	Domestic pig	LM1	Main block; N2 E6; B
Rabe Anka Siget	RA452-3-42	RA42-1123-0050	*Ovicapridae*	Sheep/goat	LM3	Main block 1; N2 E6; B
Rabe Anka Siget	RA452-4-43	RA43-1123-0051	*Ovicapridae*	Sheep/goat	LM3	Main block 1; N2 E6; B
Rabe Anka Siget	RA452-5-44	RA44-1123-0052	*Ovicapridae*	Sheep/goat	LM3	Main block 1; N2 E6; B
Rabe Anka Siget	RA452-6-45	RA45-1123-0053	*Ovicapridae*	Sheep/goat	LM1/2	Main block 1; N2 E6; B
Rabe Anka Siget	RA452-7-46	RA46-1123-0054	*Ovicapridae*	Sheep/goat	LM1/2	Main block 1; N2 E6; B
Rabe Anka Siget	RA452-8-47	RA47-1123-0055	*Sus scrofa*	Domestic pig	UM1-2	Main block 1; N2 E6; B
Rabe Anka Siget	RA473-48	RA48-1123-0056	*Ovicapridae*	Sheep/goat	Um1.2	Main block 1; F45 IL-1
Majdan 28	RA380-49	RA49-1223-0057	*Ovicapridae*	Sheep/goat	UM1/2	TU4; A
Majdan 28	RA394-50	RA50-1223-0058	*Ovicapridae*	Sheep/goat	UM3	TU4; A
Majdan 28	RA398-51	RA51-1223-0059	*Ovicapridae*	Sheep/goat	LM3	TU4; B

Majdan 28	RA420-52	RA52-1223-0060	*Ovicapridae*	Sheep/goat	UM3	TU4; D
Majdan 28	RA426A-53	RA53-1223-0061	*Sus scrofa*	Domestic pig	M1	TU4; F42 IL-1
Rabe Anka Siget	RA324-33	RA33-1123-0062	*Sus scrofa*	Domestic pig	UM1	Main block; F19 IL-3
Rabe Anka Siget	RA334-34	RA34-1123-0063	*Sus scrofa*	Domestic pig	UM2	Main block; F18 IL-2
Rabe Anka Siget	RA428-38	RA38-1123-0064	*Sus scrofa*	Domestic pig	UM2	Main Block 1; N1 E7; D
Rabe Anka Siget	RA452-9-54	RA54-1123-0065	*Ovicapridae*	Sheep/goat	M3	Main block; N2 E6; B
Rabe Anka Siget	RA304-55	RA55-1223-0066	*Ovicapridae*	Sheep/goat	UM2	TU3; Grab
Rabe Anka Siget	RA234-56	RA56-1223-0067	*Ovicapridae*	Sheep/goat	UM1	TU3; D
Rabe Anka Siget	RA247-57	RA57-1223-0068	*Sus scrofa*	Domestic pig	LM2	TU3; F
Rabe Anka Siget	RA275-58	RA58-1223-0069	*Bos taurus*	Cattle	UM1	TU3; F31 IL-3
Rabe Anka Siget	RA430-59	RA59-1223-0070	*Sus scrofa*	Domestic pig	M1	Main block 1; N4E6; B
Rabe Anka Siget	RA450-60	RA60-1223-0071	*Sus scrofa*	Domestic pig	M1	Main block 1; N1E6; B
Rabe Anka Siget	RA450-61	RA61-1223-0072	*Sus scrofa*	Domestic pig	M2	Main block 1; N1E6
Rabe Anka Siget	RA426-62	RA62-1223-0073	*Ovicapridae*	Sheep/goat	M2	Main block 1; Srt. 6 IL-1
Pecica Şanţul Mare	PE555-63	PE63-0224-0074	*Ovicapridae*	Sheep/goat	LM3	Trench; Ka1
Pecica Şanţul Mare	PE555-64	PE64-0224-0075	*Sus scrofa*	Domestic pig	LM2	Trench; Ka1
Pecica Şanţul Mare	PE555-65	PE65-0224-0076	*Ovicapridae*	Sheep/goat	M2	Trench; Ka1
Pecica Şanţul Mare	PE571-66	PE66-0224-0077	*Ovicapridae*	Sheep/goat	LM2	Trench; Ka2
Pecica Şanţul Mare	PE359-67	PE67-0224-0078	*Cervus elaphus*	Red deer	M2	Trench; K
Pecica Şanţul Mare	PE359-68	PE68-0224-0079	*Cervus elaphus*	Red deer	M2	Trench; K
Pecica Şanţul Mare	PE359-69	PE69-0224-0080	*Cervus elaphus*	Red deer	M3	Trench; K
Pecica Şanţul Mare	PE563-70	PE70-0224-0081	*Ovicapridae*	Goat	LM3	Trench; G

Pecica Şanţul Mare	PE826-71	PE71-0224-0082	*Sus scrofa*	Domestic pig	M3	Trench; S12, I
Pecica Şanţul Mare	PE702-72	PE72-0224-0083	*Ovicapridae*	Sheep/goat	M2	TR1; I
Pecica Şanţul Mare	PE702-72	PE72-0224-0084	*Ovicapridae*	Sheep/goat	M3	TR1; I
Pecica Şanţul Mare	PE345-73	PE73-0324-0085	*Sus scrofa*	Domestic pig	LM2	Ea7
Pecica Şanţul Mare	PE345-81	PE81-0324-0093	*Ovicapridae*	Sheep/goat	RM2	Ea7
Pecica Şanţul Mare	PE528-74	PE74-0324-0086	*Sus scrofa*	Domestic pig	RM2	F
Pecica Şanţul Mare	PE528-78	PE78-0324-0090	*Ovicapridae*	Sheep/goat	LM2	F
Pecica Şanţul Mare	PE528-78	PE78-0324-0091	*Ovicapridae*	Sheep/goat	LM3	F
Pecica Şanţul Mare	PE620-75	PE75-0324-0087	*Sus scrofa*	Domestic pig	LM2	Str 15, IL10
Pecica Şanţul Mare	PE620-75	PE75-0324-0094	*Sus scrofa*	Domestic pig	LM3	Str 15, IL10
Pecica Şanţul Mare	PE620-82	PE82-0324-0098	*Ovicapridae*	Sheep/goat	RM2	Str 15, IL10
Pecica Şanţul Mare	PE620-82	PE82-0324-0099	*Ovicapridae*	Sheep/goat	RM3	Str 15, IL10
Pecica Şanţul Mare	PE620-82	PE82-0324-0100	*Ovicapridae*	Sheep/goat	RM1	Str 15, IL10
Pecica Şanţul Mare	PE620-76	PE76-0324-0088	*Sus scrofa*	Domestic pig	LM2	Str 15, IL10
Pecica Şanţul Mare	PE620-76	PE76-0324-0096	*Sus scrofa*	Domestic pig	LM3	Str 15, IL10
Pecica Şanţul Mare	PE620-76	PE76-0324-0097	*Sus scrofa*	Domestic pig	LM1	Str 15, IL10
Pecica Şanţul Mare	PE210-82	PE82-0324-0110	*Sus scrofa*	Domestic pig	RM2	Tr1, D2
Pecica Şanţul Mare	PE545-79	PE79-0324-0105	*Ovicapridae*	Sheep	RM3	F

Pecica Şanţul Mare	PE545-79	PE79-0324-0095	*Ovicapridae*	Sheep	RM2	F
Pecica Şanţul Mare	PE545-79	PE79-0324-0106	*Ovicapridae*	Sheep	RM1	F
Pecica Şanţul Mare	PE533-90	PE90-0324--0121	*Ovicapridae*	Sheep/goat	LM3	B1-3
Pecica Şanţul Mare	PE533-91	PE91-0324--0122	*Ovicapridae*	Sheep/goat	RM2	B1-3
Pecica Şanţul Mare	PE533-91	PE91-0324--0123	*Ovicapridae*	Sheep/goat	RM3	B1-3
Pecica Şanţul Mare	PE578-95	PE95-0324-0128	*Ovicapridae*	Sheep/goat	RM2	D
Pecica Şanţul Mare	PE249-84	PE84-0324-0112	*Ovicapridae*	Sheep/goat	LM2	TR2S L5
Pecica Şanţul Mare	PE249-84	PE84-0324-0113	*Ovicapridae*	Sheep/goat	LM3	TR2S L5
Pecica Şanţul Mare	PE375-98	PE98-0324-0131	*Ovicapridae*	Sheep/goat	LM2	B1-2
Pecica Şanţul Mare	PE418-99	PE99-0324-0132	*Sus scrofa*	Domestic pig	RUM2	B1-2
Pecica Şanţul Mare	PE356-97	PE97-0324-0130	*Sus scrofa*	Domestic pig	LUM2	B1-2
Pecica Şanţul Mare	PE369-85	PE85-0324--0114	*Sus scrofa*	Domestic pig	RUM3	Feat 171 IL1
Pecica Şanţul Mare	PE369-86	PE86-0324--0115	*Ovicapridae*	Sheep/goat	LUM2	Feat 171 IL1
Pecica Şanţul Mare	PE225-83	PE83-0324-0111	*Sus scrofa*	Domestic pig	RUM3	TR1C D3
Pecica Şanţul Mare	PE235-96	PE96-0324-0129	*Sus scrofa*	Domestic pig	RM2	C1a
Pecica Şanţul Mare	PE300-94	PE94-0324-0127	*Sus scrofa*	Domestic pig	RM2	C2
Pecica Şanţul Mare	PE156-92	PE92-0324-0124	*Sus scrofa*	Domestic pig	RUM2	C1
Pecica Şanţul Mare	PE156-93	PE93-0324-0125	*Ovicapridae*	Sheep/goat	RM2	C1

Pecica Şanţul Mare	PE156-93	PE93-0324-0126	*Ovicapridae*	Sheep/goat	RM3	C1
Pecica Şanţul Mare	PE493-108	PE108-0324-0143	*Cervus elaphus*	Red deer	RM2	Str 4a
Pecica Şanţul Mare	PE493-108	PE108-0324-0144	*Cervus elaphus*	Red deer	RM3	Str 4a
Pecica Şanţul Mare	PE493-108	PE108-0324-0145	*Cervus elaphus*	Red deer	RM1	Str 4a
Pecica Şanţul Mare	PE569-104	PE104-0324-0137	*Ovicapridae*	Sheep/goat	LM3	C3
Pecica Şanţul Mare	PE531-100	PE100-0324-0133	*Sus scrofa*	Domestic pig	LUM2	C3
Pecica Şanţul Mare	PE282-107	PE107-0324-0141	*Ovicapridae*	Sheep/goat	LM3	C2
Pecica Şanţul Mare	PE282-107	PE107-0324-0140	*Ovicapridae*	Sheep/goat	LM2	C2
Pecica Şanţul Mare	PE282-107	PE107-0324-0142	*Ovicapridae*	Sheep/goat	LM1	C2
Pecica Şanţul Mare	PE282-106	PE106-0324-0139	*Sus scrofa*	Domestic pig	LM3?	C2
Pecica Şanţul Mare	PE171-102	PE102-0324-0135	*Ovicapridae*	Sheep/goat	LM2	F128
Pecica Şanţul Mare	PE620-80	PE80-0324-0108	*Ovicapridae*	Sheep/goat	LM1	Str 15, IL10
Pecica Şanţul Mare	PE620-80	PE80-0324-0092	*Ovicapridae*	Sheep/goat	LM2	Str 15, IL10
Pecica Şanţul Mare	PE620-80	PE80-0324-0107	*Ovicapridae*	Sheep/goat	LM3	Str 15, IL10
Pecica Şanţul Mare	PE244-81	PE81-0324-0109	*Ovicapridae*	Sheep/goat	RM2	Ea6
Pecica Şanţul Mare	PE392-101	PE101-0324-0134	*Ovicapridae*	Sheep/goat	LM2`	F141; Ea1
Pecica Şanţul Mare	PE414-103	PE103-0324-0136	*Ovicapridae*	Sheep/goat	LM2	C1a
Pecica Şanţul Mare	PE574-105	PE105-0324-0138	*Ovicapridae*	Sheep/goat	RM3	L. D

Pecica Şanţul Mare	PE306-84	PE84A-0324-0103	*Cervus elaphus*	Red deer	RM2	Ea7
Pecica Şanţul Mare	PE306-84	PE84A-0324-0104	*Cervus elaphus*	Red deer	RM3	Ea7
Pecica Şanţul Mare	PE306-77	PE77-0324-0089	*Ovicapridae*	Sheep/goat	LM2	Ea7
Pecica Şanţul Mare	PE306-77	PE77-0324-0101	*Ovicapridae*	Sheep/goat	LM3	Ea7
Pecica Şanţul Mare	PE306-83	PE83-0324-0102	*Ovicapridae*	Sheep/goat	LM2	Ea7
Pecica Şanţul Mare	PE656-87	PE87-0324--0116	*Ovicapridae*	Sheep/goat	LM2	B1-B1a
Pecica Şanţul Mare	PE656-87	PE87-0324--0117	*Ovicapridae*	Sheep/goat	LM3	B1-B1a
Pecica Şanţul Mare	PE656-88	PE88-0324--0118	*Sus scrofa*	Domestic pig	LUM2	B1-B1a
Pecica Şanţul Mare	PE656-89	PE89-0324--0119	*Cervus elaphus*	Red deer	LM2	B1-B1a
Pecica Şanţul Mare	PE656-89	PE89-0324--0120	*Cervus elaphus*	Red deer	LM3	B1-B1a
Pecica Şanţul Mare	PE653-109	PE109-0424-0146	*Cervus elaphus*	Red deer	RM2	Ea4
Pecica Şanţul Mare	PE712-110	PE110-0424-0147	*Cervus elaphus*	Red deer	RM3	S2 L13
Pecica Şanţul Mare	PE458-111	PE111-0424-0148	*Cervus elaphus*	Red deer	RM2	Ea1
Pecica Şanţul Mare	PE458-111	PE111-0424-0149	*Cervus elaphus*	Red deer	RM3	Ea1
Pecica Şanţul Mare	PE458-111	PE111-0424-0150	*Cervus elaphus*	Red deer	RM1	Ea1
Crna Bara–Prkos	CRB1003-117	CRB117-0424-0159	*Ovicapridae*	Sheep/goat	RM2	TU1
Crna Bara–Prkos	CRB2002-118	CRB118-0424-0160	*Sus scrofa*	Domestic pig	LM2	TU2
Crna Bara–Prkos	CRB2002-119	CRB119-0424-0161	*Sus scrofa*	Domestic pig	LM2	TU2

Crna Bara–Prkos	CRB2002-119	CRB119-0424-0162	*Sus scrofa*	Domestic pig	LM3	TU2
Crna Bara–Prkos	CRB2003-120	CRB120-0424-0163	*Cervus elaphus*	Red deer	LM2	TU2
Crna Bara–Prkos	CRB2003-120	CRB120-0424-0164	*Cervus elaphus*	Red deer	LM3	TU2
Crna Bara–Prkos	CRBP11-121	CRBP121-0424-0165	*Sus scrofa*	Domestic pig	RM2	Step 11
Crna Bara-Bara–Prkos	CRBP11-121	CRBP121-0424-0166	*Sus scrofa*	Domestic pig	RM3	Step 11
Crna Bara–Prkos	CRBP5-122	CRBP122-0424-0167	*Sus scrofa*	Domestic pig	RM1	Step 5
Pecica Şanţul Mare	PE423-114	PE114-0424-0153	*Cervus elaphus*	Red deer	LM2	Ea4
Pecica Şanţul Mare	PE423-114	PE114-0424-0154	*Cervus elaphus*	Red deer	LM3	Ea4
Pecica Şanţul Mare	PE278-123	PE123-0424-0168	*Ovicapridae*	Sheep/goat	RM3	OTTU 4a; L6
Pecica Şanţul Mare	PE629-112	PE112-0424-0151	*Cervus elaphus*	Red deer	RM2	F182; BP/Ea2
Pecica Şanţul Mare	PE629-112	PE112-0424-0152	*Cervus elaphus*	Red deer	RM3	F182; BP/Ea2
Pecica Şanţul Mare	PE402-124	PE124-0424-0169	*Ovicapridae*	Sheep/goat	LM3	Ea2
Pecica Şanţul Mare	PE376-125	PE125-0424-0170	*Ovicapridae*	Sheep/goat	RM2	Ea1
Pecica Şanţul Mare	PE376-126	PE126-0424-0171	*Ovicapridae*	Sheep/goat	RM3	Ea1
Pecica Şanţul Mare	PE388-115	PE115-0424-0155	*Cervus elaphus*	Red deer	RM2	OTTU 4a; L5
Pecica Şanţul Mare	PE388-115	PE115-0424-0156	*Cervus elaphus*	Red deer	RM3	OTTU 4a; L5
Pecica Şanţul Mare	PE388-115	PE115-0424-0157	*Cervus elaphus*	Red deer	RM1	OTTU 4a; L5
Pecica Şanţul Mare	PE413-136	PE136-0424-0186	*Ovicapridae*	Sheep/goat	RM2	Ea4

Pecica Şanţul Mare	PE413-136	PE136-0424-0187	*Ovicapridae*	Sheep/goat	RM1	Ea4
Pecica Şanţul Mare	PE413-137	PE137-0424-0188	*Sus scrofa*	Domestic pig	LM2	Ea4
Pecica Şanţul Mare	PE413-137	PE137-0424-0189	*Sus scrofa*	Domestic pig	LM3	Ea4
Pecica Şanţul Mare	PE279-132	PE132-0424-0180	*Sus cf. ferus*	Boar	LM3	F192, IL-1
Pecica Şanţul Mare	PE545-131	PE131-0424-0179	*Ovicapridae*	Sheep/goat	LM3	Ea3
Pecica Şanţul Mare	PE545-130	PE130-0424-0178	*Ovicapridae*	Sheep/goat	RM2	Ea3
Pecica Şanţul Mare	PE545-129	PE129-0424-0176	*Sus scrofa*	Domestic pig	LM2	Ea3
Pecica Şanţul Mare	PE545-129	PE129-0424-0177	*Sus scrofa*	Domestic pig	LM3	Ea3
Pecica Şanţul Mare	PE423-133	PE133-0424-0181	*Ovicapridae*	Sheep/goat	LM2	Ea4
Pecica Şanţul Mare	PE423-133	PE133-0424-0182	*Ovicapridae*	Sheep/goat	LM3	Ea4
Pecica Şanţul Mare	PE423-134	PE134-0424-0183	*Sus scrofa*	Domestic pig	RM2	Ea4
Pecica Şanţul Mare	PE423-135	PE135-0424-0184	*Sus scrofa*	Domestic pig	LM2	Ea4
Pecica Şanţul Mare	PE262-127	PE127-0424-0172	*Ovicapridae*	Sheep/goat	LM2	Ea1
Pecica Şanţul Mare	PE262-128	PE128-0424-0173	*Ovicapridae*	Sheep/goat	RM2	Ea1
Pecica Şanţul Mare	PE215-138	PE138-0424-0190	*Ovicapridae*	Sheep/goat	LM2	C1a
Pecica Şanţul Mare	PE215-138	PE138-0424-0191	*Ovicapridae*	Sheep/goat	LM2	C1a
Pecica Şanţul Mare	PE442-139	PE139-0424-0192	*Ovicapridae*	Sheep/goat	RM2	D0
Pecica Şanţul Mare	PE442-139	PE139-0424-0193	*Ovicapridae*	Sheep/goat	RM3	D0

Pecica Şanţul Mare	PE442-140	PE140-0424-0194	*Sus scrofa*	Domestic pig	LM3	D0
Pecica Şanţul Mare	PE486-141	PE141-0424-0195	*Ovicapridae*	Sheep/goat	LM2	D0
Pecica Şanţul Mare	PE486-141	PE141-0424-0196	*Ovicapridae*	Sheep/goat	LM3	D0
Pecica Şanţul Mare	PE486-142	PE142-0424-0197	*Sus scrofa*	Domestic pig	LM2	D0
Pecica Şanţul Mare	PE486-142	PE142-0424-0198	*Sus scrofa*	Domestic pig	LM3	D0
Pecica Şanţul Mare	PE584-143	PE143-0424-0199	*Ovicapridae*	Sheep/goat	RM2	S2L10
Pecica Şanţul Mare	PE584-143	PE143-0424-0199 un	*Ovicapridae*	Sheep/goat	RM2	S2L10
Pecica Şanţul Mare	PE652-144	PE144-0424-0200	*Sus scrofa*	Domestic pig	LM2	S2L12
Pecica Şanţul Mare	PE681-145	PE145-0424-0201	*Ovicapridae*	Sheep/goat	RM2	C5
Pecica Şanţul Mare	PE681-145	PE145-0424-0202	*Ovicapridae*	Sheep/goat	RM3	C5
Pecica Şanţul Mare	PE706-146	PE146-0424-0203	*Sus scrofa/Sus cf. ferus*	Pig/Boar	LUM2	Ea1
Pecica Şanţul Mare	PE706-146	PE146-0424-0204	*Sus scrofa/Sus cf. ferus*	Pig/Boar	LUM3	Ea1
Pecica Şanţul Mare	PE170-147	PE147-0424-0205	*Sus scrofa*	Domestic pig	LM2	F9; Ea1/BP
Pecica Şanţul Mare	PE170-147	PE147-0424-0206	*Sus scrofa*	Domestic pig	LM3	F9; Ea1/BP
Pecica Şanţul Mare	PE170-148	PE148-0424-0207	*Sus scrofa*	Pig/Boar	RUM3	F9; Ea1/BP
Klárafalva Hajdova	KF35-1	KF 1A	*Cervus elaphus*	Red deer	RM2	1; I
Klárafalva Hajdova	KF35-1	KF 1B	*Cervus elaphus*	Red deer	RM2	2; A
Klárafalva Hajdova	KF884-3	KF 2A	*Cervus elaphus*	Red deer	RUM2	2; A
Klárafalva Hajdova	KF884-3	KF 2B	*Cervus elaphus*	Red deer	RUM2	G

Klárafalva Hajdova	KF379-4	KF 3A	*Cervus elaphus*	Red deer	LM2	G
Klárafalva Hajdova	KF379-4	KF 3B	*Cervus elaphus*	Red deer	LM2	A
Klárafalva Hajdova	KF379-4	KF 4	*Cervus elaphus*	Red deer	LM3	A
Klárafalva Hajdova	KF45-5	KF 5	*Sus cf. ferus*	Boar	RUM3	A
Klárafalva Hajdova	KF386-8	KF 6	*Sus scrofa*	Domestic pig	LM3	2;A
Klárafalva Hajdova	KF695-10	KF 7	*Sus scrofa*	Domestic pig	LM2	1;C
Klárafalva Hajdova	KF695-10	KF 8	*Sus scrofa*	Domestic pig	LM3	B/C
Klárafalva Hajdova	KF1002-12	KF 9	*Sus cf. ferus*	Boar	LM2	B/C
Klárafalva Hajdova	KF1012-14	KF 10	*Sus scrofa*	Domestic pig	LM3	1: I
Klárafalva Hajdova	KF90-15	KF 11	*Sus scrofa*	Domestic pig	LM2	J1
Klárafalva Hajdova	KF90-15	KF 12	*Sus scrofa*	Domestic pig	LM3	1; C
Klárafalva Hajdova	KF51-20	KF 13A	*Ovicapridae*	Sheep/goat	RM2	1; C
Klárafalva Hajdova	KF51-20	KF 13B	*Ovicapridae*	Sheep/goat	RM2	4; A
Klárafalva Hajdova	KF51-20	KF 14A	*Ovicapridae*	Sheep/goat	RM3	4; A
Klárafalva Hajdova	KF51-20	KF 14B	*Ovicapridae*	Sheep/goat	RM3	4; A
Klárafalva Hajdova	KF954-30	KF 15A	*Ovicapridae*	Sheep/goat	LM3	4; A
Klárafalva Hajdova	KF954-30	KF 15B	*Ovicapridae*	Sheep/goat	LM3	2; H
Klárafalva Hajdova	KF978-31	KF 16A	*Ovicapridae*	Sheep/goat	RM2	2; H
Klárafalva Hajdova	KF978-31	KF 16B	*Ovicapridae*	Sheep/goat	RM2	2; I
Klárafalva Hajdova	KF998-32	KF 17A	*Ovicapridae*	Sheep/goat	LM2	2; I
Klárafalva Hajdova	KF998-32	KF 17B	*Ovicapridae*	Sheep/goat	LM2	1; I
Klárafalva Hajdova	KF801-33	KF 18A	*Ovicapridae*	Sheep/goat	LM2	1; I
Klárafalva Hajdova	KF801-33	KF 18B	*Ovicapridae*	Sheep/goat	LM2	6; H
Klárafalva Hajdova	KF799-35	KF 19A	*Ovicapridae*	Sheep/goat	RM2	6; H

Klárafalva Hajdova	KF799-35	KF 19B	*Ovicapridae*	Sheep/goat	RM2	1; E
Klárafalva Hajdova	KF799-35	KF 20A	*Ovicapridae*	Sheep/goat	RM3	1; E
Klárafalva Hajdova	KF799-35	KF 20B	*Ovicapridae*	Sheep/goat	RM3	1; E
Kiszombor Új-Élet	KZ324-2	KZ 21A	*Cervus elaphus*	Red deer	RUM2	1; E
Kiszombor Új-Élet	KZ324-2	KZ 21B	*Cervus elaphus*	Red deer	RUM2	Tr. 1; unit 1;2
Kiszombor Új-Élet	KZ517-4	KZ 22A	*Sus scrofa*	Domestic pig	RM2	Tr. 2; unit 2;2
Kiszombor Új-Élet	KZ517-4	KZ 22B	*Sus scrofa*	Domestic pig	RM2	Tr. 5; unit 3;2
Kiszombor Új-Élet	KZ552-5	KZ 23	*Sus scrofa*	Domestic pig	LM2	Tr. 5; unit 3;2
Kiszombor Új-Élet	KZ552-5	KZ 24A	*Sus scrofa*	Domestic pig	LM3	Tr. 1; unit 2;2
Kiszombor Új-Élet	KZ552-5	KZ 24B	*Sus scrofa*	Domestic pig	LM3	Tr. 1; unit 2;2
Kiszombor Új-Élet	KZ505-12	KZ 25	*Sus scrofa*	Domestic pig	LM3	Tr. 1; unit 2;2
Kiszombor Új-Élet	KZ644-15	KZ 26A	*Ovicapridae*	Sheep/goat	LM2	Tr. 1; unit 1;2
Kiszombor Új-Élet	KZ644-15	KZ 26B	*Ovicapridae*	Sheep/goat	LM2	Tr. 1; unit 6;11
Kiszombor Új-Élet	KZ644-15	KZ 27A	*Ovicapridae*	Sheep/goat	LM3	Tr. 1; unit 6;11
Kiszombor Új-Élet	KZ644-15	KZ 27B	*Ovicapridae*	Sheep/goat	LM3	Tr. 1; unit 6;11
Kiszombor Új-Élet	KZ402-16	KZ 28A	*Ovicapridae*	Sheep/goat	RM2	Tr. 1; unit 6;11
Kiszombor Új-Élet	KZ402-16	KZ 28B	*Ovicapridae*	Sheep/goat	RM2	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ402-16	KZ 29A	*Ovicapridae*	Sheep/goat	RM3	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ402-16	KZ 29B	*Ovicapridae*	Sheep/goat	RM3	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ228-19	KZ 30A	*Ovicapridae*	Sheep/goat	RM2	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ228-19	KZ 30B	*Ovicapridae*	Sheep/goat	RM2	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ638-20a	KZ 31A	*Ovicapridae*	Sheep/goat	LM2	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ638-20a	KZ 31B	*Ovicapridae*	Sheep/goat	LM2	Tr. 1; unit 5;2
Kiszombor Új-Élet	KZ638-20b	KZ 32A	*Ovicapridae*	Sheep/goat	LM3	Tr. 1; unit 5;2

Kiszombor Új-Élet	KZ638-20b	KZ 32B	*Ovicapridae*	Sheep/goat	LM3	Tr. 1; unit 5;2
Kiszombor Új-Élet	KZ205-22	KZ 33A	*Ovicapridae*	Sheep/goat	LM2	Tr. 1; unit 5;2
Kiszombor Új-Élet	KZ205-22	KZ 33B	*Ovicapridae*	Sheep/goat	LM2	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ402-23	KZ 34A	*Ovicapridae*	Sheep/goat	RM3	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ402-23	KZ 34B	*Ovicapridae*	Sheep/goat	RM3	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ278-24	KZ 35A	*Ovicapridae*	Sheep/goat	LM3	Tr. 5; unit 2;2
Kiszombor Új-Élet	KZ278-24	KZ 35B	*Ovicapridae*	Sheep/goat	LM3	Tr. 5; unit 2;2
Rabe Anka Siget	/	RA 36A	*Ovicapridae*	Sheep/goat	LM2	TU1a; B
Rabe Anka Siget	/	RA 36B	*Ovicapridae*	Sheep/goat	LM2	TU1a; B
Rabe Anka Siget	/	RA 37A	*Ovicapridae*	Sheep/goat	LM3	TU1a; B
Rabe Anka Siget	/	RA 37B	*Ovicapridae*	Sheep/goat	LM3	TU1a; B
Rabe Anka Siget	/	RA 38A	*Sus scrofa*	Domestic pig	LM2	TU1a; B
Rabe Anka Siget	/	RA 38B	*Sus scrofa*	Domestic pig	LM2	TU1a; B
Rabe Anka Siget	/	RA 39A	*Sus scrofa*	Domestic pig	LM3	TU1a; B
Rabe Anka Siget	/	RA 39B	*Sus scrofa*	Domestic pig	LM3	TU1a; B

Table B.1 Contextual information about the teeth samples used in this dissertation

Sample ID	***Taxon***	***Tooth***	***Measurements***		***Period***	***DISS Phase division***	*Age*
			Total length (in mm)	Sample B (distance from root - 0 at the root)			
KF21-1023-0001	*Ovicapridae*	LM3	34.4	0-11	1690-1550	MBA 3	4-8 years
KF23-1123-0002	*Ovicapridae*	LM3	24.5	0-13	1825-1690	MBA 2	>24 months
KF28-1123-0003	*Ovicapridae*	RM2	22	0-11	1690-1550	MBA 3	12-15 months
KF29-1123-0004	*Ovicapridae*	LM3	30.3	0-12	1825-1690	MBA 2	/
KF25B-1123-0005	*Ovicapridae*	LM3	28.2	0-13	1690-1550	MBA 3	3-4 years

KZ18-1123-0006	*Ovicapridae*	LUM2	20.5	0-12	2525-2165	EBA 1	>2 years
KZ14-1123-0007	*Ovicapridae*	RM2	30.7	0-8	2525-2165	EBA 1	~24 months
KZ13-1123-0008	*Ovicapridae*	LM3	35	0-8	2165-1935	EBA 2	~24 months
KF34-1123-0009	*Ovicapridae*	RM2	8.3	0-.8.3	1690-1550	MBA 3	/
KF34-1123-0010	*Ovicapridae*	RM3	15	0-8	1690-1550	MBA 3	/
KZ14-1123-0011	*Ovicapridae*	RM3	30.1	0-12	2525-2165	EBA 1	~24 months
KF18-1123-0012	*Ovicapridae*		30.4	0-5.4	1690-1550	MBA 3	~24 months
KF26-1123-0013	*Ovicapridae*	LM2	28	0-19	1690-1550	MBA 3	~24 months
KZ1-1123-0014	*Capreolus capreolus*	LM2	9	0-9	2525-2165	EBA 1	4-6 years
KF17-1123-0015	*Sus scrofa*	RM2	7.3	0-7.3	1690-1550	MBA 3	12-18 months
KZ1-1123-0016	*Capreolus capreolus*	LM3	9	0-9	2525-2165	EBA 1	4-8 years
KF6A-1123-0017	*Sus scrofa*	LM2	15	0-9	1690-1550	MBA 3	6-12 months
KF6B-1123-0018	*Sus scrofa*	LM2	14	0-9	1690-1550	MBA 3	6-12 months
KF16-1123-0019	*Sus scrofa*	LM2	8	0.8	1825-1690	MBA 2	6-12 months
KZ3-1123-0020	*Sus scrofa*	RM2	8	0-8	2525-2165	EBA 1	~24 months
KZ8-1123-0021	*Sus scrofa*	RUM2	8	0-8	2525-2165	EBA 1	3-4 years
KZ10-1123-0022	*Sus scrofa*	LM2	6	0-6	/		3-4 years
KZ11-1123-0023	*Sus scrofa*	LUM3	13	0-3	2525-2165	EBA 1	3-4 years
KF13-1123-0024	*Sus scrofa*	RM2	7	0-7	/		3-4 years
KF13-1123-0025	*Sus scrofa*	RM3	9	0-6	/		3-4 years
KZ20-1123-0026	*Ovicapridae*	LM2	28	0-9	1935-1825	MBA 1	3-4 years
KZ12-1123-0027	*Sus scrofa*	LM3	12	0-4	2525-2165	EBA 1	18-36 months
KF32-1123-0028	*Ovicapridae*	LM2	28	0-14	2175-1825	EBA 2/MBA 1	~24 months
KF4-1123-0029	*Sus scrofa*	RM3	14	0-7	1690-1550	MBA 3	3 years

KF12-1123-0030	*Sus scrofa*	LM2	11	0-4	2175-1825	EBA 2/MBA 1	2-3 years
RA22-1123-0031	*Ovicapridae*	RM3	26	0-6	1646-1550	MBA 3	
RA23-1123-0032	*Ovicapridae*	RM2	30	0-4	1646-1550	MBA 3	
RA24-1123-0033	*Ovicapridae*	RM2	31	0-7	1646-1550	MBA 3	
RA25-1123-0034	*Ovicapridae*	RM3	25*	0-16	1825-1645	MBA 2	
RA26-1123-0035	*Ovicapridae*	LM2	26	0-7	1825-1645	MBA 2	
RA26-1123-0036	*Ovicapridae*	LM3	32	0-6	1825-1645	MBA 2	
RA27-1123-0037	*Ovicapridae*	LM3	34	0-15	1646-1550	MBA 3	
RA24-1123-0038	*Ovicapridae*	RM3	25*	0-5	1646-1550	MBA 3	
RA23-1123-0039	*Ovicapridae*	RM3	38	0-7	1646-1550	MBA 3	
RA29-1123-0040	*Ovicapridae*	LM1/2	28	0-4	1646-1550	MBA 3	
RA30-1123-0041	*Bos taurus*	UM3	24	0-7	1646-1550	MBA 3	
RA31-1123-0042	*Ovicapridae*	UM1/2	27	0-7	1646-1550	MBA 3	
RA32-1123-0043	*Ovicapridae*	maxilla M2	26	0-6	1646-1550	MBA 3	
RA33-1123-0044	*Sus scrofa*	UM2	9	0-9	1646-1550	MBA 3	
RA34-1123-0045	*Sus scrofa*	UM3	7	0-7	1646-1550	MBA 3	
RA35-1123-0046	*Ovicapridae*	LM2	18	0-8	1646-1550	MBA 3	
RA36-1123-0047	*Sus scrofa*	LM1-2	9	0-9	1646-1550	MBA 3	
RA40-1123-0048	*Ovicapridae*	M2	30	0-9	1646-1550	MBA 3	
RA41-1123-0049	*Sus scrofa*	LM1	9	0-9	1646-1550	MBA 3	
RA42-1123-0050	*Ovicapridae*	LM3	34	0-8	1646-1550	MBA 3	
RA43-1123-0051	*Ovicapridae*	LM3	28	0-13	1646-1550	MBA 3	
RA44-1123-0052	*Ovicapridae*	LM3	18	0-8	1646-1550	MBA 3	
RA45-1123-0053	*Ovicapridae*	LM1/2	25	0-7	1646-1550	MBA 3	

RA46-1123-0054	*Ovicapridae*	LM1/2	21	0-11	1646-1550	MBA 3	
RA47-1123-0055	*Sus scrofa*	UM1-2	9	0-6	1646-1550	MBA 3	
RA48-1123-0056	*Ovicapridae*	Um1.2	28	0-8	1646-1550	MBA 3	
RA49-1223-0057	*Ovicapridae*	UM1/2	31	0-4	1870-1700	MBA 2	<2 years
RA50-1223-0058	*Ovicapridae*	UM3	16	0-10	1870-1700	MBA 2	>2 years
RA51-1223-0059	*Ovicapridae*	LM3	18	0-9	1870-1700	MBA 2	>2 years
RA52-1223-0060	*Ovicapridae*	UM3	34	0-14	1870-1700	MBA 2	>2 years
RA53-1223-0061	*Sus scrofa*	M1	8	0-8	1700-1615	MBA 3	6-12 months
RA33-1123-0062	*Sus scrofa*	UM1	9	0-9	1646-1550	MBA 3	
RA34-1123-0063	*Sus scrofa*	UM2	7	0-7	1646-1550	MBA 3	
RA38-1123-0064	*Sus scrofa*	UM2	6	0-6	1646-1550	MBA 3	
RA54-1123-0065	*Ovicapridae*	M3	25	0-9	1646-1550	MBA 3	
RA55-1223-0066	*Ovicapridae*	UM2	31	0-7	/		
RA56-1223-0067	*Ovicapridae*	UM1	27	0-8	1825-1645	MBA 2	
RA57-1223-0068	*Sus scrofa*	LM2	7	0-7	2050-1825	MBA 1	
RA58-1223-0069	*Bos taurus*	UM1	21	0-7	1825-1645	MBA 2	
RA59-1223-0070	*Sus scrofa*	M1	8	0-8	1646-1550	MBA 3	
RA60-1223-0071	*Sus scrofa*	M1	7	0-7	1646-1550	MBA 3	
RA61-1223-0072	*Sus scrofa*	M2	12	0-12	1646-1550	MBA 3	
RA62-1223-0073	*Ovicapridae*	M2	23	0-10	1646-1550	MBA 3	
PE63-0224-0074	*Ovicapridae*	LM3	32	0-15	3935-3800	MCA	
PE64-0224-0075	*Sus scrofa*	LM2	10	0-2	3935-3800	MCA	
PE65-0224-0076	*Ovicapridae*	M2	31	0-9	3935-3800	MCA	
PE66-0224-0077	*Ovicapridae*	LM2	33	0-10	3935-3800	MCA	

PE67-0224-0078	*Cervus elaphus*	M2	18	0-7	3935-3800	MCA
PE68-0224-0079	*Cervus elaphus*	M2	7	0-7	3935-3800	MCA
PE69-0224-0080	*Cervus elaphus*	M3	6	0-6	3935-3800	MCA
PE70-0224-0081	*Ovicapridae*	LM3	24	0-9	3935-3800	MCA
PE71-0224-0082	*Sus scrofa*	M3	9	0-9	1950-1920	MBA 1
PE72-0224-0083	*Ovicapridae*	M2	25	0-14	1950-1920	MBA 1
PE72-0224-0084	*Ovicapridae*	M3	24	0-14	1950-1920	MBA 1
PE73-0324-0085	*Sus scrofa*	LM2	12	0-6	1920-1900	MBA 1
PE81-0324-0093	*Ovicapridae*	RM2	25	0-13	1920-1900	MBA 1
PE74-0324-0086	*Sus scrofa*	RM2	7	0-3	1920-1900	MBA 1
PE78-0324-0090	*Ovicapridae*	LM2	24	0-5	1920-1900	MBA 1
PE78-0324-0091	*Ovicapridae*	LM3	32	0-16	1920-1900	MBA 1
PE75-0324-0087	*Sus scrofa*	LM2	6	0-6	1920-1900	MBA 1
PE75-0324-0094	*Sus scrofa*	LM3	9	0-6	1920-1900	MBA 1
PE82-0324-0098	*Ovicapridae*	RM2	22	0-6	1920-1900	MBA 1
PE82-0324-0099	*Ovicapridae*	RM3	31	0-7	1920-1900	MBA 1
PE82-0324-0100	*Ovicapridae*	RM1	14	0-10	1920-1900	MBA 1
PE76-0324-0088	*Sus scrofa*	LM2	7	0-4	1920-1900	MBA 1
PE76-0324-0096	*Sus scrofa*	LM3	10	0-3	1920-1900	MBA 1
PE76-0324-0097	*Sus scrofa*	LM1	5	0-5	1920-1900	MBA 1
PE82-0324-0110	*Sus scrofa*	RM2	10	0-6	1765-1680	MBA 2
PE79-0324-0105	*Ovicapridae*	RM3	40	0-10	1920-1900	MBA 1
PE79-0324-0095	*Ovicapridae*	RM2	33	0-8	1920-1900	MBA 1
PE79-0324-0106	*Ovicapridae*	RM1	20	0-7	1920-1900	MBA 1

PE90-0324--0121	*Ovicapridae*	LM3	28	0-15	1615-1545	MBA 3
PE91-0324--0122	*Ovicapridae*	RM2	30	0-9	1615-1545	MBA 3
PE91-0324--0123	*Ovicapridae*	RM3	22	0-9	1615-1545	MBA 3
PE95-0324-0128	*Ovicapridae*	RM2	32	0-12	1765-1680	MBA 2
PE84-0324-0112	*Ovicapridae*	LM2	13	0-7	1920-1900	MBA 1
PE84-0324-0113	*Ovicapridae*	LM3	20	0-5	1920-1900	MBA 1
PE98-0324-0131	*Ovicapridae*	LM2	28	0-7	1615-1545	MBA 3
PE99-0324-0132	*Sus scrofa*	RUM2	12	0-12	1615-1545	MBA 3
PE97-0324-0130	*Sus scrofa*	LUM2	9	0-9	1615-1545	MBA 3
PE85-0324--0114	*Sus scrofa*	RUM3	8	0-4	1820-1765	MBA 2
PE86-0324--0115	*Ovicapridae*	LUM2	20	0-12	1820-1765	MBA 2
PE83-0324-0111	*Sus scrofa*	RUM3	12	0-5	1820-1765	MBA 2
PE96-0324-0129	*Sus scrofa*	RM2	12	0-5	1680-1615	MBA 3
PE94-0324-0127	*Sus scrofa*	RM2	10	0-4	1680-1615	MBA 3
PE92-0324-0124	*Sus scrofa*	RUM2	10	0-5	1680-1615	MBA 3
PE93-0324-0125	*Ovicapridae*	RM2	6	0-3	1680-1615	MBA 3
PE93-0324-0126	*Ovicapridae*	RM3	9	0-5	1680-1615	MBA 3
PE108-0324-0143	*Cervus elaphus*	RM2	5	0-5	1820-1765	MBA 2
PE108-0324-0144	*Cervus elaphus*	RM3	8	0-5	1820-1765	MBA 2
PE108-0324-0145	*Cervus elaphus*	RM1	10	0-2	1820-1765	MBA 2
PE104-0324-0137	*Ovicapridae*	LM3	15	0-5	1680-1615	MBA 3
PE100-0324-0133	*Sus scrofa*	LUM2	8	0-8	1680-1615	MBA 3
PE107-0324-0141	*Ovicapridae*	LM3	25	0-6	1680-1615	MBA 3
PE107-0324-0140	*Ovicapridae*	LM2	19	0-4	1680-1615	MBA 3

PE107-0324-0142	*Ovicapridae*	LM1	10	0-10	1680-1615	MBA 3
PE106-0324-0139	*Sus scrofa*	LM3?	8	0-6	1680-1615	MBA 3
PE102-0324-0135	*Ovicapridae*	LM2	31	0-10		MBA 1
PE80-0324-0108	*Ovicapridae*	LM1	19	0-4	1920-1900	MBA 1
PE80-0324-0092	*Ovicapridae*	LM2	31	0-7	1920-1900	MBA 1
PE80-0324-0107	*Ovicapridae*	LM3	39	0-7	1920-1900	MBA 1
PE81-0324-0109	*Ovicapridae*	RM2	29	0-5	1900-1875	MBA 1
PE101-0324-0134	*Ovicapridae*	LM2`	32	0-6	1820-1765	MBA 2
PE103-0324-0136	*Ovicapridae*	LM2	23	0-4	1680-1615	MBA 3
PE105-0324-0138	*Ovicapridae*	RM3	26	0-11	1765-1680	MBA 2
PE84A-0324-0103	*Cervus elaphus*	RM2	19	0-6	1920-1900	MBA 1
PE84A-0324-0104	*Cervus elaphus*	RM3	23	0-5	1920-1900	MBA 1
PE77-0324-0089	*Ovicapridae*	LM2	26	0-7	1920-1900	MBA 1
PE77-0324-0101	*Ovicapridae*	LM3	34	0-14	1920-1900	MBA 1
PE83-0324-0102	*Ovicapridae*	LM2	29	0-7	1920-1900	MBA 1
PE87-0324--0116	*Ovicapridae*	LM2	17	0-7	1615-1545	MBA 3
PE87-0324--0117	*Ovicapridae*	LM3	23	0-5	1615-1545	MBA 3
PE88-0324--0118	*Sus scrofa*	LUM2	9	0-9	1615-1545	MBA 3
PE89-0324--0119	*Cervus elaphus*	LM2	11	0-6	1615-1545	MBA 3
PE89-0324--0120	*Cervus elaphus*	LM3	11	0-7	1615-1545	MBA 3
PE109-0424-0146	*Cervus elaphus*	RM2	18	0-9	1900-1875	MBA 1
PE110-0424-0147	*Cervus elaphus*	RM3	8	0-8	1765-1680	MBA 2
PE111-0424-0148	*Cervus elaphus*	RM2	13	0-6	1820-1765	MBA 2
PE111-0424-0149	*Cervus elaphus*	RM3	14	0-4	1820-1765	MBA 2

PE111-0424-0150	*Cervus elaphus*	RM1	9	0-9	1820-1765	MBA 2
CRB117-0424-0159	*Ovicapridae*	RM2	22	0-10	5210-4940	LNA
CRB118-0424-0160	*Sus scrofa*	LM2	11	0-7	4450-4330	ECA
CRB119-0424-0161	*Sus scrofa*	LM2	7	0-7	4450-4330	ECA
CRB119-0424-0162	*Sus scrofa*	LM3	8	0-3	4450-4330	ECA
CRB120-0424-0163	*Cervus elaphus*	LM2	44	0-7	5210-5010	LNA
CRB120-0424-0164	*Cervus elaphus*	LM3	49	0-5	5210-5010	LNA
CRBP121-0424-0165	*Sus scrofa*	RM2	8	0-4	4360-4250	ECA
CRBP121-0424-0166	*Sus scrofa*	RM3	10	0-3	4360-4250	ECA
CRBP122-0424-0167	*Sus scrofa*	RM1	9	0-9	/	
PE114-0424-0153	*Cervus elaphus*	LM2	17	0-6	1900-1875	MBA 1
PE114-0424-0154	*Cervus elaphus*	LM3	16	0-4	1900-1875	MBA 1
PE123-0424-0168	*Ovicapridae*	RM3	32	0-14	1820-1765	MBA 2
PE112-0424-0151	*Cervus elaphus*	RM2	11	0-6	1875-1820	MBA 1
PE112-0424-0152	*Cervus elaphus*	RM3	13	0-5	1875-1820	MBA 1
PE124-0424-0169	*Ovicapridae*	LM3	20	0-8	1875-1820	MBA 1
PE125-0424-0170	*Ovicapridae*	RM2	27	0-6	1820-1765	MBA 2
PE126-0424-0171	*Ovicapridae*	RM3	33	0-6	1820-1765	MBA 2
PE115-0424-0155	*Cervus elaphus*	RM2	20	0-4	1820-1765	MBA 2
PE115-0424-0156	*Cervus elaphus*	RM3	24	0-6	1820-1765	MBA 2
PE115-0424-0157	*Cervus elaphus*	RM1	15	0-5	1765-1680	MBA 2
PE136-0424-0186	*Ovicapridae*	RM2	27	0-5	1900-1875	MBA 1
PE136-0424-0187	*Ovicapridae*	RM1	23	0-8	1900-1875	MBA 1
PE137-0424-0188	*Sus scrofa*	LM2	7	0-7	1900-1875	MBA 1

PE137-0424-0189	*Sus scrofa*	LM3	10	0-6	1900-1875	MBA 1
PE132-0424-0180	*Sus cf. ferus*	LM3	13	0-5	1875-1820	MBA 1
PE131-0424-0179	*Ovicapridae*	LM3	28	0-8	1875-1820	MBA 1
PE130-0424-0178	*Ovicapridae*	RM2	28	0-10	1875-1820	MBA 1
PE129-0424-0176	*Sus scrofa*	LM2	6	0-6	1875-1820	MBA 1
PE129-0424-0177	*Sus scrofa*	LM3	8	0-5	1875-1820	MBA 1
PE133-0424-0181	*Ovicapridae*	LM2	25	0-7	1900-1875	MBA 1
PE133-0424-0182	*Ovicapridae*	LM3	35	0-5	1900-1875	MBA 1
PE134-0424-0183	*Sus scrofa*	RM2	10	0-4	1900-1875	MBA 1
PE135-0424-0184	*Sus scrofa*	LM2	11	0-6	1900-1875	MBA 1
PE127-0424-0172	*Ovicapridae*	LM2	36	0-5	1820-1765	MBA 2
PE128-0424-0173	*Ovicapridae*	RM2	34	0-7	1820-1765	MBA 2
PE138-0424-0190	*Ovicapridae*	LM2	10	0-6	1680-1615	MBA 3
PE138-0424-0191	*Ovicapridae*	LM2	10	0-6	1680-1615	MBA 3
PE139-0424-0192	*Ovicapridae*	RM2	13	0-5	1765-1680	MBA 2
PE139-0424-0193	*Ovicapridae*	RM3	22	0-6	1765-1680	MBA 2
PE140-0424-0194	*Sus scrofa*	LM3	4	0-4	1765-1680	MBA 2
PE141-0424-0195	*Ovicapridae*	LM2	25	0-9	1765-1680	MBA 2
PE141-0424-0196	*Ovicapridae*	LM3	32	0-4	1765-1680	MBA 2
PE142-0424-0197	*Sus scrofa*	LM2	5	0-5	1765-1680	MBA 2
PE142-0424-0198	*Sus scrofa*	LM3	6	0-6	1765-1680	MBA 2
PE143-0424-0199	*Ovicapridae*	RM2	32	0-16	1765-1680	MBA 2
PE143-0424-0199 un	*Ovicapridae*	RM2	32	0-10	1765-1680	MBA 2
PE144-0424-0200	*Sus scrofa*	LM2	9	0-5	1765-1680	MBA 2

PE145-0424-0201	*Ovicapridae*	RM2	23	0-5	1765-1680	MBA 2	
PE145-0424-0202	*Ovicapridae*	RM3	28	0-4	1765-1680	MBA 2	
PE146-0424-0203	*Sus scrofa/Sus cf. ferus*	LUM2	9	0-5	1820-1765	MBA 2	
PE146-0424-0204	*Sus scrofa/Sus cf. ferus*	LUM3	12	0-5	1820-1765	MBA 2	
PE147-0424-0205	*Sus scrofa*	LM2	6	0-6	1820-1765	MBA 2	
PE147-0424-0206	*Sus scrofa*	LM3	11	0-4	1820-1765	MBA 2	
PE148-0424-0207	*Sus scrofa*	RUM3	12	0-2	1820-1765	MBA 2	
KF 1A	*Cervus elaphus*	RM2	22	16-22	1690-1550	MBA 3	3.5 years
KF 1B	*Cervus elaphus*	RM2	7	0-7	1690-1550	MBA 3	3.5 years
KF 2A	*Cervus elaphus*	RUM2	24	18-24	1825-1690	MBA 2	5.5 years
KF 2B	*Cervus elaphus*	RUM2	10	3-10	1825-1690	MBA 2	5.5 years
KF 3A	*Cervus elaphus*	LM2	12	7-12	1690-1550	MBA 3	5.5 years
KF 3B	*Cervus elaphus*	LM2	6	0-6	1690-1550	MBA 3	5.5 years
KF 4	*Cervus elaphus*	LM3	14	10-14	1690-1550	MBA 3	~3 years
KF 5	*Sus cf. ferus*	RUM3	7	0-7	1690-1550	MBA 3	~3 years
KF 6	*Sus scrofa*	LM3	8	0-8	1690-1550	MBA 3	3-4 years
KF 7	*Sus scrofa*	LM2	8	0-8	1690-1550	MBA 3	3-4 years
KF 8	*Sus scrofa*	LM3	8	0-8	1690-1550	MBA 3	3-4 years
KF 9	*Sus cf. ferus*	LM2	8	1-8	2175-1825	EBA 2/MBA 1	3-4 years
KF 10	*Sus scrofa*	LM3	8	0-8	2175-1825	EBA 2/MBA 1	3-4 years
KF 11	*Sus scrofa*	LM2	4	0-4	1690-1550	MBA 3	3-4 years
KF 12	*Sus scrofa*	LM3	7	0-7	1690-1550	MBA 3	>18 months
KF 13A	*Ovicapridae*	RM2	23	17-23	1690-1550	MBA 3	4-6 years

KF 13B	*Ovicapridae*	RM2	8	0-8	1690-1550	MBA 3	4-6 years
KF 14A	*Ovicapridae*	RM3	22	14-22	1690-1550	MBA 3	4-6 years
KF 14B	*Ovicapridae*	RM3	14	7-14	1690-1550	MBA 3	4-6 years
KF 15A	*Ovicapridae*	LM3	27	17-27	2175-1825	EBA 2/MBA 1	4-6 years
KF 15B	*Ovicapridae*	LM3	9	2-9	2175-1825	EBA 2/MBA 1	4-6 years
KF 16A	*Ovicapridae*	RM2	25	19-25	2175-1825	EBA 2/MBA 1	1-2 years
KF 16B	*Ovicapridae*	RM2	11	5-11	2175-1825	EBA 2/MBA 1	1-2 years
KF 17A	*Ovicapridae*	LM2	26	20-26	2175-1825	EBA 2/MBA 1	~24 months
KF 17B	*Ovicapridae*	LM2	13	2-13	2175-1825	EBA 2/MBA 1	~24 months
KF 18A	*Ovicapridae*	LM2	28	21-28	2175-1825	EBA 2/MBA 1	3-4 years
KF 18B	*Ovicapridae*	LM2	4	0-4	2175-1825	EBA 2/MBA 1	3-4 years
KF 19A	*Ovicapridae*	RM2	24	17-24	1825-1690	MBA 2	3-4 years
KF 19B	*Ovicapridae*	RM2	9	0-9	1825-1690	MBA 2	3-4 years
KF 20A	*Ovicapridae*	RM3	27	21-27	1825-1690	MBA 2	3-4 years
KF 20B	*Ovicapridae*	RM3	4	0-4	1825-1690	MBA 2	3-4 years
KZ 21A	*Cervus elaphus*	RUM2	12	6-12	/		2-3 years
KZ 21B	*Cervus elaphus*	RUM2	6	0-6	/		2-3 years
KZ 22A	*Sus scrofa*	RM2	11	7-11	2165-1935	EBA 2	4-5 years
KZ 22B	*Sus scrofa*	RM2	3	0-3	2165-1935	EBA 2	4-5 years
KZ 23	*Sus scrofa*	LM2	4	0-4	2525-2165	EBA 1	4-5 years
KZ 24A	*Sus scrofa*	LM3	6	0-6	2525-2165	EBA 1	3 years
KZ 24B	*Sus scrofa*	LM3	6	0-6	2525-2165	EBA 1	3 years
KZ 25	*Sus scrofa*	LM3	4	0-4	2165-1935	EBA 2	2-3 years
KZ 26A	*Ovicapridae*	LM2	21	14-21	1935-1825	MBA 1	2-3 years

KZ 26B	*Ovicapridae*	LM2	8	0-8	1935-1825	MBA 1	2-3 years
KZ 27A	*Ovicapridae*	LM3	28	20-28	1935-1825	MBA 1	6-8 years
KZ 27B	*Ovicapridae*	LM3	7	0-7	1935-1825	MBA 1	6-8 years
KZ 28A	*Ovicapridae*	RM2	17	9-17	2525-2165	EBA 1	6-8 years
KZ 28B	*Ovicapridae*	RM2	4	0-4	2525-2165	EBA 1	6-8 years
KZ 29A	*Ovicapridae*	RM3	22	17-22	2525-2165	EBA 1	6-8y
KZ 29B	*Ovicapridae*	RM3	7	0-7	2525-2165	EBA 1	6-8y
KZ 30A	*Ovicapridae*	RM2	27	19-27	2525-2165	EBA 1	2-3 years
KZ 30B	*Ovicapridae*	RM2	6	0-6	2525-2165	EBA 1	2-3 years
KZ 31A	*Ovicapridae*	LM2	25	22-25	1935-1825	MBA 1	2-3 years
KZ 31B	*Ovicapridae*	LM2	7	0-7	1935-1825	MBA 1	2-3 years
KZ 32A	*Ovicapridae*	LM3	34	28-34	1935-1825	MBA 1	>3y
KZ 32B	*Ovicapridae*	LM3	9	0-9	1935-1825	MBA 1	>3y
KZ 33A	*Ovicapridae*	LM2	29	14-29	2525-2165	EBA 1	22-24m
KZ 33B	*Ovicapridae*	LM2	7	0-7	2525-2165	EBA 1	22-24m
KZ 34A	*Ovicapridae*	RM3	33	21-33	2525-2165	EBA 1	6-8y
KZ 34B	*Ovicapridae*	RM3	6	0-6	2525-2165	EBA 1	6-8y
KZ 35A	*Ovicapridae*	LM3	31	17-31	/		
KZ 35B	*Ovicapridae*	LM3	9	0-9	/		
RA 36A	*Ovicapridae*	LM2	28	18-28	1825-1645	MBA 2	15 months
RA 36B	*Ovicapridae*	LM2	28	0-7	1825-1645	MBA 2	15 months
RA 37A	*Ovicapridae*	LM3	28	17-28	1825-1645	MBA 2	15 months
RA 37B	*Ovicapridae*	LM3	28	0-7	1825-1645	MBA 2	15 months
RA 38A	*Sus scrofa*	LM2	10	08-10	1825-1645	MBA 2	15 months
RA 38B	*Sus scrofa*	LM2	10	0-4	1825-1645	MBA 2	15 months
RA 39A	*Sus scrofa*	LM3	15	11-15	1825-1645	MBA 2	15 months

RA 39B	*Sus scrofa*	LM3	15	0-4	1825-1645	MBA 2	15 months

Table B.2 Information of individual samples, including radiocarbon date and age (when available)

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
KF21-1023-0001	2310.2	161039.8	831.6	445708.7	6.4	8.0	0	49.8	0.9	244.6	0.1	1.5	103.1	0.9	0
KF23-1123-000	2464.4	166577.3	204.7	454269.3	17.5	25.0	0.6	58.6	1.8	272.8	0	1.7	113.9	1.2	0
KF28-1123-0003	2275.9	168542.3	328.4	484743.3	13.1	9.8	0	52.8	0.6	288.5	0.3	1.4	151.7	2.2	0
KF29-1123-0004	2306.7	167245.8	995.3	455957.6	6.5	3.9	0	48.7	0.5	220.1	0	0.8	72.1	0.6	0
KF25B-1123-0005	2812.3	161555.2	989.6	450266.9	19.0	40.7	0	60.4	1.5	268.2	0	1.3	101.6	1.1	0
KZ18-1123-0006	2287.7	151428.2	102.6	401030.2	4.0	0	0	56.8	0.3	231.1	0.2	1.5	85.1	1.5	0
KZ14-1123-0007	2393.4	171182.7	101.5	465394.9	4.8	0	0	60.9	0.4	240.1	0	1.3	72.6	1.4	0
KZ13-1123-0008	2377.2	171724.8	111.0	493748.0	7.4	4.5	0	61.7	0.1	245.9	0	1.4	107.5	1.1	7.4
KF34-1123-0009	2868.8	164015.1	126.6	450307.1	5.0	0	0	56.3	-0.1	251.7	0.1	1.6	97.9	2.6	0
KF34-1123-0010	3071.9	155542.1	122.0	440872.0	3.4	0	0	55.2	0.6	284.4	0.1	1.4	140.6	1.1	0
KZ14-1123-0011	2425.4	160739.9	103.0	440004.8	6.3	0	0	37.8	0.9	326.5	0.1	1.2	146.2	0.7	1.1
KF18-1123-0012	2429.8	155887.6	106.0	445726.2	4.4	0	0	34.8	1.4	209.9	0	1.5	73.5	0.6	0
KF26-1123-0013	2165.3	162545.8	105.9	456249.2	4.4	0	0	50.6	0.5	285.5	0	1.3	104.9	0.7	0
KZ1-1123-0014	2813.9	152772.2	102.0	436777.3	3.0	0	0	46.1	1.8	296.6	0	1.5	76.7	0.7	3.7
KF17-1123-0015	2479.2	166676.6	833.3	453334.7	7.4	11.3	0	39.8	0.6	194.9	0	1.0	13.5	0.6	4.6
KZ1-1123-0016	2653.7	159101.6	865.6	446375.6	4.0	0	0	66.3	1.4	258.4	0.1	1.1	65.2	0.7	2.3
KF6A-1123-0017	2373.2	157738.7	113.4	448079.8	21.3	30.3	0	49.2	1.1	218.6	0	1.3	9.6	1.2	0.2
KF6B-1123-0018	2229.8	164236.8	324.2	375992.0	21.8	50.3	0	18.2	0.9	182.9	0.3	0.8	12.5	0.2	3.3

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
KF16-1123-0019	2964.9	161928.4	382.3	361355.9	14.0	30.5	0	14.1	2.3	189.4	0.1	0.7	17.5	0.3	5.2
KZ3-1123-0020	3683.3	138176.1	270.5	331811.9	8.7	0	0	0.3	1.7	485.8	0.1	0.8	108.3	0.3	28.1
KZ8-1123-0021	2489.8	149985.4	309.4	347882.2	31.4	49.8	0	20.3	1.0	186.0	0.0	0.3	32.4	0.4	3.8
KZ10-1123-0022	2636.9	161755.5	390.2	363838.7	5.7	0	0	14.4	0.6	184.0	0.1	0.4	23.4	0.1	2.6
KZ11-1123-0023	2406.9	155642.9	392.7	451275.1	6.2	0	0	55.1	0.8	180.4	0.1	1.6	19.8	0.8	0
KF13-1123-0024	2788.5	159359.7	568.1	466046.9	8.5	0	0	38.5	1.5	213.1	0.1	1.8	17.2	1.0	4.5
KF13-1123-0025	2778.5	159641.4	497.6	444462.0	3.0	0	0	68.6	1.3	203.8	0.2	1.5	13.2	0.8	2.7
KZ20-1123-0026	2793.9	147259.3	1295.9	422659.3	3.8	0	0	35.9	0.7	299.5	0	1.4	124.5	0.8	48.0
KZ12-1123-0027	2242.1	173297.4	401.2	494180.2	2.2	0	0	60.8	0.4	213.2	0	1.7	19.4	1.0	0
KF32-1123-0028	2360.6	154640.1	154.8	453352.8	3.8	0	0	44.2	1.2	229.9	0.1	1.6	83.1	0.6	0
KF4-1123-0029	2788.7	152200.8	436.0	444989.9	5.1	1.4	0.1	40.7	1.1	224.3	0.1	1.8	77.5	0.8	0
KF12-1123-0030	2980.5	151629.0	575.9	434671.9	5.2	0	0	40.5	0.7	167.8	0	1.6	11.6	0.9	1.4
RA22-1123-0031	2833.4	182606.7	242.3	428542.1	4.2	0	0	42.8	0.7	292.0	0.2	0.6	138.5	0.4	0
RA23-1123-0032	2391.2	180251.9	255.6	420205.1	2.0	0	0	72.8	1.9	314.4	0.1	0.0	106.6	0.2	12.4
RA24-1123-0033	2036.3	166939.0	199.6	379885.6	2.0	0	0	27.5	0.7	256.1	0	0	56.8	0	1.8
RA25-1123-0034	3473.4	190157.0	364.4	452348.6	3.9	0	0	74.0	0.8	447.5	0.1	0.2	146.3	0.2	7.9
RA26-1123-0035	2887.0	188972.1	317.6	437779.3	25.5	0	0	63.6	0.5	307.7	0.2	0.4	107.0	0.3	4.6
RA26-1123-0036	2773.1	174602.4	158.5	397984.0	54.6	0	0	52.8	0.5	319.3	0	0	140.0	0.0	1.5

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
RA27-1123-0037	2288.9	156334.7	162.1	368148.9	8.6	49.6	0	16.4	1.4	276.6	0.2	0	112.7	0	2.7
RA24-1123-0038	1827.9	161825.0	254.2	377952.5	3.3	0	0	17.7	1.0	292.9	0	0	91.7	0.1	22.3
RA23-1123-0039	1804.7	152247.5	54.4	351943.4	1.7	0	0	24.9	1.2	250.3	0	0.3	92.2	0	16.1
RA29-1123-0040	2373.0	158216.2	411.8	365255.0	3.2	12.9	0	16.0	0.8	186.1	0.1	0	56.4	0.1	2.4
RA30-1123-0041	2761.3	161353.6	369.5	372597.8	3.8	0	0	23.3	0.2	250.4	0	0	111.2	0.1	1.5
RA31-1123-0042	2491.5	159742.7	408.5	370751.9	31.5	78.3	0	37.3	1.7	244.6	0	0	75.3	0.2	6.0
RA32-1123-0043	2977.3	160324.1	516.1	376778.9	12.5	40.0	0	18.6	0.9	269.8	0	0	117.8	0.1	7.0
RA33-1123-0044	2567.4	174832.4	445.0	403364.5	16.5	214.0	0	48.6	2.0	171.6	0	0.1	19.0	0.2	4.0
RA34-1123-0045	2999.4	183262.6	738.8	424448.0	26.3	93.8	0	46.0	0.7	201.5	0	0	16.2	0.2	6.1
RA35-1123-0046	3498.0	171054.4	458.6	386588.7	3.8	0	0	34.8	0.7	208.7	0.1	0.5	142.0	0.1	1.5
RA36-1123-0047	3126.2	165541.5	508.7	386719.0	18.9	35.0	0	36.2	3.6	315.6	0	0.4	35.1	0.4	9.0
RA40-1123-0048	2606.7	178309.1	443.0	415314.5	5.0	7.3	0	17.9	1.3	319.2	0.1	0	125.5	0	4.8
RA41-1123-0049	3495.6	168945.4	375.7	390053.0	20.0	32.2	0	6.2	2.2	265.6	0	0	22.0	0.1	8.1
RA42-1123-0050	2843.6	166862.8	490.3	384339.9	7.1	4.9	0	11.2	1.0	358.8	0	0	109.6	0	5.4
RA43-1123-0051	2411.7	163794.2	513.9	384573.6	11.3	7.3	0	12.6	1.0	348.6	0	0	117.0	0.2	6.1
RA44-1123-0052	4250.5	245032.8	766.6	572289.9	13.2	6.1	0	47.2	0.4	435.0	0	0	140.9	0	7.0
RA45-1123-0053	2859.4	171450.4	477.2	395169.0	4.3	0.1	0	18.2	0.7	293.3	0	0	89.1	0	4.3
RA46-1123-0054	3087.7	180456.2	645.5	426150.1	5.4	0	0	18.1	1.9	406.4	0	0	106.3	0.1	3.7

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
RA47-1123-0055	2866.8	181872.1	684.4	417457.4	15.2	38.5	0	19.0	1.5	238.4	0	0	17.7	0.1	3.5
RA48-1123-0056	2400.9	154525.2	163.3	453731.8	14.9	7.6	0	40.1	0.4	256.4	0	2.0	86.5	0.7	0
RA49-1223-0057	2529.9	175486.5	234.3	385483.6	9.0	0.9	0	47.9	5.4	200.1	2.0	4.1	93.7	2.4	3.4
RA50-1223-0058	2458.3	162974.9	162.2	365207.6	12.8	0.2	0	50.5	1.8	236.9	0.4	1.6	97.4	1.0	4.9
RA51-1223-0059	2398.3	146895.0	180.9	343102.0	38.5	2008.3	3.4	63.2	2.2	415.8	0.4	1.1	251.8	0.5	39.8
RA52-1223-0060	2277.0	161332.7	910.1	358394.2	48.8	2947.0	1.2	23.3	1.0	263.2	0	0.8	117.0	0.3	13.8
RA53-1223-0061	3447.8	172574.4	241.9	379749.3	3.1	0	0	11.3	1.3	193.5	0.2	0.1	32.8	0.3	27.8
RA33-1123-0062	2638.3	133821.4	144.3	386587.1	31.7	68.9	0	42.3	4.2	251.5	0	1.4	39.9	0.7	3.9
RA34-1123-0063	4099.6	139585.1	171.2	407996.5	34.1	79.9	0	46.8	4.6	280.6	0.1	1.8	33.5	1.1	10.1
RA38-1123-0064	2664.6	155932.1	214.3	441297.3	20.7	15.0	0	35.7	1.0	169.2	0.1	1.8	21.5	0.6	0.5
RA54-1123-0065	2481.1	175441.4	186.0	391921.2	7.8	4.0	0	22.1	3.3	360.9	0.1	0	134.4	0	4.1
RA55-1223-0066	2503.4	165906.0	309.2	370388.3	51.0	1260.4	0	42.9	0.5	243.8	0.1	0	114.7	0.1	25.2
RA56-1223-0067	2923.8	174597.5	207.7	403718.9	5.5	1.2	0	31.2	0.8	332.3	0.1	0.6	146.5	0.2	9.1
RA57-1223-0068	3520.1	179175.2	327.4	391970.2	5.3	0	0	28.2	0.2	189.3	0	0.1	29.9	0.1	6.3
RA58-1223-0069	2780.9	165396.4	392.6	363938.8	3.3	0	0	32.2	0.3	273.7	0	0	122.2	0	7.8
RA59-1223-0070	2794.8	174207.8	303.0	391448.6	13.3	82.4	0	17.1	2.2	211.8	0.1	0.6	18.4	0	10.5
RA60-1223-0071	3576.3	170830.7	593.1	382663.2	90.2	0	8.1	28.8	1.5	211.8	0	0.1	20.8	0.2	8.8
RA61-1223-0072	2877.4	166546.4	512.7	371621.3	7.1	6.3	0	31.2	0.0	174.5	0	0.2	9.7	0	0.6

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
RA62-1223-0073	2974.8	186962.4	143.0	419190.6	3.1	0	0	21.1	0.5	250.9	0	0	83.8	0	0.8
PE63-0224-0074	2026.8	139245.4	136.4	598861.9	13.4	0	0	0	1.4	217.6	0	0.1	78.4	0	2.5
PE64-0224-0075	2487.4	135121.6	281.1	620969.6	2.9	0	0	4.3	1.4	163.2	0	0	4.1	0	0
PE65-0224-0076	2064.8	134705.1	0	643032.8	26.9	13.7	0	4.4	1.9	178.5	0	0	59.0	0	0
PE66-0224-0077	2150.3	145070.9	47.8	576080.9	10.8	0	0	8.2	3.4	168.3	0	0	53.9	0	0
PE67-0224-0078	2004.7	147819.3	185.6	642658.5	29.6	47.7	0	0	0	196.4	0	0	60.1	0	0.9
PE68-0224-0079	2503.4	145377.0	318.6	687176.6	4.0	8.2	0	49.6	0.1	219.4	0	0.5	58.2	0	0.8
PE69-0224-0080	2063.2	144863.2	51.3	672129.1	4.0	0	0	55.7	0	162.2	0	0	56.6	0	1.6
PE70-0224-0081	2040.4	135322.7	88.6	626221.2	13.0	23.5	0	20.7	0	249.3	0	0	75.3	0	2.1
PE71-0224-0082	2413.3	145810.9	124.7	619952.3	5.2	0	0	54.8	0	120.2	0	0	6.5	0	2.4
PE72-0224-0083	1538.1	128816.3	185.1	579172.6	15.7	0	0	36.8	0	126.2	0	0	52.9	0	0.7
PE72-0224-0084	1490.8	146144.7	590.7	587257.2	7.7	6.5	0	38.7	0.8	158.8	0	0	63.4	0	0.7
PE73-0324-0085	2401.6	138904.4	950.5	611887.5	8.1	0	0	28.4	0.7	180.4	0	0	21.3	0.8	2.4
PE74-0324-0086	2345.9	142160.5	166.6	631122.7	14.1	47.8	0	14.5	1.2	140.0	0	0	9.5	0.2	1.2
PE75-0324-0087	2381.2	122424.0	460.2	547907.3	8.6	0	0	14.7	0	136.0	0	0	14.9	1.5	1.4
PE76-0324-0088	2775.6	144000.2	660.8	670072.9	1.3	0	0	23.4	0	111.7	0	0.8	4.1	0	0
PE77-0324-0089	1954.6	136633.9	209.4	659936.5	5.0	0	0	22.2	1.4	219.5	0	0	65.2	0	0
PE78-0324-0090	1890.3	134072.7	592.3	603043.9	4.9	0	0	24.2	0	191.9	0	0	67.4	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE78-0324-0091	1111.6	89798.0	294.6	385118.9	3.3	0.8	0	9.7	1.1	113.5	0	0	53.3	0	1.4
PE80-0324-0092	1849.2	139699.8	458.2	602950.1	0.7	0	0	21.1	2.2	164.7	0.4	0	68.1	0	0
PE81-0324-0093	2120.9	132097.2	432.0	546731.4	9.1	9.0	0	31.5	1.3	152.6	0	0	111.0	0	0
PE75-0324-0094	2664.2	158455.3	107.6	667302.5	2.1	0	0	27.5	0	150.0	0	0	13.6	0	0
PE79-0324-0095	1187.3	89809.3	320.7	388905.1	4.6	0	0	12.5	1.7	131.3	0	0	48.5	0	0
PE76-0324-0096	2243.6	134407.4	471.3	611656.6	3.3	0	0	48.1	0.6	96.3	0	0	4.8	0	1.1
PE76-0324-0097	1681.4	88112.8	603.7	442278.4	3.9	0	0	13.2	1.0	95.8	0	0	4.6	0	0
PE82-0324-0098	2394.5	142662.5	664.8	632131.8	55.0	0	0	41.8	3.0	134.5	0	0	74.3	0	0
PE82-0324-0099	1837.2	131816.8	633.6	603278.3	36.4	0	0	31.5	2.5	163.9	0	0	62.8	0	0
PE82-0324-0100	2196.8	138784.5	413.6	629569.9	18.2	0	0.8	23.7	1.6	158.6	0.1	0	75.2	0	0
PE77-0324-0101	2027.1	148569.5	596.5	700492.4	8.4	10.9	0	23.3	0.7	276.9	0	0	75.5	0	0
PE83-0324-0102	1559.3	123391.4	347.3	571803.6	1.1	0	0	23.4	0.8	216.4	0	0	56.7	0	0
PE84A-0324-0103	1826.2	132877.4	278.9	595407.2	1.2	0	0	15.5	0.0	106.4	0	0	42.3	0	0.7
PE84A-0324-0104	1439.9	127883.0	373.7	582299.2	10.2	4.1	0	17.8	1.6	122.7	0	0	42.8	0	0
PE79-0324-0105	2111.0	137741.0	657.0	607674.0	34.3	47.4	0	20.9	1.6	165.1	0	0	63.1	0	0.6
PE79-0324-0106	1933.8	134760.0	487.1	634564.4	14.3	0	0	17.9	0.7	178.6	0	0	80.7	0	0
PE80-0324-0107	1782.7	119507.1	34.0	522884.3	2.7	9.8	0	3.1	0.7	111.7	0	0	57.7	0	0.7
PE80-0324-0108	1751.0	124411.3	174.1	534728.4	0	0	0	23.3	0	141.7	0	0	73.0	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE81-0324-0109	1632.1	12764 0.0	507.6	59723 7.1	25.1	91.6	0	9.5	3.3	97.4	0	0	75.6	0	3.7
PE82-0324-0110	2528.6	13441 5.3	496.1	63088 6.2	6.5	0	0	21.7	0	80.9	0	0.1	3.9	0	0
PE83-0324-0111	1657.1	11808 9.0	355.1	60932 8.9	4.7	0	0	17.7	0	109.3	0	0	7.4	0	0
PE84-0324-0112	1979.9	12306 8.8	265.2	55071 2.1	7.2	0	0	10.1	0.8	238.5	0	0	57.7	0	0.1
PE84-0324-0113	1866.2	12396 4.6	361.0	57662 8.4	8.8	0	0	25.7	0.8	231.6	0	0	70.4	0	2.4
PE85-0324--0114	2391.1	13057 7.6	754.4	58664 0.6	22.1	32.1	0	38.4	0	159.7	0	0	19.0	0	2.0
PE86-0324-0115	2069.1	12577 5.7	651.2	58166 5.2	5.9	0	0	30.5	3.6	186.2	0	0	99.4	0	0
PE87-0324-0116	2257.3	12238 8.6	535.8	56275 0.7	0	0	0	33.8	0	205.2	0	0	90.8	0	0.5
PE87-0324-0117	2384.1	14579 1.5	461.4	66657 0.1	1.6	0	0	20.7	0	166.6	0	0	64.5	0	0.7
PE88-0324-0118	2182.2	12447 6.8	524.6	59428 4.5	1.2	0	0.5	19.8	0.7	115.0	0	0	5.9	0	0
PE89-0324-0119	1936.6	10307 9.8	187.9	47796 9.0	0	0	0	17.1	0	134.5	0	0	62.8	0	0
PE89-0324--0120	2046.4	13149 6.9	384.5	62502 4.2	1.1	0	0	24.0	0	184.5	0	0	41.7	0	0
PE90-0324--0121	1830.2	12995 7.1	610.6	58281 4.3	13.3	62.6	0.5	45.6	3.7	240.5	0	0	84.6	0	0
PE91-0324--0122	1686.4	12812 0.0	577.2	54041 1.6	7.2	2.5	0	29.3	1.5	160.6	0	0	60.1	0	0
PE91-0324--0123	1825.6	10802 9.5	314.7	54292 2.4	7.3	0	0	11.8	1.4	170.7	0	0	83.7	0	0
PE92-0324-0124	2243.5	12989 2.0	662.8	62733 4.0	7.4	0	0	17.6	0.6	144.5	0	0	7.0	0	0.5
PE93-0324-0125	1965.1	12383 9.4	47.2	53844 6.8	10.4	0	0	33.8	0.9	182.6	0	0	57.2	0	0
PE93-0324-0126	2285.4	12083 0.0	397.0	56670 9.8	3.3	0	0	14.6	0.8	204.1	0	0	92.9	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE94-0324-0127	2485.7	148590.5	448.1	710889.5	10.3	2.0	0	26.3	2.8	173.2	0	0	7.3	0	0
PE95-0324-0128	1833.7	131849.4	478.6	577138.6	10.7	28.0	0	14.4	0.7	214.0	0	0.3	75.5	0	0.6
PE96-0324-0129	2090.3	133122.6	617.6	627767.5	0.2	0	0	25.9	0	143.6	0	0	9.0	0	0
PE97-0324-0130	2504.5	131520.4	618.5	670264.0	26.1	3.9	2.5	15.6	0.8	164.8	0	0	28.1	0	0
PE98-0324-0131	1869.5	131204.7	526.7	589939.6	6.5	5.7	0	41.7	1.0	170.6	0	0	59.7	0	0
PE99-0324-0132	2613.0	141265.3	543.7	647363.5	0	0	0	49.7	0	174.5	0	0	27.3	0	0
PE100-0324-0133	2373.3	133558.5	721.3	614125.7	12.7	1.3	0	20.9	0.7	115.9	0	0	17.0	0	0
PE101-0324-0134	1870.6	125256.6	152.3	520298.7	12.2	23.8	0	9.4	0	126.5	0	0.6	54.4	0	0
PE102-0324-0135	1724.4	128898.7	184.1	535459.9	5.7	17.0	0	20.5	0	177.2	0	0	74.9	0	0
PE103-0324-0136	2080.6	121067.8	463.2	493756.9	0.5	0	0	17.1	0.8	167.1	0	0	56.6	0	0.1
PE104-0324-0137	2541.5	134611.8	495.5	606260.6	2.7	0	0	29.9	0.8	200.2	0	0	60.9	0	2.2
PE105-0324-0138	1916.4	128186.0	760.5	598184.7	13.2	24.4	0	14.4	1.4	167.4	0	0	119.3	0	1.2
PE106-0324-0139	2995.2	145841.6	720.7	677464.9	4.1	0	0	35.4	0.6	142.1	0	0	8.6	0	1.8
PE107-0324-0140	2195.8	125505.2	610.7	559185.7	0.6	0	0	29.8	0	102.5	0	0	86.5	0	0
PE107-0324-0141	2176.6	132608.7	598.3	547420.6	1.0	0	0	17.5	0.8	101.9	0	0	77.1	0	0.6
PE107-0324-0142	2167.3	121821.7	760.2	622441.4	1.0	0	0	14.9	1.4	110.8	0	0	72.0	0	0
PE108-0324-0143	2399.3	139935.7	660.8	706897.1	0.7	0	0	14.4	1.8	136.0	0	0	47.2	0	0
PE108-0324-0144	1793.5	112703.5	610.8	481070.8	0.6	0	0	30.7	0	116.2	0	0	28.5	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE108-0324-0145	2693.8	137455.7	866.4	617766.0	2.6	0	0	18.0	0	149.5	0	0	28.2	0	0
PE109-0424-0146	2131.8	133134.4	318.2	615837.6	0.6	0	0	9.4	0	165.5	0	0	47.5	0	0.6
PE110-0424-0147	2454.5	148991.2	830.2	698176.3	5.3	34.8	0	30.4	0	128.0	0	0	45.8	0	0.6
PE111-0424-0148	2249.2	130093.1	545.6	562517.6	0	0	0	32.5	0	130.3	0	0	38.0	0	1.1
PE111-0424-0149	1957.1	132367.1	634.4	640249.2	2.8	0	0.7	35.9	0	114.6	0	0	38.9	0	0
PE111-0424-0150	2750.6	129809.9	608.5	557024.1	5.1	0	0	13.2	0.7	149.8	0	0	54.2	0	0
PE112-0424-0151	1580.7	124326.5	331.1	545783.3	0.3	0	0	39.9	0	162.8	0	0	32.8	0	0
PE112-0424-0152	1720.8	129636.6	504.4	541829.6	1.1	0	0	37.6	0	137.5	0	0	37.9	0	0
PE114-0424-0153	1770.8	135182.2	715.2	598714.3	0.1	0	0	15.0	0	168.4	0	0	46.5	0	2.7
PE114-0424-0154	1922.2	146747.2	704.6	622465.2	1.0	0	0	22.1	0	159.5	0	0	38.0	0	1.2
PE115-0424-0155	1831.9	124121.2	476.8	592280.5	0.5	0	0	14.6	0	106.3	0	0	48.4	0	0
PE115-0424-0156	1988.6	142232.3	824.2	681168.0	0	0	0	26.9	0	127.7	0	0	52.7	0	0.7
PE115-0424-0157	2179.1	125232.8	272.2	574828.1	1.0	0	0	8.8	0	163.6	0	0	31.1	0	1.3
CRB117-0424-0159	1773.7	121353.2	348.4	529286.0	2.8	0	0	7.4	0	373.9	0	0	82.7	0	7.3
CRB118-0424-0160	1775.6	111432.9	283.1	562500.8	0.9	0	0	12.8	0	134.9	0	0	9.4	0	2.3
CRB119-0424-0161	1844.5	127272.6	493.1	610922.7	3.9	0	0	14.1	0	131.0	0	0	7.0	0	0
CRB119-0424-0162	1765.0	123307.4	565.4	540515.4	3.2	0	0	33.1	0.8	138.3	0	0	5.9	0	0
CRB120-0424-0163	2080.9	126600.7	685.4	548140.4	0	0	0	26.1	1.4	271.0	0	0	73.1	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
CRB120-0424-0164	1764.0	136045.1	704.5	652230.1	0.9	0	0	6.0	0.8	227.0	0	0	65.5	0	0
CRBP121-0424-0165	2922.6	142607.4	927.4	673830.7	2.1	0	0	13.6	2.4	144.5	0	0	13.6	0	5.7
CRBP121-0424-0166	2065.6	128493.3	867.9	586083.3	1.0	0	0	22.4	0	140.1	0.1	0	4.5	0	0
CRBP122-0424-0167	2327.8	131362.7	535.3	587179.6	0.2	0	0	0	0.7	114.8	0	0	12.1	0	6.5
PE123-0424-0168	1906.6	125542.8	480.3	566576.4	4.7	0	0	25.0	0	137.4	0	0	53.1	0	0
PE124-0424-0169	2050.9	131263.8	662.9	562515.1	7.1	0	0	20.7	0	151.2	0	0	71.0	0	0
PE125-0424-0170	1850.5	127121.1	609.4	605735.2	2.3	0	0	22.8	0.8	159.7	0	0	66.8	0	0
PE126-0424-0171	1842.2	126541.7	670.0	598779.7	7.8	7.8	0	15.6	0	153.5	0	0	88.5	0	0
PE127-0424-0172	1723.5	111019.0	480.4	465540.0	1.9	0	0	21.2	0.8	146.3	0	0	59.1	0	0.6
PE128-0424-0173	1440.3	100320.0	309.8	501608.2	24.1	92.0	0	11.1	3.2	122.4	0	0	34.1	0	0.7
PE129-0424-0176	2041.2	122367.4	329.9	549576.1	2.4	0	0.1	23.5	0	103.0	0	0	6.8	0	1.2
PE129-0424-0177	2810.1	148856.2	106.9	648118.9	0	0	0	36.6	0	146.6	0	0	9.3	0	0
PE130-0424-0178	1848.6	121945.5	413.4	581351.1	0.8	0	0	19.2	0	96.7	0	0	53.0	0	0
PE131-0424-0179	1870.1	120307.9	396.7	565355.0	19.6	0	0	20.7	0.9	164.7	0	0	79.4	0	0
PE132-0424-0180	2201.0	121687.0	387.1	588739.9	1.6	0	0	33.3	0.7	127.4	0	0	3.5	0	0
PE133-0424-0181	1875.9	121658.9	547.5	520312.7	0	0	0	27.9	0.6	177.5	0	0	67.0	0	0
PE133-0424-0182	1955.5	132391.9	623.6	600098.5	4.9	0	0.2	38.6	0.7	161.2	0	0	92.7	0	1.1
PE134-0424-0183	2266.0	136398.6	758.9	568394.3	7.4	0.4	0	35.8	0	129.0	0.4	0	11.3	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE135-0424-0184	1863.1	114867.3	130.1	530129.7	5.4	0	0	32.0	0	114.2	0	0	16.0	0	0
PE136-0424-0186	1582.2	126056.5	179.2	548927.8	4.3	0	0	15.2	0	168.6	0	0	87.1	0	0
PE136-0424-0187	1725.5	125281.7	180.3	545626.5	3.0	0	0	16.9	0	167.4	0	0	78.9	0	0
PE137-0424-0188	2353.3	130952.0	190.8	597611.5	5.3	7.3	0	15.0	0.1	178.4	0	0	14.3	0	0
PE137-0424-0189	1948.3	126201.6	244.6	604205.1	9.8	8.1	0	23.9	0	125.5	0	0	13.4	0	0
PE138-0424-0190	2232.1	126528.5	229.4	624782.3	0	0	0	36.1	0	139.8	0.3	0	59.7	0	0
PE138-0424-0191	2131.9	126832.8	465.6	590893.4	0.4	0	0	22.7	0.1	130.4	0	0	64.9	0	0
PE139-0424-0192	1948.6	114741.7	160.0	543808.6	0	0	0	20.1	0.1	199.3	0	0	82.0	0	0
PE139-0424-0193	2177.2	127335.0	130.7	575774.9	0.6	0	0	24.7	0	147.8	0	0	77.2	0	0
PE140-0424-0194	2808.4	138373.0	460.5	625298.2	10.4	45.5	0.2	32.5	0	142.9	0	0	8.3	0	0
PE141-0424-0195	2651.6	161026.9	157.6	740762.3	2.8	0	0	35.2	0	145.5	0	0	69.2	0	0
PE141-0424-0196	1967.8	123564.4	506.1	511135.5	9.2	30.4	0	34.7	2.5	125.9	0	0	54.0	0	0
PE142-0424-0197	2360.4	128282.3	277.2	559515.2	1.9	0	0	13.4	0	132.8	0	0	8.3	0	0
PE142-0424-0198	2212.7	122326.1	284.2	547800.8	8.2	21.4	0	18.6	1.3	160.6	0	0	9.6	0	0
PE143-0424-0199	1836.8	116214.6	780.6	509689.5	4.7	9.6	0	6.1	0	159.1	0	0.8	62.0	0	0
PE143-0424-0199 un	1833.7	121590.2	339.1	586690.5	114.9	925.2	0	25.9	0.9	228.3	0	0	109.3	0	0
PE144-0424-0200	2110.0	112339.3	261.2	488330.9	7.8	0	0	15.0	2.5	142.0	0	0	5.8	0	0
PE145-0424-0201	1907.1	114601.0	190.3	499441.1	2.0	0	0	17.4	0	205.5	0	0	67.2	0	0

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
PE145-0424-0202	2000.8	118720.8	183.8	505336.3	1.0	0	0	22.8	1.7	215.7	0	0	82.3	0	0
PE146-0424-0203	2283.7	107044.6	122.9	457191.7	3.6	0	0	11.1	0	138.6	0	0	14.0	0	0
PE146-0424-0204	2557.5	132677.6	511.2	571814.4	0.7	0	0	19.6	1.9	136.1	0	0	8.1	0	0
PE147-0424-0205	3324.2	157311.3	607.4	716042.2	1.1	0	0	19.5	0	149.2	0	0	13.6	0	0.1
PE147-0424-0206	2212.7	119586.2	220.8	473364.8	1.2	0	0	22.9	0	107.8	0	0	6.3	0	0.7
PE148-0424-0207	2489.2	125423.4	117.7	542170.3	4.8	0	0	18.9	0	104.5	0	0	11.1	0	0
KF 1A	3111.9	159522.3	370.2	356685.3	3.5	15.2	0.1	50.7	2.0	324.6	0	0	99.3	0.6	
KF 1B	3002.9	180399.6	400.6	403576.3	4.7	11.1	0.1	60.7	1.0	329.7	0	0	101.3	0.4	
KF 2A	2572.8	186409.5	517.6	416163.5	2.7	5.9	0	76.7	0.3	261.8	0	0	77.7	0.5	
KF 2B	2894.0	200638.1	538.4	445481.5	3.5	4.3	0	74.1	0.5	281.0	0	0	76.6	0.6	
KF 3A	3220.8	179047.7	592.1	396075.5	4.2	9.1	0.1	34.9	1.0	412.1	0	0	108.6	0.6	
KF 3B	3219.1	184949.4	638.6	411918.7	8.1	17.1	0.4	34.8	0.5	332.5	0	0	104.6	1.0	
KF 4	2965.4	179863.9	514.2	396336.4	13.7	22.7	0.1	60.8	1.0	301.1	0	0	106.1	1.0	
KF 5	2421.1	185497.3	200.6	407624.3	3.4	5.7	0.1	69.9	0.1	221.0	0	0	15.7	1.3	
KF 6	4083.3	174901.2	590.4	388443.8	15.8	24.4	0.4	54.0	2.0	251.8	0	0	19.0	2.7	
KF 7	3166.8	179219.1	557.6	405713.8	4.9	3.7	0.2	61.6	1.0	282.4	0	0	22.5	0.9	
KF 8	3124.6	177299.7	580.7	398773.2	2.3	2.3	0.4	79.3	1.1	280.3	0	0	18.1	1.3	
KF 9	3830.1	189110.9	633.9	415424.6	11.9	9.8	0.9	64.5	0.8	254.1	0	0	17.7	1.6	

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
KF 10	2870.7	183001.9	498.4	405729.2	5.5	6.6	0.1	97.8	0.4	301.8	0	0	14.0	1.2	
KF 11	4527.6	159703.6	488.9	366610.7	17.5	48.8	0.9	72.0	6.2	329.6	0	0	38.9	2.3	
KF 12	3463.9	185464.5	570.6	415929.0	14.9	43.0	0.2	75.2	1.1	221.5	0	0	17.4	1.5	
KF 13A	3558.1	179758.8	449.4	410185.9	6.4	14.1	0	61.8	0.5	344.9	0	0	159.4	0.8	
KF 13B	3871.5	173817.9	400.1	396394.8	3.1	4.6	0.1	82.7	1.5	392.4	0	0	167.0	1.0	
KF 14A	3449.3	181031.5	445.2	413536.2	5.1	8.4	0	55.3	0.5	347.7	0	0	182.3	1.3	
KF 14B	3720.3	179165.9	411.8	411241.6	3.4	4.6	0	88.6	0.8	332.4	0	0	161.1	1.8	
KF 15A	3027.9	179981.4	492.3	407029.2	7.1	11.5	0	78.9	1.0	385.4	0	0	181.4	1.2	
KF 15B	3036.7	187202.3	505.3	412116.8	4.9	6.3	0	83.1	0.6	336.1	0	0	119.7	0.4	
KF 16A	4359.0	201947.4	570.9	398405.0	9.9	9.1	0.2	70.8	2.0	479.0	0	0	161.3	1.0	
KF 16B	3272.3	300610.4	581.8	411680.2	8.1	6.0	0	59.1	1.3	426.9	0	0	192.0	0.8	
KF 17A	6599.3	303654.9	509.3	390301.0	7.7	10.2	0.2	73.5	2.6	392.2	0	0	190.3	1.7	
KF 17B	2978.0	223924.7	464.8	407914.6	3.3	4.3	0.1	61.0	1.3	352.5	0	0	127.9	0.7	
KF 18A	4700.2	229138.2	606.9	444067.3	14.4	22.8	0.3	72.6	2.4	463.6	0.1	0	203.3	1.6	
KF 18B	2935.3	171585.9	530.1	384542.0	14.3	67.3	0.5	47.0	1.6	375.9	0	0	150.4	1.1	
KF 19A	3772.9	167979.3	598.3	379220.0	9.0	11.4	0.1	70.3	1.8	470.9	0	0	181.6	1.1	
KF 19B	3283.3	182308.9	602.1	407276.7	3.6	3.5	0	73.7	0.6	372.8	0	0	140.3	0.6	
KF 20A	3636.6	178054.9	535.7	391309.0	17.9	16.8	0.2	74.1	1.9	412.8	0	0	127.8	1.4	

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
KF 20B	3337.8	188141.1	568.9	418514.5	3.9	3.1	0	61.7	1.1	356.0	0	0	151.4	0.4	
KZ 21A	4086.4	167915.1	678.2	375031.9	3.2	3.1	0.4	132.0	1.9	522.5	0	0	253.3	2.1	
KZ 21B	3926.8	161646.1	665.2	367619.4	3.0	2.9	0.5	120.4	2.2	587.4	0	0	297.5	1.7	
KZ 22A	2584.2	184899.9	180.7	412947.9	17.7	19.3	0.1	65.6	0.5	241.0	0	0	34.9	1.6	
KZ 22B	3136.6	188255.0	174.0	414177.1	14.9	11.9	0	82.1	0.4	243.3	0	0	28.6	3.4	
KZ 23	3893.7	186125.9	449.2	416808.5	5.1	7.7	0.2	39.9	0.3	355.7	0	0	43.6	4.2	
KZ 24A	3339.1	187287.3	409.6	415829.2	2.8	6.6	0.1	46.9	0.2	257.9	0	0	27.2	1.6	
KZ 24B	3252.8	187760.8	416.0	417506.9	5.4	12.5	0.2	55.0	0.2	247.7	0	0	32.9	3.8	
KZ 25	3412.5	179055.7	341.3	400483.8	2.9	3.3	0.2	57.3	0.7	509.3	0	0	291.8	0.6	
KZ 26A	2858.1	165242.3	295.4	397215.6	1.2	3.6	0.1	79.3	0.3	315.2	0	0	41.4	1.3	
KZ 26B	2665.3	159934.3	291.2	400722.9	2.8	3.6	0.1	45.4	0.3	355.8	0	0	139.9	0.5	
KZ 27A	2936.6	150686.8	246.0	399039.0	3.3	4.0	0.0	48.4	0.6	437.1	0	0	167.6	0.3	
KZ 27B	2492.2	151144.2	262.8	415877.6	3.7	9.3	0.2	58.6	0.3	411.2	0	0	172.7	0.5	
KZ 28A	2568.2	139011.6	191.6	393881.8	3.4	5.4	0	63.8	0.4	369.3	0	0	174.8	0.9	
KZ 28B	2232.6	132361.0	198.7	401208.2	4.6	4.9	0	57.1	0.5	354.3	0	0	196.4	1.6	
KZ 29A	3702.2	221578.4	168.8	392566.6	5.8	4.6	0	66.5	0.7	446.4	0	0	263.2	0.9	
KZ 29B	4960.1	258628.4	198.6	407881.8	2.8	3.8	0	40.1	0.5	446.6	0	0.1	223.6	0.5	
KZ 30A	4389.3	260274.0	169.5	393032.0	3.1	3.9	0.2	58.5	1.0	571.8	0	0	256.3	0.6	

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
KZ 30B	2290.4	211711.8	196.8	405918.7	2.8	3.5	0.1	28.0	0.3	474.1	0	0	203.0	0.1	
KZ 31A	3905.2	202942.5	297.2	399976.5	6.7	4.3	0	52.2	0.6	400.6	0	0	193.9	0.5	
KZ 31B	2820.6	175861.2	326.1	394772.6	2.7	5.7	0	39.9	0.3	310.8	0	0	125.7	0.1	
KZ 32A	3501.1	178464.0	363.2	403676.4	8.0	4.5	0	43.7	0.5	364.6	0	0	142.3	0.5	
KZ 32B	3443.5	169215.1	341.4	375922.9	3.0	4.7	0.2	56.6	1.0	456.8	0	0	229.2	0.5	
KZ 33A	2882.4	182566.0	381.6	413398.3	11.4	11.8	0.2	37.4	0.5	521.2	0	0	175.4	0.3	
KZ 33B	3374.3	168165.2	342.8	385307.6	47.3	29.5	0.5	65.2	1.7	604.8	0	0	221.5	1.7	
KZ 34A	3251.2	174577.5	236.5	396274.2	3.6	2.9	0.5	85.6	2.4	507.6	0	0	227.7	1.4	
KZ 34B	2807.4	182999.3	264.8	406871.4	5.6	5.1	0.3	58.3	0.6	353.5	0	0	171.9	0.9	
KZ 35A	3688.3	155146.1	314.7	376103.9	11.1	10.6	0.4	81.0	1.5	465.4	0	0	189.5	1.0	
KZ 35B	2677.8	161208.5	323.3	404724.4	3.8	5.7	0.1	37.8	0.3	349.1	0	0	143.2	0.4	
RA 36A	2350.0	155664.5	221.2	414837.0	2.9	3.8	0	65.7	0.2	253.6	0	0	135.4	1.2	
RA 36B	2046.7	145260.5	142.0	422739.2	3.2	5.7	2.7	235.5	0.3	343.1	0	0.1	110.8	6.2	
RA 37A	1817.1	158447.5	132.7	401991.0	2.6	5.2	0	39.6	0.4	404.7	0	0	118.2	0.3	
RA 37B	4260.3	266739.1	108.7	498125.2	2.7	4.4	0.3	83.3	1.2	673.3	0	0	205.9	0.5	
RA 38A	3452.5	211229.5	73.0	418777.8	9.2	8.9	0.1	63.6	0.4	410.9	0	0	30.7	1.3	
RA 38B	1894.0	208194.8	72.0	399892.6	5.7	11.3	0.2	78.3	0.6	497.9	0	0	41.9	2.2	
RA 39A	1877.5	190398.3	110.3	424449.2	3.7	4.8	0.1	72.0	0.2	402.3	0	0	23.4	1.3	

Sample ID	Mg ppm	P ppm	K ppm	Ca ppm	Mn ppm	Fe ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	U ppm
RA 39B	2351.3	16584 2.9	151.6	41718 1.9	5.7	13.0	0.2	30.5	0.5	386.8	0	0	31.0	1.7	

Table B.3 Chemical results from the ICP-MS and OES combined. Samples for which uranium is empty were done in 2022 prior the method alteration in 2024

Appendix C: Soil Samples Results

Similarly to Appendix B, Appendix C presents information about the samples used in this dissertation. In this case the information portrays soil samples. This includes information about sample soil structure and information, and a table of geochemical results. The second section presents the analysis results, including PCA results, and calculations from the ecological assessment.

a) Sample information

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Klarafalva	KF82			F10B; L1; Level F	cultural	82		pit fill
Klarafalva	KF137			29 G	cultural	137		pit fill
Kiszombor	KZ1-5A	Tr. 1		Core in Tr. 1	sterile	5A		sterile horizon 2
Kiszombor	KZ1-5B	Tr. 1		Core in Tr. 1	A horizon	5B		A horizon
Kiszombor	KZ1-5C	Tr. 1		Core in Tr. 1	cultural	5C		brownish horizon
Kiszombor	KZ1-5D	Tr. 1		Core in Tr. 1	cultural	5D		sterile horizon 1
Kiszombor	KZ1-5E	Tr. 1		Core in Tr. 1	cultural	5E		sterile horizon C
Kiszombor	KZ3-10A	Tr. 3		Core in Tr. 3	cultural	10A		Ao A horizon
Kiszombor	KZ3-10B	Tr. 3		Core in Tr. 3	cultural	10B		A horizon (?)
Kiszombor	KZ3-10C	Tr. 3		Core in Tr. 3	cultural	10C		B horizon
Kiszombor	KZ3-10D	Tr. 3		Core in Tr. 3	cultural	10D		C-horizon sterile

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Kiszombor	KZ5-54	Tr. 5	99.5 cm	B 49	cultural	54		deposit
Kiszombor	KZ-57		99.3 cm	F2; IL3; E 1/2	bell pit fill	57	brown	bell pit fill
Kiszombor	KZ-58				deposit	58	dark brown	deposit
Kiszombor	KZ-63		99.8 cm	B 46	deposit	63	dark brown	deposit
Kiszombor	KZD-64	Ditch	99.88 cm	Ditch with possible lining posts	ditch fill	64	brown	ditch fill
Kiszombor	KZ-66		100.2 cm	under A horizon	deposit	66	very dark greyish brown	deposit
Kiszombor	KZ-67		99.9 cm	B1 (?)	deposit	67	dark greyish brown (more yellow)	deposit
Kiszombor	KZ5-78	Tr. 5	99.41 cm		ditch fill	78	very dark brown	ditch fill
Kiszombor	KZ-113				deposit	113	brown (greyish)	deposit
Kiszombor	KZ-118		99.69 cm	F11; L1	floor	118	light yellowish brown	floor
Rabe Anka Siget	RA 1-0	Ditch	0-7 cm	Core 1	A horizon		very dark brown	friable
Rabe Anka Siget	RA 1-1	Ditch	10-14 cm	Core 1	A horizon		very dark brown	friable
Rabe Anka Siget	RA 1-3	Ditch	30-33cm	Core 1	cultural		dark brown	friable, silty
Rabe Anka Siget	RA 1-5	Ditch	41-45 cm	Core 1	cultural		dark greyish brown	friable, silty
Rabe Anka Siget	RA 1-9	Ditch	80 -83 cm	Core 1	cultural		brown	friable, silty
Rabe Anka Siget	RA 2-0	Ditch	0 -5 cm	Core 2	A horizon		very dark brown	soft, silty clay
Rabe Anka Siget	RA 2-1	Ditch	10-14 cm	Core 2	A horizon		very dark brown	soft, silty clay
Rabe Anka Siget	RA 3-0	East	0-4 cm	Core 3	A horizon		black	friable
Rabe Anka Siget	RA 4-0	East	0-4 cm	Core 4	A horizon		black	soft/ friable, silt
Rabe Anka Siget	RA 4-1	East	10-14 cm	Core 4	A horizon		black	soft/ friable, silt

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RA 4-2	East	20-24 cm	Core 4	A horizon		black	soft/ friable, silt
Rabe Anka Siget	RA 5-0	East	0-4 cm	Core 5	A horizon		black	soft
Rabe Anka Siget	RA 6-0	East	0-4 cm	Core 6	A horizon		very dark greyish brown	soft, silty, friable
Rabe Anka Siget	RA 7-0	East	0-4 cm	Core 7	A horizon		very dark brown	soft, friable
Rabe Anka Siget	RA 7-1	East	10-14 cm	Core 7	A horizon		very dark brown	soft, friable
Rabe Anka Siget	RA 8-0	East	0-4 cm	Core 8	A horizon		black	soft, compact
Rabe Anka Siget	RA 9-0	East	0-4 cm	Core 9	A horizon		very dark greyish brown	soft, friable
Rabe Anka Siget	RA 9-1	East	9-12 cm	Core 9	A horizon		very dark greyish brown	friable, compact
Rabe Anka Siget	RA 10-0	East	0-4 cm	Core 10	A horizon		very dark brown	soft, friable
Rabe Anka Siget	RA 10-1	East	10-14 cm	Core 10	A horizon		very dark brown	soft, friable
Rabe Anka Siget	RA 11-0	East	0-4 cm	Core 11	A horizon		very dark brown	soft
Rabe Anka Siget	RA 11-1	East	9-13 cm	Core 11	A horizon		very dark brown	soft
Rabe Anka Siget	RA 12-0	East	0-4 cm	Core 12	A horizon		very dark brown	compact
Rabe Anka Siget	RA 12-1	East	12-14 cm	Core 12	A horizon		very dark brown	compact
Rabe Anka Siget	RA 13-0	East	0-4 cm	Core 13	A horizon		black	compact
Rabe Anka Siget	RA 13-1	East	8-12 cm	Core 13	A horizon		black	compact
Rabe Anka Siget	RA 14-0	East	0-4 cm	Core 14	A horizon		black	clayi silt
Rabe Anka Siget	RA 14-1	East	10-14 cm	Core 14	A horizon		black	clayi silt
Rabe Anka Siget	RA 15-1	East	10-14 cm	Core 15	A horizon		very dark brown	clayi silt
Rabe Anka Siget	RA 16-1	East	14-18 cm	Core 16	A horizon		very dark brown	friable
Rabe Anka Siget	RA 17-1	East	10-14 cm	Core 17	A horizon		dark brown	friable
Rabe Anka Siget	RA 20-1	Middle tell	12-16 cm	Core 20	A horizon		black	friable silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RA 21-1	West tell	8-10 cm	Core 21	A horizon		very dark brown	friable
Rabe Anka Siget	RA 22/23-0	Outside East	0-4 cm	Core 22/23	A horizon		very dark brown	compact
Rabe Anka Siget	RA 22/23-1	Outside East	10-14 cm	Core 22/23	A horizon		very dark brown	compact
Rabe Anka Siget	RA 22/23-3	Outside East	45-49 cm	Core 22/23	cultural		brown	compact
Rabe Anka Siget	RA 22/23-4	Outside East	45-49 cm	Core 22/23	cultural		brown	friable
Rabe Anka Siget	RA 22/23-8	Outside East	80-84 cm	Core 22/23	cultural		yellowish brown	sand
Rabe Anka Siget	RA 24-0	Northern marshes	0-4 cm	Core 24	A horizon		very dark brown	clayish soil
Rabe Anka Siget	RA 24-3	Northern marshes	35-38 cm	Core 24	A horizon		very dark brown	clayish soil
Rabe Anka Siget	RA24-5	Northern marshes	55-59 cm	Core 24	cultural		brown	clayish soil
Rabe Anka Siget	RA 24-7	Northern marshes	66-69 cm	Core 24	cultural		yellowish brown	siltier sand
Rabe Anka Siget	RA 24-8	Northern marshes	80-83 cm	Core 24	sterile		light yellowish brown	siltier sand
Rabe Anka Siget	RA 25-1	East	8-12 cm	Core 25	A horizon		black	friable
Rabe Anka Siget	RA 25-4	East	43-45 cm	Core 25	cultural		yellowish brown	friable
Rabe Anka Siget	RA 26-0	West tell	0-4 cm	Core 26	A horizon		very dark brown	friable
Rabe Anka Siget	RA 26-1	West tell	10-14 cm	Core 26	A horizon		very dark brown	friable
Rabe Anka Siget	RA 26-6	West tell	57-60 cm	Core 26	cultural		yellowish brown	firmer
Rabe Anka Siget	RA 26-8	West tell	66-67 cm	Core 26	burned soil		very dark brown	friable
Rabe Anka Siget	RA 26-9	West tell	67-69 cm	Core 26	ash layer		yellowish brown	friable
Rabe Anka Siget	RA 27-0	West tell	0-4 cm	Core 27	A horizon		very dark brown	friable
Rabe Anka Siget	RA 27-8	Middle tell	67-69 cm	Core 27	ashy layer		olive brown	friable

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RA 27-10	Middle tell	77-81 cm	Core 27	cultural		brown	looser
Rabe Anka Siget	RA 28-1	Middle tell	9-12 cm	Core 28	A horizon		very dark brown	clayier silt
Rabe Anka Siget	RA 29-1	East	8-12 cm	Core 29	A horizon		very dark greyish brown	fiable
Rabe Anka Siget	RA 29-2	East	19-22 cm	Core 29	cultural		dark brown	fiable
Rabe Anka Siget	RA 29-6	East	60-62 cm	Core 29	cultural		dark yellowish brown	fiable
Rabe Anka Siget	RA 30-1	West tell	16 cm	Core 30	A horizon		greyish brown	silt
Rabe Anka Siget	RA 30-2	West tell	21 cm	Core 30	A horizon		greyish brown	silt
Rabe Anka Siget	RA 30-4	West tell	38 cm	Core 30	cultural		greyish brown	silt
Rabe Anka Siget	RA 30-6	West tell	92 cm	Core 30	cultural		olive brown	silt
Rabe Anka Siget	RA 30-7	West tell	100 cm	Core 30	cultural		brown	silt
Rabe Anka Siget	RA 30-11	West tell	140 cm	Core 30	cultural		light yellowish brown	silt
Rabe Anka Siget	RA 30-12	West tell	148 cm	Core 30	cultural		dark brown	silt
Rabe Anka Siget	RA 30-15	West tell	180 cm	Core 30	cultural		olive brown	clayier
Rabe Anka Siget	RA 30-18	West tell	235 cm	Core 30	cultural		brown	siltier clay
Rabe Anka Siget	RA 30-19	West tell	241 cm	Core 30	cultural		dark yellowish brown	siltier clay
Rabe Anka Siget	RA 30-21	West tell	260 cm	Core 30	cultural		olive brown	siltier clay
Rabe Anka Siget	RA 30-22	West tell	270 cm	Core 30	cultural		brown (greyish)	sandier silt
Rabe Anka Siget	RA 31-1	Middle tell	33 cm	Core 31	cultural		yellowish brown	sandier silt
Rabe Anka Siget	RA 31-3	Middle tell	46 cm	Core 31	cultural		dark yellowish brown	sandier silt
Rabe Anka Siget	RA 31-5	Middle tell	68 cm	Core 31	cultural		brown (greyish)	sandier silt
Rabe Anka Siget	RA 31-6	Middle tell	76 cm	Core 31	cultural		olive brown	sandier silt
Rabe Anka Siget	RA 31-10	Middle tell	115 cm	Core 31	cultural (rubble)		strong brown (orange)	sandier silt

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RA 31-13	Middle tell	130 cm	Core 31	cultural		light yellowish brown	sandier silt
Rabe Anka Siget	RA 31-14	Middle tell	139 cm	Core 31	cultural		dark brown	sandier silt
Rabe Anka Siget	RA 31-17	Middle tell	185 cm	Core 31	cultural		olive brown	sandier silt
Rabe Anka Siget	RA 31-18	Middle tell	195 cm	Core 31	cultural		olive brown	sandier silt
Rabe Anka Siget	RA 31-19	Middle tell	205 cm	Core 31	cultural		dark yelowish brown	sandier silt
Rabe Anka Siget	RA 31-20	Middle tell	213 cm	Core 31	cultural		dark yellowish brown	sandier silt
Rabe Anka Siget	RA 31-21	Middle tell	220 cm	Core 31	cultural		dark yellowish brown	sandier silt
Rabe Anka Siget	RA 32-1	East	27-30 cm	Core 32	cultural		dark yelowish brown	silty
Rabe Anka Siget	RA 32-3	East	42 cm	Core 32	cultural		dark yelowish brown	silty
Rabe Anka Siget	RA 32-7	East	63 cm	Core 32	cultural		dark yellowish brown	silty
Rabe Anka Siget	RA 32-10	East	96 cm	Core 32	disturbance/pit?		dark yellowish brown	silty
Rabe Anka Siget	RA 32-21(13?)	East	129 cm	Core 33	cultural		brown	clayier
Rabe Anka Siget	RA 32-15	East	150 cm	Core 32	sterile		dark yellowish brown	clayier
Rabe Anka Siget	RA 33-0	West tell - forest	20 cm	Core 33	A horizon		dark greyish brown	sandier silt
Rabe Anka Siget	RA 33-3	West tell - forest	49 cm	Core 33	disturbance/pit?		dark yellowish brown	silty
Rabe Anka Siget	RA 33-7	West tell - forest	82 cm	Core 33	cultural		dark yellowish brown	silty
Rabe Anka Siget	RA 33-11	West tell - forest	118 cm	Core 33	disturbance/pit?		strong brown (orange)	sandier silt
Rabe Anka Siget	RA 33-13	West tell - forest	133 cm	Core 32	cultural		very dark brown	sandier silt

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RA 33-17	West tell - forest	167 cm	Core 33	cultural		yellowish brown	sandier silt
Rabe Anka Siget	RA 33-18	West tell - forest	184 cm	Core 33	sterile		light yellowish brown	sandier silt
Rabe Anka Siget	RA 105	West tell - Main excavation block		F13	cultural			sandier silt
Rabe Anka Siget	RA 30	West tell - Main excavation block		N2E8	cultural			silty
Rabe Anka Siget	RA 32	West tell - Main excavation block		N4E7	cultural			silty
Rabe Anka Siget	RAss7	West tell - Main excavation block		N1E6	cultural			silty
Rabe Anka Siget	RAss10	Middle tell	53 cm	TU1	upper layer of structure			silty
Rabe Anka Siget	RAss25	Middle tell		TU1	foundation of floor			silty
Rabe Anka Siget	RAss29	West tell - Main excavation block		N1E8; IL1	cultural			silty
Rabe Anka Siget	RAss34	West tell - Main excavation block		N4E8	cultural			silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RAss64	West tell - Main excavation block		F18; IL1	cultural			silty
Rabe Anka Siget	RAss65	West tell - Main excavation block		F25;IL1	cultural			silty
Rabe Anka Siget	RAss67	West tell - Main excavation block		F19;IL3	cultural			silty
Rabe Anka Siget	RAss72	West tell - Main excavation block		F14;IL2	cultural			silty
Rabe Anka Siget	RAss73	West tell - Main excavation block		F11;IL1	cultural			silty
Rabe Anka Siget	RAss97	West tell - Main excavation block		N1E6; B	cultural			silty
Rabe Anka Siget	RAss106	West tell - Main excavation block		N1E5;Str. 5;IL2	cultural			silty
Rabe Anka Siget	RAss107	West tell - Main excavation block		N1E5; Str. 5;IL3	cultural			silty
Rabe Anka Siget	RAss108	West tell -		N1E5; B	cultural			silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
		Main excavation block						
Rabe Anka Siget	RAss109	West tell - Main excavation block		N1E6; B	cultural			silty
Rabe Anka Siget	RAss110	West tell - Main excavation block		N2E6; B	cultural			silty
Rabe Anka Siget	RAss111	West tell - Main excavation block		N3E5; B	cultural			silty
Rabe Anka Siget	RAss115	West tell - Main excavation block		N1E2; A	cultural			silty
Rabe Anka Siget	RAss120	West tell - Main excavation block		F13	cultural			silty
Rabe Anka Siget	RAss121	West tell - Main excavation block		N6E8	cultural			silty
Rabe Anka Siget	RAss132	West tell - Main excavation block		N2E5; C	cultural			silty
Rabe Anka Siget	RAss134a	West tell - Main excavat		N2E5; B	cultural			silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
		ion block						
Rabe Anka Siget	RAss134b	West tell - Main excavation block		N2E5; B	cultural			silty
Rabe Anka Siget	RAss136	West tell - Main excavation block		N2E5; B	cultural			silty
Rabe Anka Siget	RATU3-1	East		TU3; A	cultural			silty
Rabe Anka Siget	RATU3-2	East		TU3; A	cultural			silty
Rabe Anka Siget	RATU3-3	East		TU3; B	cultural			silty
Rabe Anka Siget	RATU3-4	East		TU3; D	cultural			silty
Rabe Anka Siget	RATU3-5	East		TU3; E	cultural			silty
Rabe Anka Siget	RATU3-6	East		TU3; F	cultural			silty
Rabe Anka Siget	RATU3-7	East		TU3	sterile			silty
Rabe Anka Siget	RATU3-8	East		TU3;F31; IL2	cultural			silty
Rabe Anka Siget	RATU3-9	East		TU3;F31; IL1	cultural			silty
Rabe Anka Siget	RATU3-10	East		TU3;F31; IL3	cultural			silty
Rabe Anka Siget	RATU3-11	East		TU3;F31; IL4	cultural			silty
Rabe Anka Siget	RATU3-12	East		TU3;F31; IL5	cultural			silty
Rabe Anka Siget	RATU3-16	East		TU3;F35; IL2	cultural			silty
Rabe Anka Siget	RATU3-17	East		TU3; F	cultural			silty
Rabe Anka Siget	RATU3-18	East		TU3;F26; IL1	cultural			silty
Rabe Anka Siget	RATU3-19	East		TU3; F34; IL1	cultural			silty
Rabe Anka Siget	RATU3-20	East		TU3	A horizon			clayier
Rabe Anka Siget	RATU3-36	East	15 cm	TU3; F26; IL2	cultural			silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Rabe Anka Siget	RATU3-51	East	90 cm	TU3; F31; IL3	cultural			silty
Rabe Anka Siget	RATU3-53	East	89 cm	TU3; F31; IL3	cultural			silty
Rabe Anka Siget	RATU3-60	East	121 cm	TU3; F35; IL2	cultural			silty
Rabe Anka Siget	RATU3-2	East		TU3; A	cultural			silty
Rabe Anka Siget	RATU3-3	East		TU3	cultural			silty
Rabe Anka Siget	RATU3-13	East		TU3	cultural			silty
Rabe Anka Siget	RATU3-14	East		TU3	cultural			sandier silt
Rabe Anka Siget	RATU3-15	East		TU3	cultural			silty
Majdan 28	Maj 8-1			Core 8	cultural			silty
Majdan 28	Maj 1	TU4		TU4	A horizon			silty
Majdan 28	Maj 3	TU4		TU4; B	cultural			silty
Majdan 28	Maj 5	TU4		TU4; D	cultural			silty
Majdan 28	Maj 7	TU4		TU4	sterile			silty
Majdan 28	Maj 8	TU4		TU4; F42; IL1	cultural			silty
Majdan 28	Maj 9	TU4		TU4; F42; IL1	cultural			silty
Majdan 28	Maj 10	TU4		TU4; F42; IL1	cultural			silty
Majdan 28	Maj 11	TU4		TU4; F40; IL1	cultural			silty
Majdan 28	Maj 12	TU4		TU4; F42; IL2	cultural			silty
Majdan 28	Maj 89	TU4	42 cm	TU4; A	cultural			silty
Majdan 28	Maj 94	TU4	51 cm	TU4; A	cultural			silty
Majdan 28	Maj 95	TU4	54 cm	TU4; F37; IL1	cultural			silty
Majdan 28	Maj 96	TU4	56 cm	TU4; F37; IL2	cultural			silty
Majdan 28	Maj 100	TU4	55 cm	TU4; C	cultural			silty
Majdan 28	Maj 102	TU4	74 cm	TU4; E	cultural			silty
Majdan 28	Maj 116	TU4	92 cm	TU4;F42;	cultural			silty
Majdan 28	Maj 123	TU4	60 cm	TU4; F40; IL1	cultural			silty
Majdan 28	Maj 124	TU4	60 cm	TU4; F40; IL1	cultural			silty
Majdan 28	Maj 125	TU4	60 cm	TU4; F40; IL2	cultural			silty

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Crna Bara–Prkos	CRB1-1	TU1	10 cm	TU1; Layer 1	A horizon	1001	very dark brown	sandy silt
Crna Bara–Prkos	CRB1-2	TU1	30 cm	Layer 1	cultural	1003	olive brown	sandy silt
Crna Bara–Prkos	CRB1-3	TU1	57 cm	Layer 2	cultural	1005	very dark greyish brown	sandy silt
Crna Bara–Prkos	CRB1-4	TU1	77 cm	Layer 3	cultural	1006, 1007, 1008, 1009	mixed layer - brown, dark greyish brown, very dark greyish brown, and brown	mixed sandy silt and clay silt
Crna Bara–Prkos	CRB1-5	TU1	111 cm	TU1	sterile	1010, 1011	olive brown; yellowish brown	sandy silt to clayi silt
Crna Bara–Prkos	CRB2-6	TU2	20 cm	TU2; Layer 1	A horizon	2001	very dark brown	sandy silt
Crna Bara–Prkos	CRB2-7	TU2	65 cm	Layer 1	cultural	2002	dark brown	sandy silt
Crna Bara–Prkos	CRB2-8	TU2	98 cm	Layer 2	cultural	2003	brown	silty sand - clayi silt
Crna Bara–Prkos	CRB2-9	TU2	128 cm	Layer 4	cultural	2006	dark brown	silty sand
Crna Bara–Prkos	CRB2-10	TU2	170 cm	Layer 3	cultural	2005	dark yellowish brown	silty sand - clayi silt
Crna Bara–Prkos	CRB2-11	TU2	196 cm	TU1; Layer 1	sterile	2007	yellowish brown	clayi silt
Crna Bara–Prkos	CRBP-12	Profile		Step 4	deposited material			
Crna Bara–Prkos	CRBP-13	Profile		Step 6	deposited material			
Crna Bara–Prkos	CRBP-14	Profile		Step 8; Layer 1	cultural			
Crna Bara–Prkos	CRBP-15	Profile		Step 9; Layer 2	cultural			
Crna Bara–Prkos	CRBP-16	Profile		Step 10; Layer 3	cultural			
Crna Bara–Prkos	CRBP-17	Profile		Step 10 under the	cultural			

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
				floor; Layer 4				
Crna Bara–Prkos	CRBP-18	Profile		Step 11; Layer 5	cultural			
Crna Bara–Prkos	CRB 22-1-1	Core 1	0-11 cm		A horizon			
Crna Bara–Prkos	CRB22-1-3	Core 1	50-54 cm	Layer 2	cultural			
Crna Bara–Prkos	CRB 22-1-7	Core 1	100-106 cm	Layer 3/1	cultural			
Crna Bara–Prkos	CRB 22-1-9	Core 1	120-125 cm	Layer 5	cultural			
Crna Bara–Prkos	CRB 22-1-11	Core 1	145-150 cm	Layer 6	cultural			
Crna Bara–Prkos	CRB 22-1-13	Core 1	168-172 cm	Layer 7	cultural			
Crna Bara–Prkos	CRB 22-3-1	Core 3	1-8 cm		A horizon			
Crna Bara–Prkos	CRB 22-3-5	Core 3	51-57 cm	Layer 3	cultural			
Crna Bara–Prkos	CRB 22-3-11	Core 3	112-118 cm	Layer 5	cultural			
Crna Bara–Prkos	CRB 22-3-12	Core 3	126-133 cm	Layer 6	cultural			
Crna Bara–Prkos	CRB 22-5-1	Core 5	5-10 cm		A horizon			
Crna Bara–Prkos	CRB 22-5-4	Core 5	37-42 cm	Layer 2	cultural			
Crna Bara–Prkos	CRB 22-5-7	Core 5	78-83 cm	Layer 3	cultural			
Crna Bara–Prkos	CRB 22-5-13	Core 5	144-150 cm	Layer 5	cultural			
Crna Bara–Prkos	CRB 22-7-1	Core 7	7-12 cm		A horizon			
Crna Bara–Prkos	CRB 22-7-4	Core 7	39-45 cm	Layer 2	cultural			
Crna Bara–Prkos	CRB 22-7-6	Core 7	86-90 cm	Layer 3	cultural			
Crna Bara–Prkos	CRB 22-7-9	Core 7	115-120 cm	Layer 4	cultural			
Crna Bara–Prkos	CRBP22-7-12	Core 7	152-156 cm	Layer 5	cultural			
Crna Bara–Prkos	CRBP22-9-2	Core 9	15-21 cm		A horizon			
Crna Bara–Prkos	CRBP22-9-4	Core 9	40-46 cm	Layer 2	cultural			
Crna Bara–Prkos	CRBP22-9-9	Core 9	90-95 cm	Layer 5	cultural			
Crna Bara–Prkos	CRBP22-9-11	Core 9	101-104 cm	Layer 6	cultural			

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Crna Bara–Prkos	CRBP22-9-13	Core 9	115-125 cm	Layer 7	cultural			
Crna Bara–Prkos	CRBP22-9-15	Core 9	145-151 cm	Layer 8	cultural			
Pecica Santul Mare	PE1-1		24-30 cm		malacology samples			
Pecica Santul Mare	PE1-2		50-55 cm		malacology samples			
Pecica Santul Mare	PE1-3		60-70 cm		malacology samples			
Pecica Santul Mare	PE1-4		75-85 cm		malacology samples			
Pecica Santul Mare	PE1-5		87-96 cm	level E	malacology samples			
Pecica Santul Mare	PE1-6		100-110 cm	level F	malacology samples			
Pecica Santul Mare	PE1-7		113-120 cm	level G	malacology samples			
Pecica Santul Mare	PE1-8		120-130 cm	level H	malacology samples			
Pecica Santul Mare	PE1-9		136 - 145 cm		malacology samples			
Pecica Santul Mare	PE1-10		160 cm	level L	malacology samples			
Pecica Santul Mare	PE1-893			IL-6; I	cultural			
Pecica Santul Mare	PE1-901			Ja3; J	cultural			
Pecica Santul Mare	PE1-910			Ka2; K	cultural			

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Pecica Santul Mare	PE-896			IL-7; I	cultural			
Pecica Santul Mare	PE-897			IL-7; I	cultural			
Pecica Santul Mare	PE-915			La1; L	cultural			
Pecica Santu Mare	129 SOIL			C1	soil from maxilla sample context 07-156; enamel sample number PE156-92	07-156		
Pecica Santu Mare	PE107-0324-141 Soil				cultural			
Pecica Santul Mare	PE2005-1-1	Core 1	295 - 340 cm		cultural			
Pecica Santul Mare	PE2005-1-4	Core 1	420 - 450 cm		cultural			
Pecica Santul Mare	PE2005-1-8	Core 1	570 - 600 cm		cultural			
Pecica Santul Mare	PE2005-2-1	Core 2	0 - 20 cm		cultural			
Pecica Santul Mare	PE2005-2-4	Core 2	80 - 100 cm		cultural			
Pecica Santul Mare	PE2005-2-6	Core 2	135 - 160 cm		cultural			
Pecica Santul Mare	PE2005-2-7	Core 2	160 - 170 cm		cultural			
Pecica Santul Mare	PE2005-2-10	Core 2	260 - 290 cm		cultural			
Pecica Santul Mare	PE2005-3-1	Core 3	0-20 cm		cultural			
Pecica Santul Mare	PE2005-3-5	Core 3	110-125 cm		cultural			
Pecica Santul Mare	PE2005-3-6	Core 3	150 cm		cultural			
Pecica Santul Mare	PE2005-3-8	Core 3	320 cm		cultural			
Pecica Santul Mare	PE2005-3-10	Core 3	380 cm		cultural			
Pecica Santul Mare	PE2005-4-1	Core 4	0-30 cm		cultural			
Pecica Santul Mare	PE2005-4-4	Core 4	105-120 cm		cultural			

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Pecica Santul Mare	PE2005-4-8	Core 4	160-190 cm		cultural			
Pecica Santul Mare	PE2005-4-10	Core 4	230-270 cm		cultural			
Pecica Santul Mare	PE2005-4-15	Core 4	460-490 cm		cultural			
Pecica Santul Mare	PE2005-6-1	Core 6	0-35 cm		cultural			
Pecica Santul Mare	PE2005-6-4	Core 6	120-150 cm		cultural			
Pecica Santul Mare	PE2005-6-6	Core 6	160-165 cm		cultural			
Pecica Santul Mare	PE2005-6-8	Core 6	180-240 cm		cultural			
Pecica Santul Mare	PE2005-6-13	Core 6	340-380 cm		cultural			
Pecica Santul Mare	PE2005-8-2	Core 8	20-40 cm		cultural			
Pecica Santul Mare	PE2005-8-6	Core 8	125-142 cm		cultural			
Pecica Santul Mare	PE2005-8-9	Core 8	160-180 cm		cultural			
Pecica Santul Mare	PE2005-8-11	Core 8	208-240 cm		cultural			
Pecica Santul Mare	PE2005-8-13	Core 8	260-295 cm		cultural			
Pecica Santul Mare	PE2005-8-17	Core 8	430-465 cm		cultural			
Pecica Santul Mare	PE2005-10-1	Core 10	0-35 cm		cultural			
Pecica Santul Mare	PE2005-10-5	Core 10	140-165 cm		cultural			
Pecica Santul Mare	PE2005-10-7	Core 10	200-260 cm		cultural			
Pecica Santul Mare	PE2005-10-9	Core 10	340-370 cm		cultural			
Pecica Santul Mare	PE2005-1-4.1		420 - 450 cm		cultural			
Pecica Santul Mare	PE2005-2-1.1		0 - 20 cm		A horizon			
Pecica Santul Mare	PE2005-2-6.1		135 - 160 cm		cultural			
Pecica Santul Mare	PE2005-2-7.1		160 - 170 cm		cultural			
Pecica Santul Mare	PE2005-2-10.1		260 - 290 cm		A horizon			
Pecica Santul Mare	PE2005-3-1.1		0-20 cm		cultural			
Pecica Santul Mare	PE2005-3-6.1		150 cm		cultural			

Site	Sample lab ID	Location	Depth of sample below surface	Context	Soil context	Context no.	Munsell	Soil type
Pecica Santul Mare	PE2005-3-8.1		320 cm		cultural			
Pecica Santul Mare	PE2005-4-4.1		105-120 cm		cultural			
Pecica Santul Mare	PE2005-4-4.2		105-120 cm		cultural			
Pecica Santul Mare	PE2005-4-8.1		160-190 cm		cultural			
Pecica Santul Mare	PE2005-4-10.1		230-270 cm		cultural			
Pecica Santul Mare	PE2005-6-1.1		0-35 cm		cultural			
Pecica Santul Mare	PE2005-6-4.1		120-150 cm		cultural			
Pecica Santul Mare	PE2005-6-13.1		340-380 cm		cultural			
Pecica Santul Mare	PE2005-8-2.1	tell	20-40 cm		cultural			
Pecica Santul Mare	PE2005-8-6.1	tell	125-142 cm		cultural			
Pecica Santul Mare	PE2005-8-9.1	tell	160-180 cm		cultural			
Pecica Santul Mare	PE2005-8-11.1	tell	208-240 cm		cultural			
Pecica Santul Mare	PE2005-8-13.1	tell	260-295 cm		cultural			
Pecica Santul Mare	PE2005-10-1.1		0-35 cm		cultural			
Pecica Santul Mare	PE2005-10-5.1		140-165 cm		cultural			
Pecica Santul Mare	PE2005-10-5.2		140-165 cm		cultural			
Pecica Santul Mare	PE2005-10-7.1		200-260 cm		cultural			

Table C.1 Soil samples information

Sample lab ID	P ppm	Cu ppm	Cu ppm	66 Zn ppm	As ppm	Cd ppm	Sn ppm	Ba ppm	Pb ppm	Fe ppm
KZ1-5A	3138.5	9.6	9.6	20.8	0.9	0.2	0	64.9	6.1	6.9
KZ1-5B	3977.4	8.5	8.5	20.5	1.0	0.5	0	66.3	5.3	6.1
KZ1-5C	951.7	4.2	4.1	6.7	1.2	0.1	0	39.0	3.6	4.1
KZ1-5D	456.7	3.1	3.1	2.5	1.6	0.1	0	53.0	4.0	4.5
KZ1-5E	289.5	2.4	2.5	3.6	0.9	0.0	0	26.0	3.5	4.0
KZ3-10A	4351.7	10.0	10.2	25.3	1.0	0.2	0	74.4	5.4	5.8
KZ3-10B	1860.9	4.9	4.9	10.4	0.6	0.1	0	56.2	3.9	4.2
KZ3-10C	625.1	3.4	3.4	5.4	1.1	0.1	0	48.0	3.8	4.3
KZ3-10D	331.2	2.4	2.5	4.8	1.1	0.1	0	39.6	3.5	3.8
KZ5-54	5237.0	13.2	13.3	44.6	1.9	0.2	0	89.2	4.3	4.6
KZ-57	1445.9	6.0	6.0	12.9	0.9	0.1	0	44.9	4.0	4.6
KZ-58	996.8	6.1	6.2	9.4	0.7	0.1	0	25.7	3.4	3.7
KZ-63	3301.7	7.7	7.6	22.2	0.7	0.1	0	70.9	3.9	4.2
KZD-64	2614.6	9.1	9.2	24.8	1.0	0.1	0	83.3	4.1	4.4
KZ-66	1870.8	7.8	7.9	21.4	1.2	0.1	0	60.8	4.5	4.8
KZ-67	1927.1	7.4	7.4	17.2	0.9	0.1	0	73.2	3.9	4.1
KZ5-78	1862.7	8.4	8.4	19.5	0.9	0.1	0	87.2	2.9	3.3
KZ-118	37.0	0.1	0.2	1.1	0.0	0.0	0	1.4	0.1	0.1
KF82	2223.5	9.9	10.1	33.0	1.9	0.2	0	62.4	5.6	6.0
KF137	2072.4	7.0	7.0	28.1	2.1	0.1	0	43.0	4.7	5.3
RA 1-3	1170.9	5.8	6.1	4.3	0.6	0.1	0	45.4	5.6	6.2
RA 1-5	3861.0	11.1	10.6	9.3	1.4	0.1	0	68.4	4.9	5.2
RA 1-9	632.0	4.5	4.9	-2.1	1.0	0.1	0	36.0	5.1	5.5
RA 4-0	1649.6	10.6	10.6	15.6	0.7	0.2	0	50.2	7.0	7.6
RA 4-2	1758.9	10.4	10.3	17.6	0.7	0.2	0	56.7	6.8	7.4
RA 8-0	1715.4	11.1	11.0	16.2	0.7	0.1	0	52.3	6.5	7.1
RA 20-2	1533.9	9.1	9.0	15.5	0.7	0.2	0	48.8	7.7	8.4
RA 22/23-0	769.0	7.7	7.7	9.5	0.8	0.1	0	6207.7	6.9	7.4
RA 22/23-3	979.9	8.0	8.0	9.3	1.2	0.1	0	39.0	6.0	6.5

RA 22/23-4	674.7	6.4	6.5	7.2	1.6	0.1	0	41.0	5.1	5.5
RA 22/23-8	402.6	4.8	4.8	6.9	1.1	0.1	0	40.0	4.7	5.0
RA 24-0	299.0	10.9	10.9	10.5	1.5	0.1	0	38.1	9.4	10.2
RA 24-3	161.8	7.9	8.0	9.7	0.5	0.1	0	40.3	6.5	7.0
RA 24-5	165.6	6.2	6.2	9.5	0.4	0.0	0	47.6	3.8	4.1
RA 24-7	180.7	5.1	5.2	9.0	0.4	0.1	0	60.3	6.5	7.0
RA 24-8	141.0	4.0	4.0	8.4	0.3	0.1	0	40.6	4.3	4.7
RA 25-4	290.4	3.7	3.8	4.5	0.4	0.1	0	27.6	5.0	5.3
RA 26-6	1722.1	12.3	12.3	23.5	2.1	0.1	0.1	38.9	5.0	5.4
RA 27-0	1815.0	7.1	7.1	17.1	1.1	0.1	0	34.5	4.7	5.1
RA 27-8	5875.9	10.6	10.9	37.4	3.1	0.1	0.2	44.9	4.4	5.3
RA 27-10	2759.1	8.9	9.0	33.9	2.5	0.1	0.1	91.8	4.3	4.6
RA 28-1	2759.1	8.9	9.0	33.9	2.5	0.1	0.1	62.7	4.3	4.6
RA 29-1	1548.3	7.3	7.4	15.2	0.8	0.1	0	62.7	6.3	6.8
RA 29-2	751.2	4.2	4.4	7.3	0.9	0.1	0	44.0	3.7	4.4
RA 29-6	1151.5	4.3	4.3	10.7	1.0	0.1	0	25.4	4.2	4.5
RA 30-1	1793.9	7.4	7.4	20.1	1.6	0.1	0	32.6	4.9	5.3
RA 30-2	1575.7	6.5	6.4	17.2	1.3	0.1	0	48.9	4.3	4.8
RA 30-4	4885.0	6.6	6.7	29.5	3.2	0.1	0	42.4	4.2	4.5
RA 30-11	2843.8	19.5	18.4	21.1	1.2	0.1	0.1	72.1	4.1	4.5
RA 30-12	1886.3	9.3	9.6	39.9	1.9	0.1	0	11907.9	3.6	4.3
RA 30-15	1689.2	11.2	11.1	16.1	0.8	0.2	0	64.0	6.5	7.0
RA 30-18	302.5	3.5	3.5	4.8	0.6	0.1	0	74.4	5.0	5.3
RA 30-19	302.1	3.9	3.9	3.7	0.7	0.1	0	54.9	4.9	5.2
RA 30-22	242.8	3.2	3.2	3.5	0.7	0.1	0	24.0	4.5	4.8
RA 31-1	2401.5	8.5	8.7	18.0	1.5	0.1	0.1	26.4	4.4	4.7
RA 31-3	2401.5	8.5	8.7	18.0	1.5	0.1	0.1	39.8	4.4	4.7
RA 31-5	2251.9	9.2	9.3	25.2	1.0	0.1	0.1	51.1	3.5	3.8
RA 31-10	1226.9	2.9	2.9	10.3	2.8	0.1	0	51.1	3.9	4.3
RA 31-13	2125.7	5.5	5.6	21.2	1.4	0.2	0	44.4	5.0	5.4
RA 31-14	558.8	4.9	5.1	8.2	0.9	0.1	0	40.6	4.2	4.9
RA 31-17	409.9	3.2	3.3	3.8	0.6	0.1	0	53.3	4.2	4.5

RA 31-18	411.0	3.0	3.1	5.2	0.6	0.1	0	23.9	4.3	5.1
RA 31-19	354.1	3.5	3.5	5.6	0.6	0.1	0	28.5	4.8	5.2
RA 31-21	285.3	2.3	2.4	3.6	0.6	0.1	0	38.8	4.1	4.5
RA 32-1	1415.4	6.1	6.2	11.7	1.0	0.1	0	32.2	5.3	5.8
RA 32-3	1360.8	6.3	6.5	10.7	1.2	0.1	0	33.1	4.1	4.4
RA 32-7	1176.1	5.1	5.2	11.3	0.9	0.1	0	42.5	4.2	4.5
RA 32-10	866.1	4.5	4.6	6.5	1.1	0.1	0	44.6	5.1	5.5
RA 32-21(13?)	754.0	3.1	3.2	4.8	0.9	0.1	0	30.7	4.6	4.9
RA 32-15	479.6	2.4	2.5	4.4	0.8	0.1	0	37.6	4.1	4.4
RA 33-0	2074.1	6.5	6.6	19.8	1.3	0.1	0	35.6	5.3	5.8
RA 33-3	3215.9	8.3	8.4	27.3	2.1	0.1	0	38.1	4.5	4.8
RA 33-7	1864.8	6.3	6.4	16.4	2.9	0.1	0	50.8	4.7	5.1
RA 33-11	1059.7	4.8	4.9	7.3	5.1	0.1	0	53.1	5.4	5.9
RA 33-13	1179.4	4.6	4.7	6.8	4.8	0.1	0	36.4	5.0	5.5
RA 33-17	786.2	4.3	4.3	5.5	2.7	0.1	0	32.1	4.7	5.0
RA 33-18	601.2	3.2	3.3	5.0	1.5	0.1	0	30.7	4.7	5.1
RA 105	1900.0	5.7	5.7	17.6	1.4	0.1	0	29.7	3.8	4.1
RA 30	1216.8	11.7	11.7	19.1	1.8	0.1	0	27.6	4.3	4.6
RA 32	3158.4	134.8	133.7	40.7	3.2	0.2	1.2	56.6	3.8	4.2
RAss7	2175.2	5.7	5.9	16.5	1.4	0.1	0.4	54.4	2.7	2.9
RAss10	1652.3	5.3	5.2	15.5	1.3	0.1	0.1	79.3	3.2	3.5
RAss25	2585.2	4.7	4.7	14.4	1.7	0.1	0	45.2	3.3	3.6
RAss29	3402.7	5.6	5.8	27.0	2.3	0.1	0.2	56.6	4.1	4.8
RAss34	4929.2	18.1	18.2	45.7	2.6	0.2	0.1	49.4	4.5	4.8
RAss64	1969.4	5.6	5.8	18.7	1.6	0.1	0.2	71.9	2.7	3.0
RAss65	2811.2	7.3	7.5	24.1	1.8	0.1	0.1	112.1	4.4	5.3
RAss67	4814.7	9.5	9.4	36.6	1.7	0.1	0	41.3	3.4	3.7
RAss72	3149.6	8.0	8.4	25.9	1.5	0.1	0	55.8	4.5	5.4
RAss73	2314.1	6.6	6.5	17.7	1.0	0.1	0.1	111.1	3.6	4.0
RAss97	1988.2	7.3	7.2	23.0	1.6	0.2	7.6	71.4	2.3	2.6
RAss106	2064.4	6.8	6.9	16.3	1.3	0.1	0	55.8	3.9	4.4
RAss107	2061.6	7.5	7.7	22.8	1.5	0.2	0.9	48.0	3.4	3.6

RAss108	5543.1	8.8	8.8	30.8	2.2	0.1	0	47.0	3.5	3.8
RAss110	2977.0	7.0	6.9	19.8	1.4	0.1	0.1	50.4	3.3	3.6
RAss115	1106.5	3.4	3.5	9.4	0.7	0.2	0.1	75.4	2.6	2.8
RAss120	2947.1	8.7	8.8	20.7	1.7	0.1	0	46.2	3.7	4.0
RAss121	2463.7	7.9	7.8	28.0	7.0	0.1	0	35.2	5.5	6.3
RAss132	2009.5	3.9	4.0	11.7	2.7	0.1	0	68.7	3.5	3.7
RAss134a	2597.0	7.4	7.5	18.9	2.3	0.1	0	52.0	3.3	3.6
RAss134b	4472.9	9.6	9.6	30.1	2.3	0.1	0.1	44.4	3.9	4.2
RAss136	2205.4	6.9	6.8	22.6	2.0	0.1	0	65.2	3.6	4.1
RATU3-1	2024.2	6.8	6.9	17.7	0.9	0.1	0	59.1	3.6	4.2
RATU3-2	1422.2	5.4	5.5	15.7	1.0	0.1	0	59.2	3.8	4.2
RATU3-3	2401.5	8.5	8.7	18.0	1.5	0.1	0.1	46.3	4.4	4.7
RATU3-4	421.8	3.5	3.7	4.0	0.6	0.2	1.2	39.0	3.4	3.7
RATU3-5	521.5	3.9	4.0	3.5	0.7	0.1	0	51.1	4.1	4.7
RATU3-6	463.6	3.0	3.0	3.8	0.6	0.1	0	28.7	3.7	4.1
RATU3-7	477.0	3.1	3.2	5.0	0.6	0.1	0	28.5	4.3	4.8
RATU3-8	1812.3	6.3	6.6	16.5	0.9	0.1	0	32.8	3.8	4.3
RATU3-9	679.8	3.0	3.2	6.5	0.8	0.1	0	29.1	3.9	4.3
RATU3-10	1784.3	6.2	6.3	16.3	0.9	0.1	0	42.9	3.7	4.2
RATU3-11	926.4	4.2	4.3	10.3	0.7	0.1	0	30.2	3.6	4.1
RATU3-12	1922.9	7.2	7.3	23.2	1.1	0.1	0	57.0	4.4	5.0
RATU3-16	930.1	4.3	4.3	8.2	1.0	0.1	0	40.6	4.4	4.9
RATU3-17	3058.3	19.3	19.4	21.6	1.3	0.1	0.1	35.9	4.4	5.0
RATU3-18	1677.7	6.4	6.6	14.7	1.0	0.1	0	27.8	5.6	6.4
RATU3-19	1506.7	6.0	6.1	14.0	0.8	0.1	0	62.7	3.7	4.2
RATU3-20	2411.2	7.7	7.6	16.3	1.2	0.1	0	49.5	6.4	7.3
RATU3-36	1404.3	6.5	6.6	11.8	1.1	0.1	0	44.1	4.4	5.0
RATU3-51	1250.7	5.9	5.9	10.2	1.0	0.1	0	50.0	4.3	4.8
RATU3-53	487.9	3.9	3.9	2.8	0.8	0.1	0	41.0	4.1	4.7
RATU3-60	1499.8	6.5	6.6	14.4	1.2	0.1	0	37.8	4.2	4.7
MA 8-1	4123.5	9.7	10.1	8.5	1.7	0.4	0.8	27.6	7.7	8.4
Maj 1	2686.5	10.2	10.4	16.9	0.8	0.2	0	29.6	7.4	8.2

Maj 3	1471.9	6.0	6.2	10.6	1.1	0.1	0.1	67.2	3.8	4.5
Maj 5	735.8	4.0	4.1	3.8	0.9	0.1	0	56.2	3.9	4.7
Maj 7	1357.8	6.1	6.3	10.6	1.2	0.1	0	43.5	4.0	4.8
Maj 8	1887.6	6.7	7.0	11.5	0.5	0.2	0.2	39.2	1.6	1.8
Maj 9	766.1	4.0	4.2	6.4	0.7	0.2	0.1	51.3	2.4	2.7
Maj 10	1056.4	5.1	5.3	10.8	0.8	0.2	0.1	40.0	2.8	3.0
Maj 11	1161.7	4.9	4.9	8.6	1.2	0.1	0	34.4	3.4	3.8
Maj 12	1410.6	5.3	5.6	10.1	1.0	0.1	0	35.9	3.3	3.9
Maj 89	1182.2	5.7	5.7	8.2	0.9	0.1	0	47.9	3.1	3.5
Maj 94	636.9	2.9	3.0	4.9	0.5	0.2	0.1	39.5	1.7	1.8
Maj 95	1673.8	6.3	6.4	10.6	1.2	0.1	0	34.0	3.8	4.6
Maj 96	1662.0	6.0	6.3	10.8	1.1	0.1	0	23.3	4.1	4.9
Maj 100	1113.7	5.2	5.4	7.8	1.1	0.1	0	45.2	3.9	4.7
Maj 116	1300.0	4.3	4.4	9.6	0.6	0.2	0.1	46.0	1.8	1.9
Maj 123	1462.7	8.9	9.2	9.8	1.1	0.1	0	39.8	3.6	4.3
Maj 124	1122.5	6.2	6.4	9.1	1.1	0.1	0	33.6	3.6	4.3
Maj 125	595.0	2.7	2.9	4.5	0.5	0.2	0.1	43.5	1.8	2.0
CRB1-1	2007.2	5.0	5.1	12.2	0.8	0.1	0	36.9	4.6	4.9
CRB1-2	1746.8	3.6	3.6	8.9	0.8	0.1	0	23.0	3.2	3.5
CRB1-3	1725.2	3.2	3.4	9.3	1.3	0.1	0.1	50.3	4.3	4.7
CRB1-4	1297.5	3.2	3.2	7.9	1.4	0.1	0	44.3	4.1	4.4
CRB1-5	536.6	1.9	2.0	3.7	1.3	0.1	0	56.4	3.6	3.9
CRB2-6	2647.2	8.4	8.7	20.7	0.8	0.2	0	48.8	7.2	7.9
CRB2-7	2055.3	4.6	4.7	11.9	0.7	0.1	0	32.3	3.5	3.8
CRB2-8	1465.2	2.6	2.7	8.8	0.6	0.1	0	57.0	2.8	3.0
CRB2-9	907.6	2.9	2.9	4.2	1.1	0.1	0	49.9	4.4	4.7
CRB2-10	1892.1	3.8	3.9	12.0	0.8	0.1	0	50.3	3.7	3.9
CRB2-11	567.2	2.7	2.8	2.9	1.1	0.1	0	31.9	4.0	4.3
CRBP-12	2092.9	5.4	5.5	13.3	0.9	0.1	0	51.7	4.7	5.1
CRBP-14	2129.8	4.9	4.8	11.9	1.2	0.1	0	28.3	7.2	7.9
CRBP-15	2669.1	9.0	8.9	19.7	1.3	0.2	0	51.8	8.5	9.3
CRBP-16	1808.6	7.3	7.4	13.1	1.1	0.1	0	49.2	6.2	6.7

CRBP-17	1256.9	2.6	2.7	6.3	0.8	0.1	0	67.6	2.9	3.1
CRBP-18	515.7	2.2	2.2	3.5	1.3	0.1	0	52.6	3.8	4.2
CRB 22-1-1	2302.8	8.3	8.5	19.2	0.6	0.2	0	42.5	6.2	6.8
CRB22-1-3	1457.6	5.1	5.1	11.9	0.3	0.1	0	36.9	2.6	2.8
CRB 22-1-7	2436.0	5.6	5.7	12.9	0.6	0.2	0	55.2	3.9	4.3
CRB 22-1-9	1402.2	4.2	4.4	9.0	0.8	0.1	0	33.2	3.5	3.8
CRB 22-1-11	1041.0	3.7	3.7	6.9	1.1	0.1	0	62.3	3.6	3.9
CRB 22-3-1	2372.1	8.5	8.4	20.6	0.5	0.2	0	55.4	7.0	8.1
CRB 22-3-5	3154.3	7.7	7.7	19.7	1.1	0.2	0	47.6	4.7	5.2
CRB 22-3-11	3093.7	10.4	10.6	25.4	0.7	0.2	0	52.0	7.6	8.2
CRB 22-7-1	2524.3	8.7	9.0	21.6	0.8	0.2	0	61.4	6.8	7.5
CRB 22-7-4	2504.1	8.3	8.5	21.0	0.8	0.2	0	71.9	6.6	7.2
CRB 22-7-6	4085.4	8.1	8.3	27.6	1.4	0.2	0	70.3	7.9	8.5
CRB 22-7-9	1384.4	5.6	5.9	10.8	1.0	0.1	0	68.6	4.1	4.5
CRBP22-7-12	2140.6	6.0	6.1	22.5	1.0	0.1	0	100.8	5.9	6.8
CRBP22-9-4	2392.4	6.7	6.8	20.2	0.9	0.2	0	37.7	5.7	6.2
CRBP22-9-9	1846.7	5.3	5.3	16.4	1.0	0.1	0	46.3	4.5	4.9
CRBP22-9-11	1933.9	6.4	6.6	17.1	0.7	0.2	0	59.7	5.9	6.5
CRBP22-9-13	1165.8	4.7	4.8	13.7	1.3	0.1	0	49.9	4.9	5.4
CRBP22-9-15	2089.5	5.2	5.0	15.8	1.4	0.1	0	55.6	4.1	4.4
PE1-1	6623.0	5.0	4.9	37.7	2.5	0.2	0.2	52.1	4.6	4.8
PE1-2	4559.7	9.1	9.0	30.4	8.9	0.1	0.1	54.2	7.0	7.5
PE1-3	21093.7	16.0	16.2	106.1	11.2	0.3	0.3	78.5	6.5	6.9
PE1-4	7985.7	7.3	7.5	35.0	2.3	0.2	0.1	117.4	7.0	7.5
PE1-5	8323.5	18.8	19.0	61.2	2.2	0.3	0.2	222.3	4.8	5.1
PE1-6	898.9	3.1	3.0	30.3	4.0	0.1	0.0	95.2	5.9	6.3
PE1-7	935.1	6.0	6.1	21.3	1.1	0.1	0.0	146.5	6.9	7.3
PE1-8	15510.3	10.1	9.9	78.7	3.6	0.3	0.1	40.7	5.1	5.4
PE1-9	15885.8	12.0	12.1	75.7	3.5	0.3	0.2	37.2	3.9	4.1
PE1-10	3308.2	14.6	14.6	39.0	6.6	0.1	0.1	155.0	7.9	8.7
PE1-893	2777.9	10.5	10.4	31.1	5.6	0.1	0.1	239.4	5.9	6.3
PE1-901	2655.0	10.2	10.5	24.1	1.6	0.1	0.0	66.6	6.5	7.1

PE1-910	2443.5	8.3	8.4	21.9	1.8	0.1	0.0	42.7	5.3	6.0
PE-896	2176.5	9.3	9.3	26.5	3.2	0.2	0.1	70.6	8.2	8.8
PE-897	3552.2	13.9	13.9	34.4	3.6	0.2	0.3	68.2	8.3	8.8
PE-915	3240.7	10.7	10.7	27.4	2.9	0.2	0.0	47.2	6.9	7.4
PE2005-1-4	8538.7	10.0	10.3	82.4	3.1	0.2	0.1	67.4	3.9	4.3
PE2005-1-8	3952.4	13.7	13.6	28.8	3.4	0.2	0.1		5.3	6.2
PE2005-2-1	1517.5	6.5	6.6	10.6	2.1	0.1	0	70.3	5.2	5.8
PE2005-2-4	3695.1	14.7	14.8	32.8	0.8	0.2	0	65.3	7.1	8.2
PE2005-2-6	2179.7	5.4	5.4	15.1	0.9	0.1	0	74.7	2.0	2.3
PE2005-2-7	2340.1	6.1	6.3	18.8	2.3	0.1	0	84.9	4.3	5.1
PE2005-2-10	2340.1	6.1	6.3	18.8	2.3	0.1	0	56.8	4.3	5.1
PE2005-3-1	1528.6	6.8	6.8	12.3	1.9	0.1	0	83.6	4.9	5.7
PE2005-3-5	4500.4	16.0	15.9	39.6	0.8	0.2	0	83.6	7.6	9.0
PE2005-3-6	3231.5	11.6	11.6	24.5	1.7	0.1	0	61.4	4.9	5.6
PE2005-3-8	2482.7	9.4	9.4	21.6	2.3	0.1	0	92.2	4.5	5.2
PE2005-3-10	678.0	4.5	4.6	4.7	0.9	0.1	0	71.8	4.3	5.2
PE2005-4-1	333.0	3.2	3.3	3.1	0.7	0.1	0	74.5	4.0	4.5
PE2005-4-4	4133.8	16.1	16.3	33.2	0.8	0.2	0	40.7	7.1	8.1
PE2005-4-8	1909.1	5.2	5.5	13.7	1.8	0.1	0	42.1	4.0	4.6
PE2005-4-10	3140.3	7.0	7.0	20.2	2.2	0.1	0	90.4	4.1	4.9
PE2005-4-15	2629.0	10.3	10.2	18.5	1.3	0.1	0	63.7	4.8	5.7
PE2005-6-1	77.9	3.1	3.1	2.3	0.3	0.0	0	72.9	3.8	4.3
PE2005-6-4	4576.9	12.0	11.8	43.4	1.0	0.1	0	68.2	6.8	8.1
PE2005-6-6	4200.6	10.0	9.8	34.9	1.3	0.1	0.1	69.2	5.4	6.4
PE2005-6-8	1619.1	6.8	6.8	11.7	1.4	0.1	0	79.5	4.0	4.6
PE2005-6-13	885.5	5.9	5.9	7.9	0.9	0.1	0	84.7	4.8	5.5
PE2005-8-2	169.1	4.1	4.2	3.5	0.6	0.1	0	45.2	5.2	6.0
PE2005-8-6	1392.2	7.7	7.8	13.9	2.1	0.1	0	39.2	5.8	6.7
PE2005-8-9	4610.6	12.9	12.8	33.9	2.1	0.2	0	50.6	4.1	4.9
PE2005-8-11	2853.3	9.5	9.6	18.2	2.0	0.1	0	53.9	5.7	6.6
PE2005-8-13	2989.8	8.7	8.9	17.7	2.3	0.1	0	74.3	5.3	6.1
PE2005-8-17	467.7	3.5	3.6	3.5	2.6	0.1	0	41.2	4.1	4.7

PE2005-10-1	162.5	3.7	3.7	3.2	0.4	0.1	0	55.2	5.0	5.6
PE2005-10-5	892.1	4.4	4.3	7.3	0.8	0.1	0	45.3	5.6	6.5
PE2005-10-7	2044.4	7.8	7.7	15.2	1.4	0.1	0	70.1	4.3	5.0
PE2005-10-9	1267.5	6.6	6.7	12.1	1.3	0.1	0	47.9	4.7	5.3
129 SOIL	369.0	4.1	4.1	4.2	0.6	0.1	0	56.7	4.8	5.4
PE107-0324-141 Soil	10866.9	8.4	8.8	46.3	2.2	0.2	0	66.1	4.1	4.9

Table C.2 Soil samples results

b) Sample analysis

PCA

The elements included in the PCA are listed in Table C.2, representing those deemed the most suitable indicators of human activity. The analysis produced two principal component loadings (Figure C.1), and the resulting sample distribution plot includes all samples, including those identified as outliers.

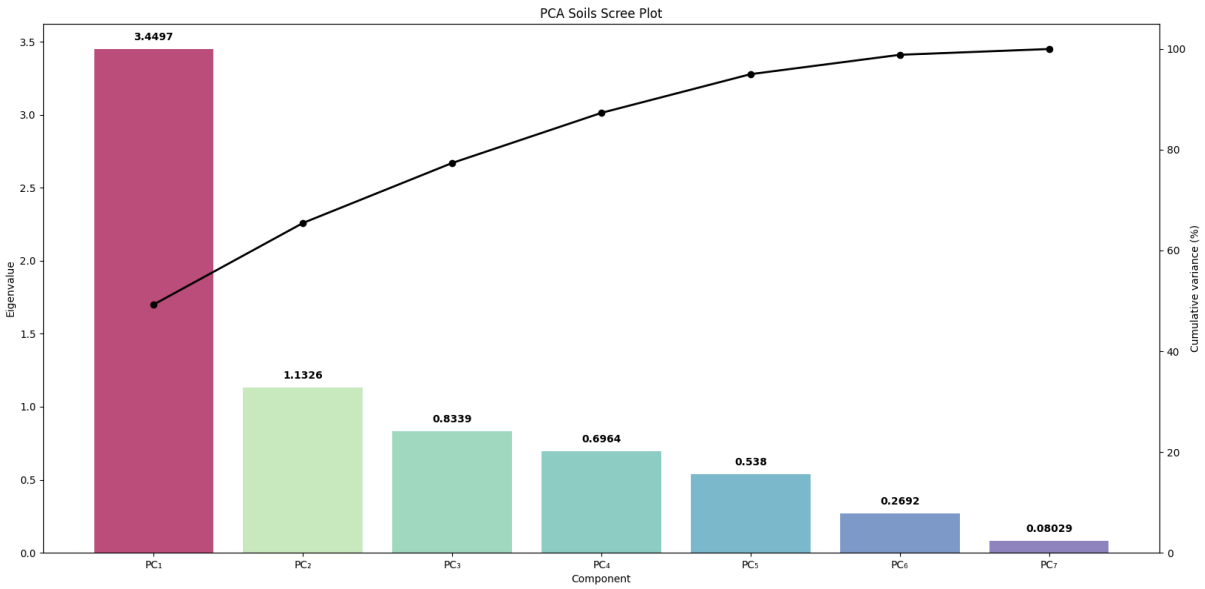


Figure C.1 PCA histogram showing different components

While Chapter 10 presented only the PCA results with outliers removed—since their inclusion obscured the overall pattern, the original PCA plot includes all analyzed samples. This full graph, shown in Figure C.2, displays the extreme outliers positioned along the outer edges of each axis, illustrating the full range of geochemical variability captured in the dataset.

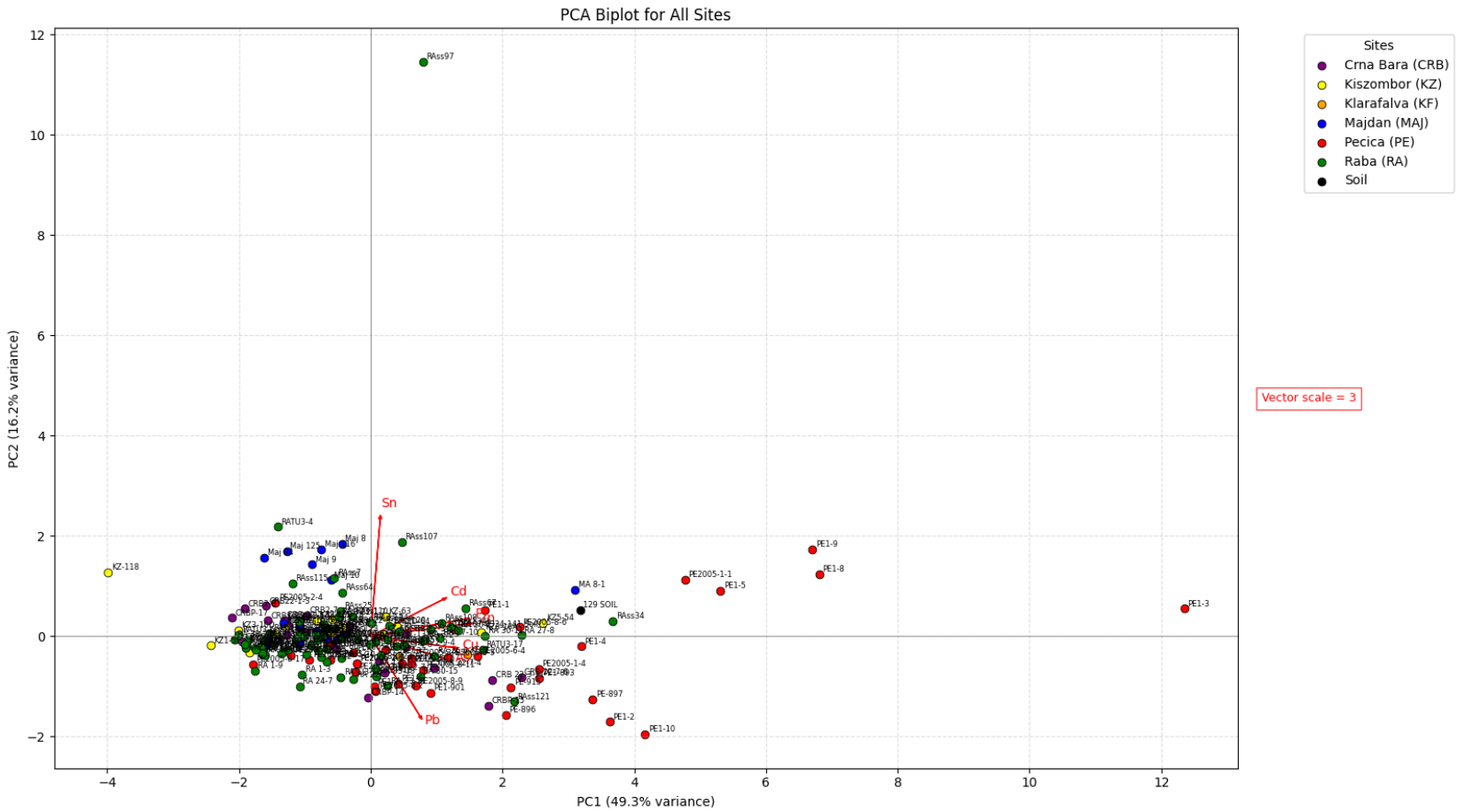


Figure C.2 Graph showing all samples including outlie

Ecological results

The ecological results reflect the present-day contamination levels of the soil samples according to established modern standards. While these values are important to consider, it is essential to recognize that they represent only a fraction of what the impacts may have been in the past, as discussed in Chapter 8.

The ecological risk assessment is based on the calculated ecological factor, which in turn relies on site-specific background values.

$$EF = \frac{\left(\frac{M}{Y}\right) sample}{\left(\frac{M}{Y}\right) background}$$

The ecological risk factor was calculated using background values specific to each site, as shown in Table #. This highlights the importance of site-specific sampling, since the differences between background values are substantial and would have directly influenced the resulting ecological risk scores presented in Table

	BGkz	BGram	BGpe	BGcrb	PZavr
P	3138.5	611.3	360.5	551.9	3556.8
Cu	9.6	3.9	4.2	2.3	9.9
Zn	20.8	6.7	5.1	3.3	21.7
As	0.9	0.9	0.8	1.2	0.9
Cd	0.2	0.1	0.1	0.1	0.2
Sn	0.0	0.0	0.0	0.0	0.0
Pb	6.9	4.7	5.2	4.1	7.5
Fe	1504.1	1415.8	834.0	804.1	1226.3

Table C.3 Showing the background levels for each site according to element

Anthropogenic enrichment	
EF < 1	no enrichment
EF 1–3	minor enrichment
EF 3–5	moderate enrichment
EF 5–10	moderately severe enrichment
EF 10–25	severe enrichment

EF 25–50	very severe enrichment
EF > 50	extremely severe enrichment

Table C.4 Anthropological enrichment chart

Sample ID	P	Cu	Zn	As	Cd	Sn	Pb
KZ1-5C	0.3	0.4	0.3	1.3	0.5	0	0.6
KZ1-5D	0.2	0.4	0.2	2.4	0.5	0	0.9
KZ1-5E	0.1	0.2	0.1	0.7	0.1	0	0.4
KZ3-10A	1.9	1.4	1.7	1.4	1.6	0	1.2
KZ3-10B	0.9	0.8	0.8	1.0	1.2	0	1.0
KZ3-10C	0.2	0.4	0.3	1.4	0.6	0	0.7
KZ3-10D	0.1	0.2	0.2	1.1	0.4	0	0.5
KZ5-54	1.7	1.4	2.2	2.1	0.9	0	0.7
KZ-57	0.6	0.8	0.8	1.3	0.9	0	0.8
KZ-58	0.4	0.7	0.5	0.9	0.6	0	0.6
KZ-63	1.8	1.3	1.8	1.3	1.3	0	1.0
KZD-64	0.8	0.9	1.1	1.0	0.7	0	0.6
KZ-66	0.8	1.1	1.4	1.8	1.0	0	0.9
KZ-67	0.8	0.9	1.0	1.1	0.8	0	0.7
KZ5-78	0.9	1.3	1.4	1.5	0.7	0	0.7
KZ-118	0.6	0.7	2.8	2.2	0.0	0	0.7
KF82	0.5	0.8	1.2	1.5	0.7	0	0.6
KF137	0.4	0.5	0.9	1.5	0.4	0	0.5
RA 1-3	2.0	1.6	0.7	0.8	1.0	0	1.4
RA 1-5	6.4	2.9	1.4	1.6	0.6	0	1.1
RA 1-9	1.0	1.1	-0.3	1.1	0.6	0	1.1
RA 22/23-3	1.6	2.1	1.4	1.4	1.2	0	1.4
RA 22/23-4	1.3	1.9	1.3	2.1	1.4	0	1.4
RA 22/23-8	0.8	1.4	1.2	1.4	1.1	0	1.2
RA 24-5	0.3	1.6	1.5	0.4	0.3	0	0.9
RA 24-7	0.3	1.3	1.3	0.4	1.0	0	1.4
RA 25-4	0.8	1.7	1.2	0.8	1.9	0	1.9
RA 26-6	1.7	1.9	2.1	1.4	0.7	0	0.7
RA 27-8	5.8	1.7	3.4	2.2	0.7	0	0.7
RA 27-10	2.9	1.5	3.3	1.8	0.8	0	0.6
RA 29-2	2.0	1.8	1.8	1.6	1.2	0	1.5
RA 29-6	2.0	1.2	1.7	1.2	1.3	0	1.0
RA 30-4	7.1	1.5	3.9	3.2	1.3	0	0.8
RA 30-11	5.7	6.1	3.9	1.7	1.7	0	1.1
RA 30-12	1.6	1.3	3.2	1.2	0.6	0	0.5
RA 30-15	3.3	3.4	2.9	1.0	1.9	0	1.7
RA 30-18	0.5	0.9	0.7	0.7	1.0	0	1.1
RA 30-19	0.7	1.4	0.8	1.2	1.3	0	1.5

Sample ID	P	Cu	Zn	As	Cd	Sn	Pb
RA 30-22	0.7	1.4	0.9	1.3	1.5	0	1.7
RA 31-1	4.3	2.4	3.0	1.9	1.2	0	1.1
RA 31-3	4.3	2.4	3.0	1.9	1.2	0	1.1
RA 31-5	3.2	2.1	3.3	1.0	0.9	0	0.7
RA 31-10	1.2	0.4	0.9	1.9	0.7	0	0.5
RA 31-13	3.5	1.4	3.2	1.6	1.7	0	1.2
RA 31-14	0.9	1.3	1.2	1.1	0.9	0	1.1
RA 31-17	1.0	1.3	0.9	1.0	1.5	0	1.5
RA 31-18	0.9	1.0	1.0	0.8	1.4	0	1.4
RA 31-19	0.6	1.0	0.9	0.7	1.1	0	1.2
RA 31-21	0.8	1.1	1.0	1.2	1.5	0	1.7
RA 32-1	3.2	2.2	2.4	1.7	1.8	0	1.7
RA 32-3	2.5	1.9	1.8	1.5	1.2	0	1.1
RA 32-7	1.9	1.3	1.7	1.0	1.0	0	0.9
RA 32-10	2.1	1.7	1.4	1.9	1.9	0	1.7
RA 32-21(13?)	1.8	1.2	1.1	1.6	1.8	0	1.5
RA 33-3	4.3	1.7	3.3	2.0	1.1	0	0.8
RA 33-7	2.4	1.3	1.9	2.6	0.9	0	0.8
RA 33-11	0.9	0.6	0.6	2.9	0.6	0	0.6
RA 33-13	0.9	0.6	0.5	2.6	0.6	0	0.6
RA 33-17	0.8	0.7	0.5	1.9	0.8	0	0.7
RA 105	2.8	1.3	2.4	1.4	1.0	0	0.8
RA 30	1.1	1.6	1.5	1.1	0.6	0	0.5
RA 32	3.6	24.1	4.2	2.6	1.2	0	0.6
RAss7	3.8	1.6	2.6	1.7	1.4	0	0.7
RAss10	2.5	1.2	2.1	1.3	0.7	0	0.7
RAss25	6.4	1.8	3.3	2.9	2.1	0	1.1
RAss29	2.7	0.7	2.0	1.3	0.5	0	0.5
RAss34	5.5	3.2	4.7	2.0	1.4	0	0.7
RAss64	4.0	1.8	3.5	2.2	1.7	0	0.8
RAss65	3.7	1.5	2.9	1.6	1.1	0	0.9
RAss67	6.6	2.1	4.6	1.7	1.3	0	0.7
RAss72	5.1	2.0	3.8	1.6	1.5	0	1.1
RAss73	4.1	1.8	2.9	1.2	1.2	0	0.9
RAss97	3.8	2.2	4.0	2.2	2.1	0	0.6
RAss106	3.5	1.8	2.5	1.6	1.0	0	1.0
RAss107	3.8	2.2	3.9	1.9	2.2	0	0.9
RAss108	6.9	1.7	3.5	1.9	0.7	0	0.6
RAss110	4.0	1.5	2.4	1.3	0.8	0	0.6
RAss115	2.8	1.4	2.2	1.3	2.9	0	0.9
RAss120	6.2	2.9	4.0	2.5	1.5	0	1.1
RAss121	1.8	0.9	1.8	3.5	0.5	0	0.6
RAss132	4.2	1.3	2.2	3.9	1.4	0	1.0
RAss134a	6.1	2.7	4.1	3.8	1.6	0	1.1
RAss134b	8.0	2.7	4.9	2.9	1.3	0	1.0

Sample ID	P	Cu	Zn	As	Cd	Sn	Pb
RAss136	3.0	1.5	2.8	1.9	0.6	0	0.7
RATU3-1	3.4	1.8	2.7	1.1	0.7	0	0.9
RATU3-2	2.7	1.6	2.7	1.3	1.0	0	1.0
RATU3-3	4.3	2.4	3.0	1.9	1.2	0	1.1
RATU3-4	1.5	2.0	1.3	1.4	3.6	0	1.7
RATU3-5	1.0	1.2	0.6	0.9	1.1	0	1.2
RATU3-6	1.3	1.3	1.0	1.2	1.5	0	1.5
RATU3-8	2.4	1.3	2.0	0.8	0.8	0	0.7
RATU3-9	1.6	1.1	1.3	1.3	0.9	0	1.3
RATU3-10	2.6	1.5	2.2	0.9	0.8	0	0.8
RATU3-11	1.6	1.1	1.6	0.8	0.9	0	0.9
RATU3-12	2.6	1.5	2.9	1.0	1.0	0	0.9
RATU3-16	1.4	1.0	1.1	1.1	0.9	0	0.9
RATU3-17	5.5	5.5	3.6	1.7	1.2	0	1.2
RATU3-18	2.8	1.7	2.3	1.1	0.9	0	1.4
RATU3-19	2.6	1.6	2.2	1.0	1.4	0	0.9
RATU3-36	2.8	2.0	2.1	1.5	1.3	0	1.2
RATU3-51	2.4	1.7	1.8	1.2	1.3	0	1.2
RATU3-53	1.1	1.4	0.6	1.3	1.2	0	1.4
RATU3-60	2.3	1.6	2.0	1.2	0.7	0	0.9
MA 8-1	7.5	2.8	1.4	2.1	4.9	0	2.0
Maj 3	4.0	2.6	2.6	2.0	2.0	0	1.6
Maj 5	2.4	2.1	1.2	2.1	2.0	0	2.0
Maj 8	7.6	4.3	4.3	1.5	5.9	0	0.9
Maj 9	3.7	3.1	2.9	2.4	7.4	0	1.7
Maj 10	2.6	2.0	2.5	1.3	3.5	0	1.0
Maj 11	1.9	1.2	1.3	1.3	0.5	0	0.8
Maj 12	3.9	2.3	2.5	1.9	1.8	0	1.4
Maj 89	2.7	2.0	1.7	1.4	1.4	0	1.0
Maj 94	3.3	2.4	2.3	1.7	6.6	0	1.2
Maj 95	5.1	3.0	2.9	2.5	2.2	0	1.8
Maj 96	4.5	2.6	2.7	2.1	2.3	0	1.7
Maj 100	3.2	2.4	2.1	2.3	1.9	0	1.7
Maj 116	5.4	2.8	3.7	1.6	6.6	0	1.0
Maj 123	4.2	4.0	2.6	2.1	2.3	0	1.6
Maj 124	3.0	2.6	2.2	2.0	2.1	0	1.5
Maj 125	2.8	2.0	2.0	1.6	7.6	0	1.2
CRB1-2	3.2	1.6	2.7	0.7	1.0	0	0.9
CRB1-3	3.0	1.3	2.7	1.1	1.3	0	1.1
CRB1-4	2.2	1.3	2.2	1.1	1.1	0	1.0
CRB2-7	3.9	2.2	3.8	0.6	1.5	0	1.0
CRB2-8	2.4	1.1	2.4	0.4	0.9	0	0.7
CRB2-9	1.7	1.3	1.3	1.0	1.1	0	1.2
CRB2-10	2.6	1.3	2.8	0.5	0.8	0	0.7
CRBP-12	3.5	2.2	3.7	0.7	1.2	0	1.1

Sample ID	P	Cu	Zn	As	Cd	Sn	Pb
CRBP-14	3.7	2.0	3.4	1.0	1.3	0	1.8
CRBP-15	3.2	2.6	3.9	0.7	1.6	0	1.5
CRBP-16	2.6	2.5	3.1	0.8	1.2	0	1.3
CRBP-17	3.7	1.9	3.0	1.0	1.1	0	1.2
CRBP-18	0.9	0.9	1.0	1.1	0.8	0	1.0
CRB22-1-3	3.3	2.8	4.5	0.3	1.2	0	0.9
CRB 22-1-7	4.0	2.2	3.5	0.4	1.6	0	0.9
CRB 22-1-9	2.5	1.8	2.7	0.6	1.3	0	0.9
CRB 22-1-11	2.2	1.9	2.4	1.1	1.6	0	1.1
CRB 22-3-5	4.5	2.7	4.7	0.7	1.5	0	1.0
CRB 22-3-11	3.6	2.9	4.9	0.4	1.6	0	1.3
CRB 22-7-4	3.1	2.5	4.4	0.5	1.5	0	1.2
CRB 22-7-6	4.4	2.1	5.0	0.7	1.7	0	1.2
CRB 22-7-9	1.9	1.9	2.4	0.6	1.0	0	0.8
CRBP22-7-12	1.9	1.3	3.3	0.4	0.7	0	0.8
CRBP22-9-4	2.8	1.9	4.0	0.5	1.4	0	1.0
CRBP22-9-9	2.1	1.5	3.2	0.5	0.9	0	0.8
CRBP22-9-11	2.1	1.7	3.2	0.4	1.1	0	1.0
CRBP22-9-13	0.8	0.8	1.6	0.4	0.6	0	0.5
CRBP22-9-15	2.3	1.4	2.9	0.7	1.0	0	0.7
PE1-1	5.1	0.3	2.1	0.8	0.6	0	0.3
PE1-2	2.6	0.4	1.2	2.2	0.3	0	0.3
PE1-3	15.8	1.0	5.6	3.7	1.2	0	0.4
PE1-4	5.4	0.4	1.7	0.7	0.7	0	0.4
PE1-5	6.1	1.2	3.2	0.7	0.9	0	0.3
PE1-6	0.3	0.1	0.8	0.7	0.2	0	0.2
PE1-7	0.7	0.4	1.1	0.3	0.4	0	0.4
PE1-8	13.0	0.7	4.7	1.3	1.1	0	0.3
PE1-9	15.4	1.0	5.2	1.5	1.2	0	0.3
PE1-10	2.2	0.8	1.8	1.9	0.4	0	0.4
PE1-893	1.1	0.4	0.9	1.0	0.3	0	0.2
PE1-901	1.9	0.6	1.2	0.5	0.3	0	0.3
PE1-910	2.2	0.6	1.4	0.7	0.5	0	0.4
PE-896	1.1	0.4	1.0	0.7	0.4	0	0.3
PE-897	1.9	0.6	1.3	0.8	0.4	0	0.3
PE-915	2.2	0.6	1.3	0.9	0.5	0	0.4
PE2005-1-1	6.8	0.7	4.7	1.1	0.8	0	0.2
PE2005-1-4	3.4	1.0	1.7	1.3	0.6	0	0.4
PE2005-1-8	3.5	1.3	1.7	2.1	1.1	0	0.9
PE2005-2-4	6.5	1.4	3.2	1.2	0.7	0	0.5
PE2005-2-6	3.7	0.8	2.1	1.6	0.4	0	0.6
PE2005-2-7	3.7	0.8	2.1	1.6	0.4	0	0.6
PE2005-3-5	5.5	1.7	3.0	1.3	1.0	0	0.7
PE2005-3-6	5.0	1.6	3.1	2.0	1.0	0	0.7
PE2005-3-8	1.9	1.0	0.9	1.1	1.4	0	1.0

Sample ID	P	Cu	Zn	As	Cd	Sn	Pb
PE2005-4-4	4.5	1.0	2.3	1.9	1.0	0	0.8
PE2005-4-8	6.9	1.3	3.1	2.1	0.9	0	0.7
PE2005-4-10	4.6	1.5	2.3	1.0	0.8	0	0.7
PE2005-6-4	7.6	1.5	4.5	1.1	1.1	0	0.8
PE2005-6-6	4.7	1.7	2.4	1.8	1.2	0	0.9
PE2005-6-8	2.4	1.3	1.5	1.1	1.3	0	1.0
PE2005-8-2	1.7	0.8	1.2	1.1	0.5	0	0.6
PE2005-8-6	7.1	1.7	3.7	1.4	1.2	0	0.5
PE2005-8-9	4.3	1.2	2.0	1.3	0.6	0	0.7
PE2005-8-11	5.1	1.3	2.1	1.7	1.0	0	0.7
PE2005-8-13	1.2	0.8	0.6	2.9	1.1	0	0.8
PE2005-8-17	0.6	1.1	0.8	0.6	1.3	0	1.3
PE2005-10-5	4.0	1.3	2.1	1.2	0.8	0	0.7
PE2005-10-7	2.5	1.1	1.7	1.2	0.8	0	0.7
129 SOIL	14.3	0.9	4.3	1.2	0.9	0	0.4
PE107-0324-141 Soil	6.7	1.3	3.7	1.1	0.8	0	0.5
PE2005-3-5	0.8	0.4	0.8	0.3	0.1	0.0	0.1
PE2005-8-17	0.8	0.4	0.8	0.3	0.1	0.0	0.1
RA 32	0.0	0.1	0.3	0.3	0.1	0.0	0.1
RA 33-18	0.8	7.3	1.5	0.6	0.3	0.0	0.1
RA 33-11	0.1	0.2	0.5	0.5	0.1	0.0	0.1
RA 33-3	0.2	0.3	0.5	0.8	0.1	0.0	0.1
RA 33-0.1	0.6	0.6	1.1	0.4	0.2	0.0	0.1
CRBP-15	0.5	0.6	1.1	0.4	0.2	0.0	0.2
CRB 22-5-4	0.3	0.5	1.0	0.2	0.1	0.0	0.1
Maj-8	0.4	0.6	1.2	0.2	0.2	0.0	0.1

Table C.5 Calculations of ecological factor (EF)

The next test applied was the ecological risk factor analysis, using Toxic-response Factors (Tir) from Zhao et al. (2022). These factors indicate which samples present an ecological risk based on their contamination levels. In this analysis, phosphorus (P) and tin (Sn) were excluded because no Tir background values for these elements are provided in the available literature.

$$ER = \text{Tir} * \text{Cir}$$

	Tir	
Cd	=	30
As	=	10
Cu	=	5
Pb	=	5
Zn	=	1

Table C.6 Toxic index values

Er < 40	low risk
40 ≤ Er < 80	moderate risk
80 ≤ Er < 160	considerate risk
160 ≤ Er < 320	high risk
Er ≥ 320	very high risk

Table C.7 Ecological risk (Er) values assessment

Sample ID	Cu	Zn	As	Cd	Pb
KZ1-5C	2.2	0.3	0.6	15.0	2.9
KZ1-5D	1.6	0.1	0.7	10.0	3.2
KZ1-5E	1.2	0.2	0.4	5.0	2.9
KZ3-10A	5.2	1.2	0.5	35.0	4.2
KZ3-10B	2.6	0.5	0.3	23.3	3.0
KZ3-10C	1.8	0.3	0.5	16.7	3.1
KZ3-10D	1.2	0.2	0.5	13.3	2.7
KZ5-54	6.8	2.1	0.9	26.7	3.3
KZ-57	3.1	0.6	0.4	21.7	3.3
KZ-58	3.2	0.5	0.3	15.0	2.7
KZ-63	4.0	1.1	0.3	23.3	3.0
KZD-64	4.8	1.2	0.5	21.7	3.1
KZ-66	4.0	1.0	0.6	23.3	3.4
KZ-67	3.8	0.8	0.4	18.3	3.0
KZ5-78	4.3	0.9	0.4	13.3	2.4
KZ-118	0.1	0.1	0.0	0.0	0.1
KF82	5.1	1.6	0.9	26.7	4.3
KF137	3.7	1.3	1.0	16.7	3.8
RA 1-3	7.5	0.6	0.9	29.3	6.6
RA 1-5	14.2	1.4	2.1	16.3	5.5
RA 1-9	5.8	-0.3	1.5	19.6	5.7
RA 22/23-3	10.3	1.4	1.8	35.9	6.8
RA 22/23-4	8.3	1.1	2.4	35.9	5.8
RA 22/23-8	6.1	1.0	1.6	29.3	5.2
RA 24-5	7.9	1.4	0.5	9.8	4.3
RA 24-7	6.6	1.3	0.6	29.3	7.4
RA 25-4	4.8	0.7	0.6	32.6	5.5
RA 26-6	15.8	3.5	3.1	35.9	5.7
RA 27-8	13.6	5.6	4.7	35.9	5.6
RA 27-10	11.5	5.1	3.7	35.9	4.8
RA 29-2	5.4	1.1	1.3	22.8	4.6
RA 29-6	5.5	1.6	1.5	35.9	4.7
RA 30-4	8.5	4.4	4.8	42.4	4.7
RA 30-11	25.0	3.2	1.8	42.4	4.7
RA 30-12	11.9	6.0	2.8	35.9	4.5

Sample ID	Cu	Zn	As	Cd	Pb
RA 30-15	14.4	2.4	1.1	48.9	7.4
RA 30-18	4.5	0.7	0.9	29.3	5.6
RA 30-19	5.1	0.5	1.1	29.3	5.5
RA 30-22	4.1	0.5	1.0	26.1	5.0
RA 31-1	10.9	2.7	2.3	32.6	5.0
RA 31-3	10.9	2.7	2.3	32.6	5.0
RA 31-5	11.9	3.8	1.5	29.3	4.0
RA 31-10	3.7	1.5	4.2	35.9	4.5
RA 31-13	7.1	3.2	2.1	52.2	5.7
RA 31-14	6.3	1.2	1.4	26.1	5.2
RA 31-17	4.1	0.6	0.8	29.3	4.8
RA 31-18	3.9	0.8	0.8	32.6	5.4
RA 31-19	4.4	0.8	0.9	29.3	5.5
RA 31-21	3.0	0.5	0.9	26.1	4.7
RA 32-1	7.8	1.8	1.6	39.1	6.1
RA 32-3	8.1	1.6	1.8	32.6	4.7
RA 32-7	6.5	1.7	1.3	29.3	4.7
RA 32-10	5.7	1.0	1.7	39.1	5.8
RA 32-21(13?)	4.0	0.7	1.4	35.9	5.2
RA 33-3	10.6	4.1	3.2	39.1	5.1
RA 33-7	8.1	2.5	4.4	35.9	5.3
RA 33-11	6.1	1.1	7.6	35.9	6.2
RA 33-13	5.9	1.0	7.2	35.9	5.8
RA 33-17	5.5	0.8	4.0	35.9	5.3
RA 105	7.4	2.6	2.1	32.6	4.4
RA 30	15.0	2.9	2.7	35.9	4.8
RA 32	173.4	6.1	4.8	52.2	4.4
RAss7	7.4	2.5	2.2	39.1	3.1
RAss10	6.8	2.3	1.9	22.8	3.6
RAss25	6.0	2.2	2.5	42.4	3.8
RAss29	7.2	4.1	3.4	32.6	5.1
RAss34	23.2	6.9	3.9	62.0	5.0
RAss64	7.2	2.8	2.4	42.4	3.2
RAss65	9.3	3.6	2.6	39.1	5.6
RAss67	12.2	5.5	2.6	45.7	3.9
RAss72	10.3	3.9	2.2	45.7	5.7
RAss73	8.5	2.7	1.5	32.6	4.2
RAss97	9.4	3.4	2.5	55.4	2.8
RAss106	8.7	2.4	2.0	29.3	4.7
RAss107	9.7	3.4	2.2	58.7	3.8
RAss108	11.3	4.6	3.2	29.3	4.0
RAss110	8.9	3.0	2.1	29.3	3.8
RAss115	4.4	1.4	1.1	55.4	3.0
RAss120	11.2	3.1	2.6	35.9	4.2
RAss121	10.2	4.2	10.5	32.6	6.6

Sample ID	Cu	Zn	As	Cd	Pb
RAss132	5.0	1.8	4.0	32.6	3.9
RAss134a	9.6	2.8	3.5	32.6	3.8
RAss134b	12.4	4.5	3.5	35.9	4.4
RAss136	8.9	3.4	3.1	22.8	4.3
RATU3-1	8.7	2.7	1.4	19.6	4.4
RATU3-2	6.9	2.4	1.4	26.1	4.4
RATU3-3	10.9	2.7	2.3	32.6	5.0
RATU3-4	4.6	0.6	0.9	48.9	3.9
RATU3-5	5.1	0.5	1.0	26.1	5.0
RATU3-6	3.8	0.6	0.9	26.1	4.3
RATU3-8	8.1	2.5	1.3	29.3	4.6
RATU3-9	3.9	1.0	1.2	19.6	4.6
RATU3-10	8.0	2.4	1.3	26.1	4.4
RATU3-11	5.4	1.5	1.0	26.1	4.3
RATU3-12	9.3	3.5	1.6	35.9	5.3
RATU3-16	5.6	1.2	1.5	29.3	5.2
RATU3-17	24.8	3.2	2.0	32.6	5.3
RATU3-18	8.3	2.2	1.4	26.1	6.7
RATU3-19	7.7	2.1	1.2	39.1	4.4
RATU3-36	8.4	1.8	1.6	32.6	5.2
RATU3-51	7.6	1.5	1.4	32.6	5.0
RATU3-53	5.0	0.4	1.2	26.1	5.0
RATU3-60	8.4	2.2	1.7	22.8	5.0
MA 8-1	12.4	1.3	2.5	130.4	8.9
Maj 3	7.8	1.6	1.6	35.9	4.7
Maj 5	5.1	0.6	1.4	29.3	4.9
Maj 8	8.6	1.7	0.8	71.7	1.9
Maj 9	5.2	1.0	1.1	75.0	2.8
Maj 10	6.6	1.6	1.2	68.5	3.2
Maj 11	6.3	1.3	1.8	16.3	4.0
Maj 12	6.9	1.5	1.5	32.6	4.1
Maj 89	7.4	1.2	1.4	29.3	3.7
Maj 94	3.7	0.7	0.7	62.0	1.9
Maj 95	8.1	1.6	1.8	35.9	4.8
Maj 96	7.7	1.6	1.6	42.4	5.1
Maj 100	6.7	1.2	1.7	32.6	4.9
Maj 116	5.6	1.4	0.8	78.3	2.0
Maj 123	11.5	1.5	1.6	39.1	4.5
Maj 124	7.9	1.4	1.6	39.1	4.5
Maj 125	3.5	0.7	0.7	78.3	2.1
CRB1-2	7.9	2.7	2.5	28.2	4.3
CRB1-3	7.0	2.8	3.9	42.4	5.7
CRB1-4	7.1	2.4	4.1	35.3	5.4
CRB2-7	10.3	3.6	2.0	42.4	4.6
CRB2-8	5.8	2.7	1.7	28.2	3.6

Sample ID	Cu	Zn	As	Cd	Pb
CRB2-9	6.4	1.3	3.3	31.8	5.7
CRB2-10	8.5	3.6	2.5	31.8	4.8
CRBP-12	11.9	4.0	2.8	38.8	6.2
CRBP-14	10.8	3.6	3.5	42.4	9.6
CRBP-15	19.9	5.9	4.0	74.1	11.4
CRBP-16	16.2	4.0	3.4	45.9	8.2
CRBP-17	5.8	1.9	2.3	21.2	3.8
CRBP-18	4.9	1.1	4.0	24.7	5.1
CRB22-1-3	11.3	3.6	0.9	28.2	3.4
CRB 22-1-7	12.3	3.9	1.7	52.9	5.2
CRB 22-1-9	9.4	2.7	2.3	38.8	4.7
CRB 22-1-11	8.1	2.1	3.4	42.4	4.7
CRB 22-3-5	17.1	5.9	3.2	56.5	6.3
CRB 22-3-11	22.9	7.7	2.0	74.1	10.0
CRB 22-7-4	18.3	6.3	2.5	63.5	8.7
CRB 22-7-6	17.9	8.4	4.1	84.7	10.4
CRB 22-7-9	12.5	3.3	3.1	42.4	5.5
CRBP22-7-12	13.3	6.8	3.1	42.4	8.2
CRBP22-9-4	14.8	6.1	2.6	63.5	7.5
CRBP22-9-9	11.7	5.0	3.0	42.4	6.0
CRBP22-9-11	14.2	5.2	2.2	52.9	7.9
CRBP22-9-13	10.5	4.1	4.0	45.9	6.5
CRBP22-9-15	11.4	4.8	4.1	49.4	5.3
PE1-1	5.9	7.4	4.9	59.2	4.6
PE1-2	10.7	6.0	17.5	43.4	7.2
PE1-3	18.9	20.9	22.1	130.3	6.7
PE1-4	8.6	6.9	4.5	90.8	7.2
PE1-5	22.2	12.0	4.3	98.7	4.9
PE1-6	3.7	6.0	7.8	35.5	6.1
PE1-7	7.1	4.2	2.1	47.4	7.1
PE1-8	12.0	15.5	7.0	110.5	5.2
PE1-9	14.2	14.9	6.9	106.6	4.0
PE1-10	17.2	7.7	13.0	55.3	8.4
PE1-893	12.4	6.1	11.0	55.3	6.1
PE1-901	12.1	4.7	3.1	35.5	6.9
PE1-910	9.8	4.3	3.5	47.4	5.7
PE-896	10.9	5.2	6.3	63.2	8.5
PE-897	16.4	6.8	7.1	67.1	8.5
PE-915	12.7	5.4	5.8	63.2	7.1
PE2005-1-1	11.8	16.2	6.1	82.9	4.2
PE2005-1-4	16.2	5.7	6.7	59.2	6.0
PE2005-1-8	7.7	2.1	4.2	39.5	5.6
PE2005-2-4	6.4	3.0	1.7	19.7	2.2
PE2005-2-6	7.2	3.7	4.6	23.7	4.9
PE2005-2-7	7.2	3.7	4.6	23.7	4.9

Sample ID	Cu	Zn	As	Cd	Pb
PE2005-3-5	13.7	4.8	3.3	47.4	5.4
PE2005-3-6	11.1	4.2	4.5	39.5	5.0
PE2005-3-8	5.3	0.9	1.7	43.4	5.0
PE2005-4-4	6.1	2.7	3.6	35.5	4.4
PE2005-4-8	8.3	4.0	4.3	35.5	4.7
PE2005-4-10	12.2	3.6	2.6	39.5	5.5
PE2005-6-4	11.8	6.9	2.6	51.3	6.1
PE2005-6-6	8.1	2.3	2.8	35.5	4.4
PE2005-6-8	6.9	1.5	1.8	39.5	5.3
PE2005-8-2	9.1	2.7	4.1	35.5	6.5
PE2005-8-6	15.2	6.7	4.1	67.1	4.7
PE2005-8-9	11.2	3.6	3.9	35.5	6.4
PE2005-8-11	10.3	3.5	4.5	47.4	5.9
PE2005-8-13	4.2	0.7	5.1	35.5	4.5
PE2005-8-17	4.3	0.6	0.7	31.6	5.4
PE2005-10-5	9.2	3.0	2.7	35.5	4.8
PE2005-10-7	7.8	2.4	2.6	35.5	5.1
129 SOIL	9.9	9.1	4.2	59.2	4.7
PE107-0324-141 Soil	11.8	6.9	3.2	43.4	4.3

Table C.8 Ecological factor results

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