Charles University

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Diploma thesis

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Knee Fibulas: Military Factor or Cultural Symbol?

An Analysis of the Material Composition of Roman-Provincial Knee Fibulas in the Central Danube Region and their Sociocultural and Technological Connotations

Kolínkovité spony: vojenský prvek nebo kulturní symbol?

Analýza materiálového složení římsko-provinciálních kolínkovitých spon ve středním Podunají
a jejich sociokulturní a technologické konotace

In Prague, on the 21st of May 2025

Supervisor: Mgr. Matěj Kmošek Dis.

Declaration

I declare that I have written my thesis independently, that I have properly cited all sources and literature used, and that the thesis has not been used in the during another university study or for obtaining another or the same degree.

In Prague, on the 21st of May 2025

Matej Lelovič

Acknowledgements

My thanks go to Mgr. Matěj Kmošek Dis., who provided me with his invaluable insights and dutiful guidance throughout my MA study. Without him, I would not have learned the skills needed to execute this research. Next I would like to thank all my colleagues from The Laboratory of Analytical Conservation at The institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i, namely Bc. Čeněk Fouček and Mgr. Filip Ševčík, for their support and valuable advice. Furthermore, I would like to thank Martijn Wijnhoven, Ph.D. for providing me the opportunity to work with the material from Carnuntum.

My gratitude also goes to all the institutions I have visited and to the people who have facilitated these visits and provided me with the material. First I would like to thank The institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. I, the director Mgr, Balász Komoróczy, Ph. D., and Mgr. Alina Szabová, who have allowed me access to the Moravian knee brooches. Other thanks go to The institute of Archaeology of the Slovak Academy of Sciences, Nitra, the director doc. PhDr. Matej Ruttkay, CSc. and PhDr. Ján Rajtár, CSc., who have allowed me to work on material from Slovak site. My gratitude also goes to Kulturfabrik Hainburg and Mag. Jasmine Cencic, for granting me the opportunity to examine the knee brooches for Carnuntum. Finally I thank the Czech National Museum and Mgr. Tomáš Janek, for allowing me to work with knee brooches found in Bohemia.

Last but certainly not least I thank my mother, Jana Lelovičová, for ever providing me with a safe space to work from, and her lasting support during my study, never doubting my success. Thank you, mom.

Matej Lelovič

Keywords

English

Knee fibulas, roman period, Limes Romanus, middle Danube region, copper alloys, technology

Česky

Kolínkovité spony, doba římská, Limes Romanus, střední Podunají, slitiny mědi, technologie

Abstract

The thesis deals with the issue of the material composition of roman or roman-provincial knee-fibulas in the Central Danube region and the associated socio-cultural and technological connotations. These fibulas are considered typical military components of clothing. They were mainly widespread in the Rhineland and the Central Danube region, and the peak of their production was reached between the C1 and C2 stages (150–300AD). According to the results of material analyses to date, most fibulas of this type are made by casting from high-lead bronze.

The aim of this thesis is to test the central hypothesis of whether roman-provincial knee-fibulas were deliberately produced from different alloys, specific to the environment for which they were intended (military vs. civilian). While knee-fibulas are strongly associated with the Roman army, in addition to the military environment, they are also found in the Roman civilian contexts and abundantly in the Barbaricum, where they are often found in graves and settlements. During the research, a catalogue of a representative number of fibulas (lower hundreds of pieces) originating from both military, civilian and barbarian environments in the central Danube region will be created. These fibulas will then be analysed using pXRF and selectively also XRF, metallography and SEM/EDS to test the initial hypothesis. A summary of the state of research and a detailed description of the methods used and the course of investigation will be an integral part of the thesis.

Abstrakt

Diplomová práce se zabývá problematikou materiálového složení římských, resp. římsko-provinciálních kolínkovitých spon ve středním Podunají a s tím spojitých socio-kulturních a technologických konotací. Tyto spony jsou badately interpetovány jako typické vojenské součásti oděvu. Byly rozšířené především v Porýní a středním Podunají a vrcholu produkce bylo dosaženo na pomezí stupňů C1 a C2. Dle dosavadních výsledků materiálových analýz je převážná část spon tohoto typu vyráběna odléváním z vysoce olovnatého cínového bronzu.

Cílem práce je ověřit ústřední hypotézu, zda římsko-provinciální kolínkovité spony byly vědomě vyráběny z různých slitin, specifických dle prostředí, pro které byly určeny (vojenské vs. civilní). Kolínkovité spony jsou sice silně spojovány s římskou armádou, avšak kromě vojenského prostředí se nacházejí i v římském civilním prostředí a hojně také v prostředí Barbarika, kde

jsou často objevovány v hrobech a na sídlištích. V průběhu bádání bude vytvořen katalog reprezentativního počtu spon (nižší stovky kusů) pocházejících jak z vojenského, tak civilního a barbarského prostředí ve středním Podunají. Tyto spony pak budou analyzovány pomocí pXRF a výběrově také ED-XRF, případně metalografií a SEM/EDS pro testování vstupní hypotézy. Nedílnou součástí práce bude souhrn stavu bádání a podrobný popis využitých metod a průběhu zkoumání.

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1. Introduction

Roman provincial knee brooches are currently not the type of item which comes to mind, when people mention Roman legions. However, that might have been the case in antiquity. They were a prevalent type of garment fastener in the Roman army for a whole century. Their production began sometime during the reign of emperor Hadrian (117-138 AD), they reached peak popularity during the second half of the 2nd century AD and their production ended sometime during the first half of the 3rd century AD (Böhme 1972, 19–21; Jobst 1975, 68; Cociş 2004, 105; Petković 2010, 129). Their massive use among soldiers, legionaries and auxiliaries alike, is attested by large collections of knee brooches found in legionary forts, and numerous finds from other military installations like watchtowers or temporary camps (Ivleva 2016, 121–122). Moreover, their popularity is not limited to a few provinces. In fact, Roman-provincial knee brooches can be found on the whole Limes Romanus, form Brittania to Syria (Jobst 1975, 59; Schmid 2010, 33).

The diffusion of the knee-brooches among the roman soldiery leads to a possibility, that civilian population took notice of them, and started wearing them as well. If the reason was to associate oneself with the roman army or they were used purely based upon their decorative value, it is difficult to tell. Their use by civilian populace is attested by several tombstones, clearly depicting non-soldier figures and even a woman, wearing the knee brooches (Schmid 2010, 33–34; Ivleva 2017, 79–80). This prominence in fashion was not limited only to the area of the provinces, however. In the second half of the 2nd century AD, the Germanic populations in the middle Danube area adopted this style of brooch. Not only are there numerous finds of roman-provincial knee brooches in Germanic settlement contexts, but the Germans started their own local production of Germanic types of knee brooches (Salač *et al.* 2008, 81; Drobejar 2012a, 239-241).

The procurement of brooches by three completely different groups of people, along with some preliminary results of material analysis lead to a question: "*Were the brooches made of different alloys based upon who the final customer was supposed to be?"* This is the question this thesis will attempt to answer by securing a large-enough sample of Roman provincial knee brooches from three different contexts: military, civilian and Germanic. The brooches are analysed through X-ray fluorescence and traceology. The XRF analysis was conducted by analysing drilled core samples taken from the brooches in a tabletop XRF machine. Traceology is a supplementary analysis, aimed to document traces on the surface of the knee brooches. This kind of analysis has not been applied to roman provincial brooches as it is not as popular as other types of analyses. While not necessary to answer the research question, it will allow for an interesting insight into the life cycle of knee brooches.

The aim of the thesis is therefore to answer the question of whether the craftsmen actively manipulated the material composition of brooches based upon a target customer, and to give us an insight into the use-wear pattern of the brooches by utilising modern methods of analysis. A chapter dedicated to the historical and archaeological context will provide the reader with information about the brooches themselves, from their significance as a dress accessory to their production and typology. The chapter will also provide sufficient overview of the historical development of the area, including specific sites, from which the brooches come from. This general chapter will be followed by a second chapter, explaining the selected methodology, discussing the methods of analysis and their advantages and disadvantages. A description of the process of material analysis will follow, including used pieces of equipment and method of their utilisation during the analysis. The thesis will provide results and a final discussion, in which the results will be evaluated based on the methodology of the analyses. A conclusive chapter will summarize the output of this research and the possible scientific directions that may be taken in the future to continue to understand the Roman brooches in their complexity.

2. Historical and archaeological context

To better understand the importance and prevalence of Roman-provincial knee brooches in the 2nd and 3rd centuries it is good to put them into context. By describing the brooches themselves, how they were made and worn by the people who appreciated them so much. Moreover, it is good to have an overview of the current state of research of the knee brooches and the typologies which I will use, do categorise them.

2.1. Knee Brooches as dress accessory

Brooches in general were a common constituent of a Roman dress, and their primary role was that of a garment fastener. Roman women usually wore two brooches, one on each shoulder, while men wore a single brooch on their right shoulder, as attested by pictorial evidence (fig. 1.; 2.) (Kvetánová 2006, 380; Ivleva 2017, 70). They were usually worn with the headplate pointing downward, while the foot and catch plate aimed upward (Riha 1979, 42; Cociş 2004, 158). As a part of everyday life and their important role in the Roman clothing/fashion (alongside which they evolved according to current fashion trends), brooches are one of the most common finds in Roman archaeology. Thanks to their varied typology, they serve as an important dating tool, as many types occur during very limited timeframes (Drobejar 2002,303).

While looking at Roman provincial brooches, one must also consider their secondary function – that of a decorative element, comparable to jewellery. Thanks to the brooch's prominent position at the shoulder level, they became an agent of expression for the wearer. In the current discussion above the social meaning of these object, it is more and more postulated that the brooches are not only mere functional products, but also tools for a non-verbal communication of one's status, profession, political and religious believes, ethnicity and gender (Ivleva 2017, 75). The decorative aspect of brooches is further emphasized by depictions of individuals wearing brooches on their chest and therefore completely striping them of their primary function as fasteners (Ivleva 2017, 70).

This decorative aspect of brooches offers a new perspective upon an intensively discussed problematic. Some brooches were also made in relatively tiny dimensions alongside their normal sized counterparts. The question of "why" had therefore been a discussed topic." Two

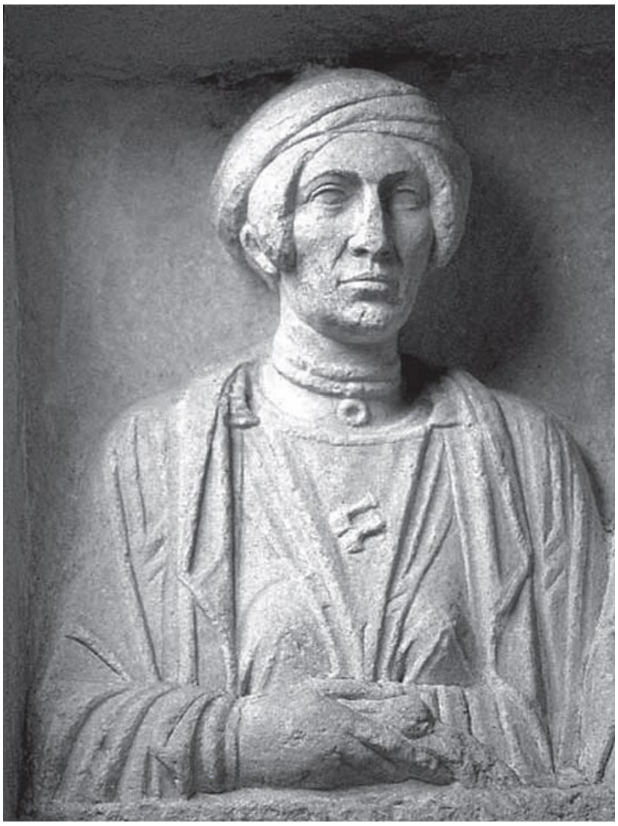

Fig. 1.: A funerary monument depicting a woman wearing two Doppelknopffibeln on her shoulders and two knee brooches at the centre of the dress as decorations, Neumarkt im Tauchenland, Austria (Ivleva 2017, fig. 4.2.)

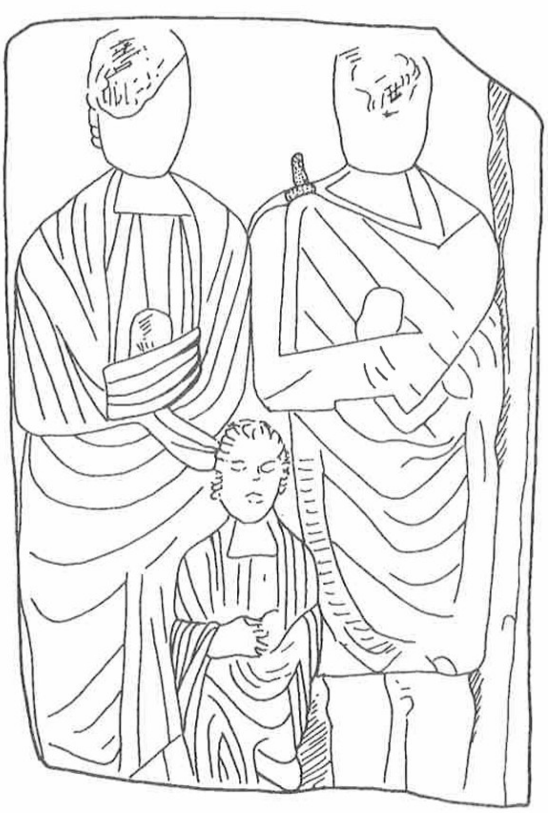

Fig. 2.: A funerary monument depicting a roman male (on the right) wearing a knee brooch on his right shoulder, Brâncovenești, Romania (Cociș 2004, Pl. CLXXVII/1a)

solutions were offered throughout the years: either the smaller size brooches were intended for children, or for women. The main argument behind these interpretations was that the child and female garments were lighter and therefore did not need fully sized brooches (Cociş 2004, 159). However, neither one of these theories was satisfactory and only with the recognition of a purely decorative function. It is therefore assumed, that the smaller versions of certain brooch types were not intended for their primary functional role but were produced and bought purely for their decorative value (fig. 1) (Ivleva 2017, 70).

One of the most prevalent types of brooches in the area of study during second half of the 2nd century and early periods of the 3rd century AD were Roman-provincial knee brooches (fig. 3.). This type is regarded a *'soldatenfibeln'* because the majority of them were found in military sites along the Limes. They were found from Britain, throughout Rhine and Danube Limes up to Syria (Jobst 1975, 59; Schmid 2010, 33). They are also present in Barbaricum, concentrating on the far side of the Limes (Kubín 2002, 46–47; Frýzl 2016, 59–63). Their interpretation as a strictly male and military artifact is starting to be contested thanks to numerous finds from civilian settlements and sculptural depictions (Schmid 2010, 33–34; Ivleva 2017, 79–80). While the knee brooches are interpreted as a typical military artefact, it is not at all surprising that they were used by the civilian populations as well. The Roman army was one of the most important institutions of the Roman world. Especially in the provinces, through which Limes Romanus passed, the legions were omnipresent (Southern 2006, 77–78). The legionaries had to purchase most of the brooches from craftsmen outside of their forts and camps. These craftsmen ran private enterprises and therefore were not limited to do only business with the army, and they could be accessed by the general populace (Southern 2006, 78; Kehne 2007, 329). The brooches were therefore an accessible article to the common people and not only reserved for the soldiers.

Fig. 3.: A typical roman-provincial knee brooch, type Jobst 13C, Račice-Pístovice (photo: The institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

The two-piece knee brooches get their name from the characteristic bend of the bow above the headplate. The headplate can be offset from the body by a knob (Kubín 2002, 46). Headplates assume forms of spiral sleeves for the spring, or have rectangular and semi-circular shapes, with the spring secured underneath the headplate. A hinged construction for the spring is also possible although much less numerically represented (Gugl 1995, 34). Regardless of the type of headplate, decoration using punching or engraving in *‘wolf teeth’* or *‘battlement’* patterns is common. These decorations can be organised in a single or several lines running parallel to each other or criss-crossing one another (Jobst 1975, 66–67). Most typologies are based upon the shape of the headplate and style of decoration. The bow has usually D-shaped or trapezoidal cross-section, with triangular or rectangular cross-sections occurring sporadically (Jobst 1975, 61). A long and narrow catch plate is attached to a short foot. The foot may be ended either in a knob or a straight cut-off (Frýzl 2016, 57; Cociş 2019, 26).

While knee brooches are of smaller dimensions, averaging between 2,5–5 centimetres in length, the bent bow offered large enough space between the pin and the bow to accommodate thicker garments (Cociş 2004, 159–160). Roman-provincial knee brooches were worn primarily by soldiers as attested by plethora of finds from legionary and auxiliary forts and camps. They are common fids in all corners of these installations. Brooches are also frequent finds in milecastles, turrets and fortlets (Ivleva 2016, 121–122). Besides these finds of brooches in sites where the soldiers were posted during peacetime, they can also be found on battlefields. For example, Kelkriese, where the battle of Teutoburg Forest took place in 9 AD, yielded around 80 brooches (Ivleva 2016, 123). While the site is from an older period and the brooches of different types, they still attest the presence of these accessories during the battle, testifying to their important role in Roman military clothing (Ivleva 2016, 123). This important role in soldier's garment led to a demand for constant supply of knee brooches, which was satisfied by local workshops close to soldier's postings (Ivleva 2016, 123–124). While not being intensively decorated and rarely made of rare metals, the shape itself gives the knee brooches an attractive and distinctive look. Thanks to this recognisable and enticing shape, it is not surprising that the civilian population adopted this type of brooch. This adoption is supported for example by a tombstone from Neumarkt im Tauchental, depicting a woman wearing either two knee brooches or one double-bow knee brooch (Fig. 1; Schmid 2010, 34; Ivleva 2017, 79).

Finds of roman-provincial knee brooches are not uncommon in Germanic settlement and burial contexts (Frýzl 2016, 58). However, we can only speculate about how the Roman-provincial knee brooches were worn beyond the Limes. Roman pictorial evidence is of little help here, because of the misconceptions that many Roman authors had regarding the German tribesman, who were probably a not so common encounter (Bazovský 2005, 96). Data from burials are also not determinant, since the burial practice among the German tribes at the time, in the middle Danube area, was cremation (Frýzl 2016, 67–68). We can however still speculate that brooches were worn in a similar fashion as in the Roman provinces. Despite possible similarities in use-pattern, changes in the social-significance of the brooches are probable. This is due to the fact, that the brooches had to be imported (Frýzl 2016, 68; Ivleva 2017, 80). We can however also speculate, that the Roman-provincial knee brooches could have been brought too Germanic contexts as plunder.

2.2. Romans in the Middle Danube region

The lands along the middle Danube were gradually annexed by the Romans during the reign of Augustus (27 BC – AD 14) around the turn of the epoch. These newly acquired territories mostly retained their autonomy temporarily and Roman legions and auxiliaries stayed mostly in the interior of the provinces. Tribes controlling the frontier of the Empire were bound to the state by client status. In exchange for gifts, they protected the interior parts of the provinces (Breeze – Jilek – Thiel 2009, 50). Only minor fortifications and small camps were established on the Danube frontier up until and during the reign of emperor Tiberius (Ployer – Sommer 2022, 59).

This state changed during the reigns of the last emperors from the Julio-Claudian dynasty, Claudius and Nero (AD 41 – 68). During this time, the Romans slowly but surely encroached upon the still nominally autonomous tribal-held frontier. Legionaries and auxiliaries established new military installations on major roads, crossroads, river crossings and river confluences. The first legionary fortress at Carnuntum was built during this period (Ployer–Sommer 2022, 59). Systematic fortification of the middle Danube boundary (also called *Ripa Pannonica*) began during the rule of Flavian dynasty (AD 69 – 96) and lasted until the reign of emperor Trajan (AD 98 – 117) (Zsolt 2011, 32). Several large legionary forts were established during this time. These were Castra Regina (Noricum), Lauriacum (Rhaetia), Vindobona, Carnuntum, Brigetio and Aquincum (Breeze – Jilek – Thiel 2009, 53). In addition to these permanent forts made of stone, more than a hundred auxiliary and temporary camps, made of earth and timber, were scattered around *Ripa Pannonica*. These forts and encampments were supplemented by watchtowers following the river Danube. Some narrower parts of the river could be reinforced with ditches, palisades and earthwork. Behind the towers ran the Limes Road connecting all the towers together. This road also connected to other ones leading from the interior of the provinces where the forts and camps were built, allowing for a quick reaction of soldiers stationed there (Ployer – Sommer 2022, 59). This system is a groundwork upon which later emperors would build on for the next 150 years. Mainly in form of reconstructions of earth and timber forts into stone. *Ripa Pannonica* did not see broader changes in its structure until reign of Diocletian who enacted broad reforms of the whole empire, including the army (Zsolt 2011, 33).

The middle Danube region became a theatre for a large-scale armed conflict in the second half of the 1st century AD. This conflict lasted between 166 – 180 AD and was fought between Rome under the leadership of emperor Marcus Aurelius (and his co-emperor Lucius Verus) and a coalition of Germanic tribes comprising mainly of Marcommani, Quadi and Sarmatians along with many other tribes. These groups invaded Roman territory in 166 AD (the start date is a topic of much discussion) most probably because of pressure due to migrations in the Germanic world (Komoróczy *et al.* 2020, 174–175). This theory is backed up by primary sources as ancient historians mention envoys of the Marcomanni and Quadi pleading for resettlement in the Empire prior to the conflict. Such pleads appear suddenly as both tribes were clients of the Empire before the wars (Dobesch 1994, 17; Kovács 2009, 204). Moreover, the denial of resettling both tribes (without prior conflict) into the Empire also puzzles modern historians, as such events were not unprecedented (Dobesch 1994, 17). Komoróczy *et al.* define the geographical setting of these tribes in their work as follows: *“The Quadian settlements of this period are located in Southwestern Slovakia east of the Little and White Carpathian Mountains. Most researchers agree that in the same time a major part of the Marcomanni already settled directly in the foreland of the Noric-Pannonian border west of the Carpathian mountain range, i.e. in modern Central and South Moravia, in the Slovak part of the Morava River valley and the trans-Danubian parts of Lower Austria.”* (Komoróczy *et al.* 2020, 176).

Incursions continued until the year 171 AD and took a heavy toll on all the Danube provinces. The attacks even reached northern Italy, destroying Opitergium and besieging Aquileia (Kovács 2009, 221). The Roman inability to respond to these attacks had two main reasons. Whole legions and parts of others were participating in the Parthian wars (161-166 AD) and the Antonine plague, which the soldiers brought back with them from the east (Kovács 2009, 203–215). Roman campaigns which followed the attacks are divided as *expeditio Germanica prima* (168–176 AD) and *secunda* (178 – 180 AD) (Komoróczy *et al.* 2020, 175).

The first campaign was to start in the year 168 AD but due to another outbreak of the Antonine plague in the army, the reinforcing legions had to withdraw back to Italy. It was only in 169 AD, that the emperor managed to get to the frontier. His presence did not swing the fortune of war to the Roman side and in either 170 or 171 AD the Romans suffered a catastrophic defeat on the far side of the Danube. The defeat was followed by the aforementioned attack on Italy (Kovács 2009, 216–221). This last incursion was repulsed by the end of the year 171 AD and lead to a peace treaty with the Germans. The year 171 AD marks a shift in the war as from now on, the fighting would mostly take place on the far side of the Danube (Kovács 2009, 225–226). Already in 172 AD, the treaty was breached by the Quadi, who were then joined by the Marcomanni. It is in this period, when the idea of establishing two new provinces was most probably conceived. The new provinces were to be named *Marcomannia* and *Sarmatia* (Kovács 2009, 205). This is supported by the dating of the military installation at Mušov between the years 172 and 180 AD (Komoróczy *et al.* 2020, 210). By the year 175 AD the Romans defeated the rebelling tribes and secured another peace treaty (Komoróczy *et al.* 2020, 175).

The peace would not last however and by 177 AD, war broke out again. In 178 AD the second campaign against the Germans, *expeditio Germanica secunda* was launched. The second campaign is very poorly described in ancient sources and historians must rely on short notions and recounts of actions of officers and officials on monuments and grave stelae (Kovács 2009, 244). After achieving several victories in 178 and 179 AD, Marcus Aurelius refused to negotiate peace with the offending Germans. We do not know why however, because in March 180 AD he died in a camp somewhere on the Danube (with Sirmium, Vindobona and Carnuntum being the most probable sites) (Dietz 1994, 7; Kovács 2009, 249–250). Originally, it was presumed, that right after the death of his father, Commodus signed a hasty treaty with the Germans and returned to Rome. This narrative is however incorrect, and Commodus left only after successfully concluding the campaign sometime in the summer of 180 AD and enforcing a peace treaty with the Marcomanni and Quadi. While we do not know the exact terms of the treaty (providing of auxiliary troops, ban of tribal assembly and prohibition of waging war described as being parts of the treaty), it has been viewed by both ancient and contemporary historians as a blunder on Commodus' side. Given that the Germans were severely outmatched, the treaty did not seem to solve anything, and the Romans returned to the right side of the Danube abandoning the ambitions of expanding the Empire (Dietz 1994, 7; Kovács 2009, 252–254). However, more and more evidence suggests that the decision to abandon the newly conquered territories and putting an end to the lengthy conflict was a sound decision. Not only that, but ancient sources hint at the possibility, that the abandonment of these territories was planned even before Marcus' death (Kovács 2009, 254–258). The conflict was a drain for the already strained economy and manpower problems caused by the Antonine plague and near constant large-scale warfare since 161 AD made garrisoning the other frontiers almost impossible. Moreover, the newly acquired provinces would have required a constant garrison, further straining the imperial budget, while providing almost no economic benefits to the Empire (Dietz 1994, 7; Kovács 2009, 257–258). By opting to leave instead, such issues were evaded, while leaving the economically and militarily decimated tribes in place as a buffer between the Romans and stronger tribes deeper in Germania (Kovács 2009, 258). This argument of leaving the weakened Marcomanni and Quadi in their respective homelands provides a satisfying answer to the questions of *"Why did Marcus Aurelius refuse to resettle their populations inside Roman territory?"* and *"Was the plan to establish the provinces of Marcomannia and Sarmatia abandoned during the life of Marcus Aurelius?"*.

As mentioned previously, the historical records regarding the campaigns outside of Roman territory are dubious. Consequently, most of our knowledge regarding the movements of the army, and the progress of the campaigns and goals of the invasion is derived from archaeological excavations. Most of archaeological evidence comes from roman military camps in territories of the Germans. The significance of their discoveries lies mainly in their spatial distribution (Hüssen *et al.* 2020, 29–30). The proximity of Roman temporary camps to roads and rivers, which were the main communication routes as well as local Germanic

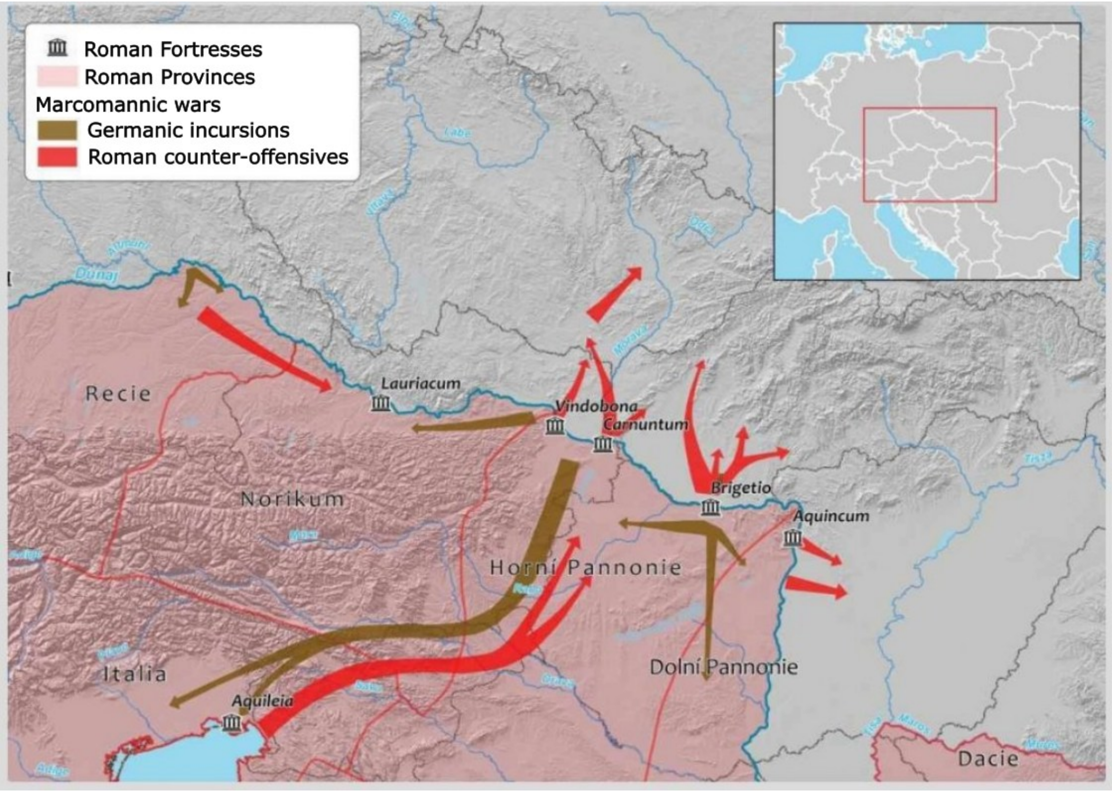

Fig. 4. Map depicting the Germanic incursions and Roman counter-offensives during the Marcomannic wars

settlements shows a well co-ordinated plan of occupation. Control of roads and rivers enabled movement of troops and supplies and allowed for controlling of the movements of the population. Furthermore, the estimated outer perimeter of the Marcomannic territory was guarded by several military installations as well (Komoróczy *et al.* 2020, 250–251). This placement allowed for defence of the territory while controlling who and what gets in or out (Hüssen *et al.* 2020, 31). An important aspect of the occupation was the fort at Mušov-Burgstall. It was positioned in the probable centre of Marcomannic domain. There was a nearby Germanic settlement and an extraordinary grave, commonly reffered to as "royal grave". Furthermore the unusual form of fortification and the presence of civilian buildings inside of the fort at Mušov-Burgsall hint at more than a temporary occupation plan (Hüssen *et al.* 2020, 13).

After his triumph in Rome in October 180 AD, Commodus embarked on *expeditio Germanica tertia* which lasted from 180 until 183 AD. This campaign was aimed against the Buri tribe (the conflict is also referred to as *Expeditio Burica*), who were allied to Rome during the second Marcommanic war. For whatever reason (Roman treaty with Marcomanni and Quadi being the most probable reason), they started a war against the Romans, which lasted until 183 AD when they were completely defeated (Dietz 1994, 10–11). Thanks to three costly campaigns and his own personal participation in two of them, Commodus started rebuilding legionary and auxiliary forts into stone (*castella),* increased the number of watchtowers on the Limes and stationed new troops at the Danube frontier (Wilkes 2005, 160; Jilek 2009, 57; Kovács 2009, 261–262). These improvements to the Limes, including upgrades to camp fortifications and infrastructure continued with the Severan dynasty (193–235 AD). However, the peaceful co-existence with the Germanic tribes (mainly thanks to the Severans bribing the Germanic tribes) resulted in downsizing of the garrisons and the fact that the fortification improvements advanced very slowly or were outright abandoned (Podborský 1993, 481; Zsolt 2011, 33). Instead, the investment went to the civilian settlements adjacent to the forts and camps and the camp interiors (Jilek 2009, 57; Zsolt 2011, 33). This decision to not invest into improving the fortifications of the Limes further would come back to haunt the Romans in the 3rd century AD. The defensive posture of the Romans meant that the Germanic tribes along the Danube regained much of their strength by 235 AD when Alexander Severus was killed by Maximunus Thrax. The internal turmoil along with pressures from beyond the Danube led to a complete collapse of *Ripa Pannonica* in the middle of the 3rd century AD (Wilkes 2005, 160; Jilek 2009, 57–58; Zsolt 2011, 33).

The Germanic populations were left decimated beyond the middle Danube Limes after the conclusion of the Marcomannic wars (Kovács 2009, 258). Many settlements were destroyed by the invading Romans during their campaigns against the Marcomanni and Quadi (Podborský 1993, 473). It is therefore surprising, that not only did the tribes manage to survive the aftermath, but they became stronger. After the conflict an intermingling of different cultural influences can be observed in the material culture (Podborský 1993, 484). Influences of Przeworsk culture and Elbe-Germans can be seen as well as Roman-provincial influence. Contacts with the Romans paradoxically intensified after the Marcomannic wars. Evidence of this intensification of contacts is attested by an increase of finds of pottery, coinage, bronze vessels and luxurious items of Roman provenance at Germanic sites, mainly in southern Moravia and northern Austria. These finds come mainly from burials, most important of which are the ones from Wulzeshofen, Čáčov and Štibořice (Podborský 1993, 484-487). By the beginning of 3rd century AD, Roman imports start to accumulate in south-western Slovakia instead. Most important sites in south-western Slovakia are burial grounds at Očkov and Stráže (Podborský 1993, 487). The increase of contacts with the Romans was caused by two factors. The Roman traders, which followed Roman army into the Barbaricum during the wars continued to conduct trade with the locals even after the conclusion of the conflict. Furthermore, thanks to the investments into the civilian towns and infrastructure, an increase of wealth in the middle Danube Limes also enabled commerce to thrive (Podborský 1993, 486–487).

2.3. Description of the sites selected for research

The following chapter will broadly describe the types types of sites which provided the brooches for this research. The sites were not studied individually, but rather, knee brooches originating from these sites were stored in one of four modern-day institutions. To the four institutions which were visited during this research, I express my gratitude for giving me the opportunity to conduct it. The institutions visited and numbers of brooches they provided are as follow:

1. The institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.; 84 pieces
2. The institute of Archaeology of the Slovak Academy of Sciences, Nitra; 103 pieces
3. Kulturfabrik Hainburg; 78 pieces
4. Czech National Museum; 9 pieces

2.3.1. Permanent camps

Permanent camps, both legionary and auxiliary, are not differentiated from the temporary camps in ancient literature. The only distinction is that the permanent camps were meant for winter stays, while the temporary ones were usually for summer periods (Hanel 2007, 407). The presence of buildings, first made of timber, later rebuilt in stone, attest to the long-lasting development and occupation of permanent camps. The buildings offered better protection from harsh seasonal conditions, while providing an improved standard of living for the soldiers stationed inside. Generally, all roman military camps had a long, rectangular or trapezoidal shape with rounded corners, with two or four gates, regardless of the type of unit stationed there (Hanel 2007, 398). Depending on the character of stationed unit, the importance of the site and the size of garrison, the internal structures of camps could vary to surprisingly high degrees. While the small camps could only have a few barracks buildings and a middling number of ovens to make food in, the largest of forts included command buildings, luxury housing for the generals and officers, along with utility buildings, like military hospitals, veterinary buildings or baths (Hanel 2007, 403–407).

Fortifications around the camps consisted of a rampart, in front of which a V-shaped ditch or ditches were placed. In the case of permanent camps, the *vallum* was built using an earth-and-timber rampart. This rampart had a 3 metre-wide wooden framework filled with earth, on top of which was a walk, protected by a wooden parapet with crenelations (Hanel 2007, 402). The ramparts were later rebuilt in stone, with a possible reinforcement in form of earthen rampart on the inner side of the wall. Moreover, the gates of the camp were protected by towers, which could also be displaced along the walls, if the situation in the area mandated such additional defence (Hanel 2007, 402). As mentioned previously, rebuilding of camps and their fortifications into stone material took over a century, as the project was started by Hadrian, and still was not finished by the beginning of the crisis of the 3rd century (Zsolt 2011, 33).

2.3.2. Temporary camps

Temporary camps are a somewhat of an elusive topic in Roman archaeology. They share their basic characteristics with the permanent camps – the disposition, number of gates and the fortification style of the camp itself (Hüssen *et al.* 2020, 16). However, the main difference between the permanent camps and the temporary ones is the absence of any buildings whatsoever, in the temporary camps. The internal build-up consisted exclusively of tents. Therefore, except for the ditches, the *vallum,* and the adjacent baking ovens*,* there are no archeologically detectable structures in the temporary camps (Hüssen *et al.* 2020, 18). The temporary camps are therefore hard to detect and confirm. The current methodology applied to research is therefore based around aerial survey, field survey, metal detecting, GIS processing, with occasional trial trenching (Komoróczy *et al.* 2020, 178).

The materials used for building the vallum raise questions toward the character of these camps. While there are no permanent buildings inside the fortification, the perimeter walls on the sites of Charvátská Nová Ves, Přibice and Závod were built of unfired mudbricks (Hüssen *et al.* 2020, 16-18). Mudbricks were a popular construction material along the Danube and the camp at Iža is built exclusively of mudbricks. However, this was due to the easy accessibility to the material, abundant in the alluvial landscapes. The mudbricks are therefore a demanding construction material, especially logistically, as they are made of clay, which had to be transported to the sites of temporary camps (Komoróczy *et al.* 2020, 247–248). Both the time investment into the construction and the more durable character of the fortification therefore points towards the intention of building a permanent military installation on the sites (Komoróczy *et al.* 2020, 248).

Just like permanent camps in the provinces, the temporary camps varied widely in their spatial extent. It is therefore also possible, to determine what purpose the camp served and what kind of unit was stationed there (Hanel 2007, 407; Hüssen *et al.* 2020, 16). The largest of temporary camps, namely Engelhartstetten, Charvátská Nová Ves, Mušov – na Pískách, Runhof and Přibice, reached the extent between 37 and 47 hectares. These are almost the same size as legionary forts in Xanten and Oberaden (with their size around 50 hectares), which both housed two roman legions (Hanel 2007, 407; Komoróczy *et al.* 2020, 244). Nonetheless it is not possible to draw direct comparisons between sizes of contigents posted at permanent camps with buildings and temporary camps in active warzone utilising tents of similar sizes.

The tents took up more space, while the units could have some non-combat related staff attached to them. Therefore, larger spaces were needed for a similarly sized units in the temporary camps (Komoróczy *et al.* 2020, 244).

The temporary camps have complicated archaeological relations with Germanic settlements. There are very often stratigraphical overlaps between Germanic settlements and the camps. It is hard to determine, however, whether the settlement preceded these camps, or if the locals moved into the vacated camp premises, after the invading Romans left after the peace treaty of 180 AD (Hüssen *et al.* 2020, 19).

2.3.3. Germanic settlements

Roman authors do not deal with Germanic settlement patterns in the second half of the 2nd century and the first half of the 3rd century AD in their work. However, archaeology provides insight into this problematic thanks to large-scale excavations, as the ones in Křepice or Vyškov. These settlements are estimated to have reached an extent somewhere between 1,5-3 hectares. The settlement in Vyškov was situated near a watercourse on a gentle slope. A concentration of storage pits, workshops and ovens was situated at the bottom of the settlement (Podborský 1993, 473; Drobejar 2002, 371–373). Along these objects, pieces of crucibles, iron ores, furnaces and pottery kilns were also found, suggesting metallurgical and pottery production on the site (Drobejar 2002, 373).

The huts had a rectangular floor plan and, in most cases, covered an area of 15m^2, but larger and smaller houses do occur. The huts were made by daubing. Inventories of these huts consist mainly of pottery, brooches and bone combs. A big part of these finds shows a strong influence of Przeworsk culture from the north (Podborský 1993, 473-477). In the last quarter of the 2nd century, an increase of items of roman provenance can be observed. This increase is most probably closely tied to the outbreak of the Marcomannic wars. The roman artefacts include middle-gallic terra sigillata, glass objects, small bronze objects and militaria (Podborský 1993, 477–478). A similar inventory is present at other sites, like Křepice, Ladná or Vícemilice. It needs to be stated, that some brooches might actually come from burial contexts, instead of settlement ones. This is due to the relatively close proximity of Germanic burial grounds to the settlements themselves. If a metal detector survey was conducted during or after the excavation, the actual find spot may have been misinterpreted, or the burial ground itself might not yet be discovered.

2.3.4. Other sites

Some Roman-provincial brooches from Moravia and Slovakia come from as of yet unexcavated sites. Especially in Moravia, the large-scale survey efforts produce a lot of data and material. A lot of new sites have been discovered this way (Komoróczy *et al.* 2020, 178). Nonetheless, a lot of these sites are of unknown character. Therefore, they have been marked as "survey sites" rather than speculating on their true nature. Furthermore, the nine knee brooches from Bohemia are all finds without context. All we know is that three of them come from excavations in Prague, while one comes from Kouřim. These have been marked as "unknown".

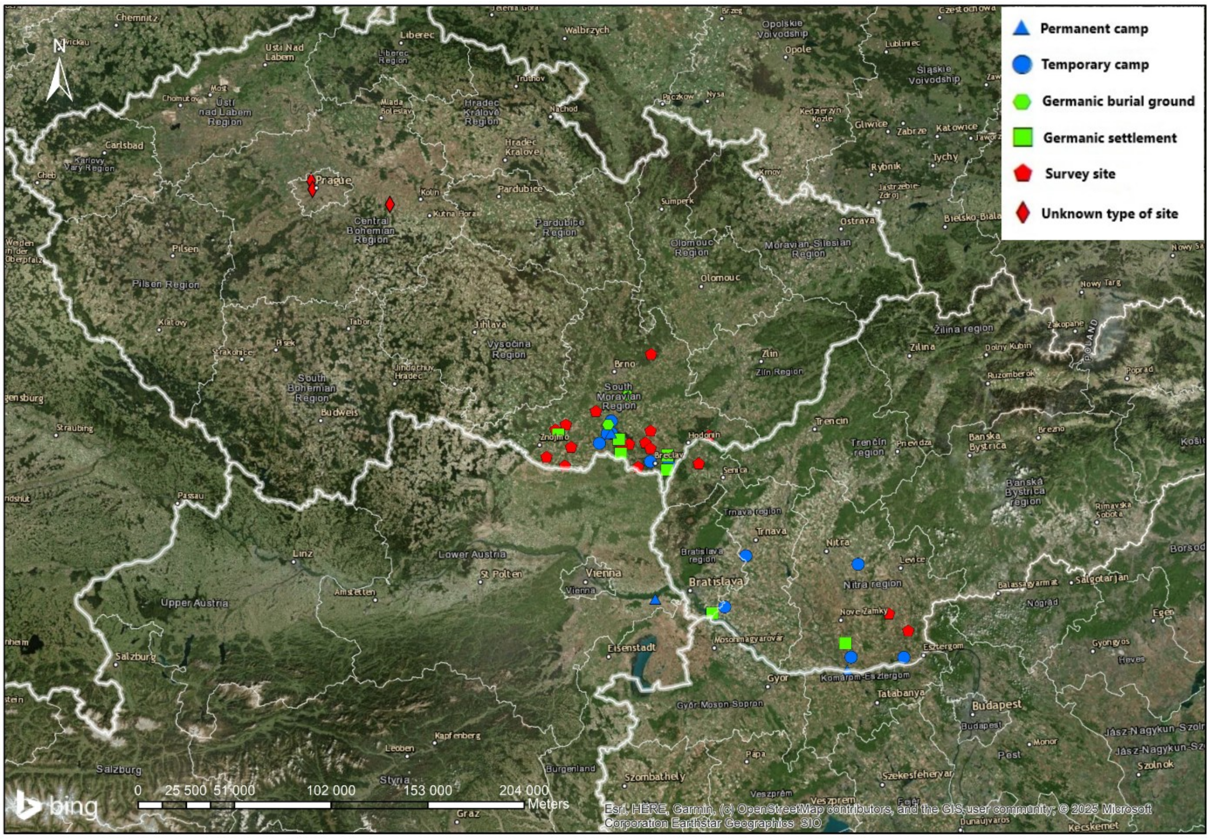

Fig.5.: Map of sites providing Roman-provincial knee brooches for research (author: N. Mořkovská)

2.4. Manufacturing technology of Roman-provincial knee brooches

Knee brooches are in most cases made from copper alloys. Copper by itself, while ductile and malleable, is a very soft metal, which limits its use. If alloyed with other metals however, its desired properties are improved, while mitigating its disadvantages. The most typical alloying elements are tin resulting in bronze and zinc creating brass. Lead was usually also included resulting in 'leaded' alloys, further enhancing their features (Kmošek 2017, 3–4). Both tin bronze and brass were created probably primarily by smelting already reduced copper with tin or zinc ore (Drábková 2023, 41).

It is important to keep in mind that we may for example qualify some brooches strictly as "bronzes" but they may contain low admixtures of zinc. This is because ancient metalworkers understood that low admixtures of certain elements (at around 2%) enhance the mechanical properties of resulting alloys. Tin enhances the hardness of the resulting alloy while zinc acts as a deoxidant, lowering the possibility of casting defects. Addition of lead lowers the melting point of the alloy and enhances its viscosity making casting small, complex items much easier. Low lead admixtures also improve workability of the resulting alloy, making decoration easier (Bayley–Butcher 2004, 15–16).

It appears that ancient metalworkers used different alloys not only because of their mechanical properties but also because of their aesthetic ones. Recent research made it clear that there may be links between artefact typologies and alloy composition (Dungworth 1997, 906). As Tatiana Ivleva states: *"A brooch's visual dominance may have allowed them to act like a badge, signalling affiliations and preferences in the individual's status, profession, religion, politics, ethnicity, and gender. The choice of a particular type of brooch can be regarded as an act of self-expression and a negotiation of socially constructed identities."* (Ivleva 2017, 75). Therefore, we not only need to think about the material composition in terms of what was technologically advantageous, but also in what was fashionable and what the wearer wanted to signal by wearing a brooch made of certain alloy. Bronze is typically brown, but with an increase of tin content come lighter tones and brass is gold-ish yellow thanks to the admixture of zinc (fig. 6.) (Bayley–Butcher 2004, 16). Hence, it is possible to attest that not only do tin and zinc admixture enhance the mechanical properties of the alloy, but also their visual aspects.

Fig. 6.: Difference in colour between brass and tin bronze (generated by Chat GPT AI)

Knee brooches were cast typically in piece moulds. Investment moulds are also suggested as a possibility, but piece moulds are much easier to prepare allowing for a much greater production throughput (Bayley–Butcher 2004, 27). The moulds were typically made of clay but could have also been made of bronze or stone (Cociş 2004, 25). Moulds made of stone and bronze would have not only been used as casting moulds, but also as moulds for wax. This wax was then used as a pattern for investment casting (Cociş 2019, 34).

A workshop would have had several patterns for moulds, which could be re-used indefinitely in the case of piece moulds. These patterns were usually made of soft materials, like lead, wood or bone, but metalworkers could also use finished brooches made of iron and bronze as patterns (Bayley–Butcher 2004, 29; Cociş 2004, 25). Using finished brooches as patterns has several issues. Mainly the need to add runners and sprues manually and the contraction of cooling metal, resulting in a smaller final casting than the original pattern. The patterns were usually larger, had several thickened parts and downsized perforations to counteract the contraction of the metal (Bayley–Butcher 2004, 29). Patterns are a rare find because they are easily transported and make for the most important part of the manufacturers inventory (Cociş 2019, 22). If a metalworker wanted to move his workshop, all he needed were the patterns and his tools and he could resume production elsewhere, if he could establish a proper supply chain.

After selecting the desired casting pattern, it was pressed longitudinally into a clay lump, while a second part of the future mould was pressed on top of it. When the clay dried up, the casting pattern was taken out and the two halves of the clay mould were sealed together, probably with more clay. While joining the parts together, a sprue cup was added to the mould, if it was not a part of the original casting pattern (Bayley–Butcher 2004, 29; Cociş 2004, 25–26). A further increase in efficiency could have been achieved, if the manufacturers decided to use double moulds. This practice is attested at multiple sites throughout Britain and Dacia (Bayley–Butcher 2004, 29; Cociş 2004, 25–26)

The mould had to be fired, probably in a kiln along with other ceramic objects, and then molten metal was poured into the mould. As the moulds did not perfectly copy the original shape of the pattern, the molten metal found its way into the gap between the two halves of the mould, which resulted in a casting flash (Cociş 2019, 22). As apparent from several unfinished knee brooches, the metal was poured either through the foot, or from the direction of the socket for the spring, underneath the headplate (fig. 7, 8, 9). After the metal solidified and cooled off, the mould was broken, and the brooch was extracted. It proceeded to be further worked.

Fig. 7.: Unfinished casting of a knee brooch with the sprue cup connected to the socket of the brooch of the brooch (Cociș 2019, Pl.120/17)

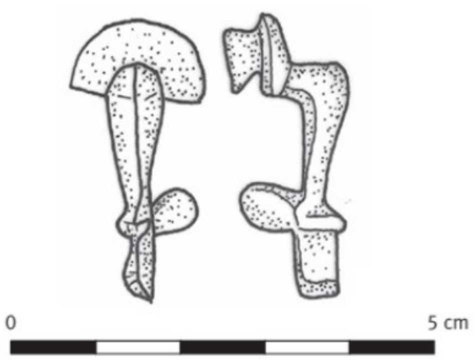

Fig. 8.: Unfinished casting of a knee brooch with the sprue cup connected to the foot of the brooch (Cociș 2019, Pl.149/157)

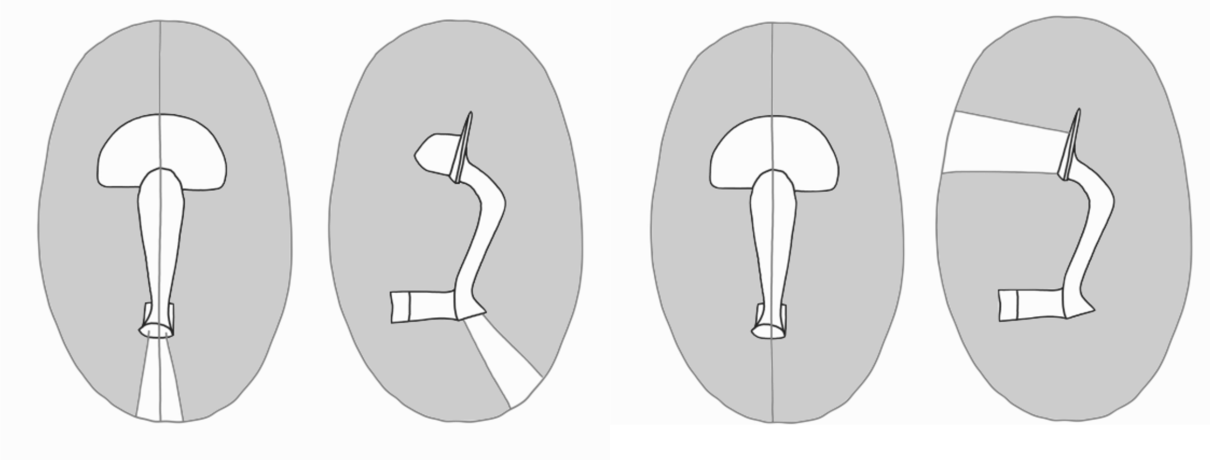

Fig. 9.: Illustration of brooches in the casting moulds (author: M. Grňová)

This work included removal of the casting flash by grinding and polishing (Bayley–Butcher 2004, 31). Furthermore, the sprue cup was cut off. If the metal was poured through the foot, the excess material of the sprue cup could have been fashioned into decorative knob. However as apparent from the unfinished castings of brooches, the knob could have been a desired decoration of the foot and can be observed even if the sprue cup was attached to the socket for spring. A spring was manufactured and added separately after giving the body of the brooch its final form. It is worth to point out that the springs were made of a different alloy than the brooch. This was because of a need for malleability and ductility for the process of spring manufacturing (Cociş 2019, 22). After these steps were completed, a decoration could have been added if desired. Generally, decoration on knee brooches could be created by punching, engraving, stamping, faceting, tinning, rarely also gilding, granulation and adorning with filigree (Cociş 2004, 32–34).

There are rare instances in which brooches are made from different materials than copper alloys, namely iron and silver. Sorin Cociş collected a total of 2214 roman brooches from Dacia of various types in his work *Fibulele din Dacia Romană*. Such a high number gives us a good insight into ratios of materials used in production of roman brooches. He states that 94,75% are made of copper alloys, while 2,16% are made of silver and 2,98% of iron (Cociş 2004, 157). In cases of Roman Britain and Austria, the research done on 445 brooches from Richborough collection by Justine Bayley and Sabrina Butcher and 395 finds from Lauriacum by Werner Jobst show us the same picture. Only 1,79% of brooches from Richborough collection (Bayley–Butcher 2004, 26) and 2% of brooches from Lauriacum (Jobst 1975, 153) were made of silver. While there are knee brooches made of silver (Cociş 2004, 92; Jobst 1975, 153), in our area of study, we are dealing strictly with pieces made from copper alloys. Three silver roman knee brooches were found in Bohemia, from Semčice – Žerčice, Sokoleč and Tatce however, they are all parts of private collections (Drobejar 2012b, 121–122) and therefore could not be accessed for research.

Brooch workshops are generally hard to confirm archaeologically. As mentioned in chapter 2.1. the demand for knee brooches was probably satisfied by local craftsmen, producing brooches for nearby military installations. Ancient sources do not pay the brooch workshops any attention and modern research is focused mainly on town centres, monumental structures and military forts. Brooch workshops located in peripheries of these forts and towns are therefore easily missed (Cociş 2019, 13–15). Other factor is the small scale of the whole operation. Small items like brooches can be mass-produced using only small forges, tools and moulds. Small forges are hard to detect, and small dimensions of the equipment and casting patterns means that the workshops may have been easily moved. Last aspect of brooch manufacture is the fact that the brooches were not only produced in specialised workshops but also in for example military workshops (Ivleva 2016, 123). The material for casting was readily available and a manufacture of such a tiny mould would not be a problem. This solution was also practical as the brooches were often lost by the soldiers. Having a workshop ready to replace such losses was therefore very practical (Cociş 2019, 13–15).

The only brooch workshop found within the Empire with all its elements was excavated in Cluj-Napoca, Romania. This single workshop demonstrated what level of mass production was possible if the right tools were utilised. The workshop took up only 88m^2 and was equipped with three simple forges for melting of metal. Despite the relatively small size, the floor was covered with fragments of estimated 2000-3000 moulds (Cociş 2019, 18–22). An unfinished casting of a lead knee brooch casting pattern was found in a non-workshop context Porollisium. Other lead patterns for knee brooches are attested on sites of Aparhant (Cociş 2019, 50), Sisak (Cociş 2019, 55) and Flavia Solva (Cociş 2019, 58). Further workshops producing knee brooches based upon either remains of clay moulds or discarded castings are suggested in Dacia Porolissensis, Dierna, Durostorum, Téglagyár, Brigetio, Carnuntum, Neckermarkt, Cetium, Gleisdorf, Iuvavum, Ovilava, Salzburg-Glas, Aelium Cetium, Virunum, Wals-Loig, Celeusum and Submuntorium (Schmid 2010, 34; Cociş 2019, 35–67). An interesting observation based upon finds of moulds can be made. In some workshops, both Roman-provincial and Germanic type knee brooches were made alongside one another. This points to a demand for both types of knee brooches inside the Empire (Cociş 2019, 38).

2.5. Typologies of knee brooches

As we know, there is not one universal typology for brooches. Their typologies vary widely throughout the Empire, depending on location and time period. Therefore, various typologies have to be considered, when dealing with brooches outside the Empire’s borders. Knee brooches which are the focus of this study were typically worn by roman legionaries. Legionaries came from all corners of the Empire and detachments or auxiliaries from any legion could have ended up far from their original postings (Kovács 2009, 261). One therefore must deal with brooches, which are typical for province of Germania, as well as Pannonia.

The oldest typology of imperial Roman brooches was published in 1897 by Oscar Almgren in form of his dissertation. In his work *Studien über nordeuropäische Fibelformen der ersten nachchristlichen Jahrhunderte mit Berücksichtigung der provinzialrömischen und südrussischen Formen,* he laid out the groundwork for all further studies of roman brooches of this period. While his work may seem outdated his typology is still referenced in all modern catalogues and typology studies and is still relevant to this day. Almgren has divided the brooches into seven numbered groups and two special groups. In group V, Almgren recognises knee brooches as a separate series (no.9) within the group and calls them “*Knieförmig gebogene Fibeln ohne Kamm”* (Almgren 1923, 62–64, Fig. 138–147). Derivates of knee brooches are further mentioned in “special series” which are also part of group V (Almgren 1923, 68-70, Fig. 132, 137, 150). These are, however, knee brooches of Germanic origin and Almgren recognises that they come from beyond the Limes. Roman-provincial knee brooches are in a special group called *Spezifisch provinzialrömische Fibelformen, die nur sporadisch in Nordeuropa Vorkommen* (Almgren 1923, 106). Of these, only pieces A-246, A-247 and A-248 are of the typical Roman-provincial type (Almgren 1923, Taf. XI: 246–248).

For Germania and the Rheine frontier, the most referenced work is *Die Fibeln der Kastelle Saalburg und Zugmantel* by Astrid Böhme published in 1972. Böhme had collected 117 roman-provincial knee brooches and established 3 groups - groups 19–21, each with several subtypes (Böhme 1972, 18–22). These brooches were categorised based on the shape of the headplate.

Böhme 19 (A 247) has a semicircular shape, Böhme 20 (A-246) rectangular and Böhme 21 (A 248) spiral (Böhme 1972, 18–22). Especially brooches of type Böhme 21 are typical for upper Germanic and Rhaetian Limes and aren't as common in other parts of the Limes (Jobst 1975, 59).

Brooches found in central Danube region are best described by Werner Jobst in his work *Die römischen Fibeln aus Lauriacum* published in 1975. His typology is most relevant for this study and will be therefore referenced the most. Jobst follows up upon the typology established by A. Böhme for knee brooches from Germania but modifies it to better fit the central Danube region. Only two groups are formed, again based on the shape of the headplate. Group Jobst 12 (A 248) has the spiral covering the spring while Jobst 13 (A 246–247) is characterised by either rectangular or a semicircular headplate. Group 13 is essentially a combination of Bohme's groups 19 and 20, which Jobst describes as redundant (Jobst 1975, 59–68). While some brooch types might be almost identical with their counterparts from Germania (Jobst 12C–Jobst 12F) some are a completely localised form (Jobst 12A–Jobst 12B), which were not found outside of Noricum and Pannonia (Jobst 1975, 67).

From Jobst's typology, the most important types for this study are Jobst 13C and Jobst 13D (fig. 10). The difference is that the former type had an undecorated headplate, and the latter had a *"wolf's teeth"* decoration (Jobst 1975, 65–67) which was done by tremolo chasing. These two types make up vast majority of gathered and sampled brooches for this study. This is not surprising, as Jobst himself states, that the popularity of the type Jobst 12 decreases significantly further down the stream of Danube (Jobst 1975, 68). His statement is supported by the fact that out of all the 145 sampled brooches, there are only five brooches of Jobst 12 type from Bohemia, Moravia and Slovakia.

Fig.10.: Brooches cat. no. 38 and 40 of type Jobst 13C (left) and Jobts 13D (right) (photo: The Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

Typological studies of Böhme and Jobst shed light on Roman brooches from Germania, Rhaetia, Noricum and Pannonia Superior. However further down the stream of Danube, new forms which do not fit into neither of their categories started occurring. Work of Mónika Merczi, *Térdfibulák Komárom-esztergom megyéből,* is focusing strictly on 162 knee brooches from Pannonia Inferior (Merczi 2011, 7). Merczi recognises the work of both Böhme and Jobst but sees it as adequate to reevaluate them to better accommodate new finds from Hungary. Much like Böhme, Merczi created three types for roman-provincial knee brooches. Type A has the cylindrical sleeve and type B is a group of brooches with headplates (Merczi 2011, 25–29). These are the same types which both Böhme and Jobst recognise. However, Merczi added type C, which is only rarely seen in the provinces to the west. This type has a needle shaft, held by a socket. Parallels can be drawn between this group, and groups of knee brooches found in today Serbia, Roman Moesia Superior (Merczi 2011, 50). Merczi's study must be taken into account because of the proximity of Brigetio, Komárom or Aquincum to the Slovak sites relevant to this thesis.

Changes in the shape of knee brooches, as could have been seen in Merzci's publication are much more drastic further south, in southern Pannonia Inferior and Moesia Superior. These new forms from today's Serbia were first catalogued by Dragoljub Bojović in 1983 in publication *Rimske fibule Singidunuma.* This catalogue was based just on the finds from the site of Sigundunum. Therefore, a choice was made to use a publication from 2010 *Rimske fibule u Srbiji od I do V veka n.e.* from Sofia Petković. Her research is both much broader in scope and more recent which is why her typology had been chosen as a reference point for this area. In her work, knee brooches are a part of Group V and are further divided into 3 types (tip 18–20).

Tip 18 is a group with the closest ties to provinces to the west. Brooches of this type are a combination off all groups described by Böhme and Jobst and include all brooches with any shape of headplate or a cylindrical sleeve (Petković 2010, 129–135). Tip 19 corresponds with Merczi type C/1–C/2 (Merczi 2011, Kat. Nr. 158–160). This type utilises a hinged spring in a cast cylinder sleeve (fig. 11). The spring was to be inserted into either a longitudinally or transversely positioned catch plate. The bow was flattened and continued back in the direction of the foot. The sleeve with the spring was usually joined further back on this surface, instead of the typical way right underneath the bow as seen with types Jobst 12 and 13 (Petković 2010, 143–148). Tip 20 is the most elaborate one as it has a flattened bow which is bent into a volute (fig. 12). This type is similar to Merczi type C/3–C/4 (Merczi 2011, Kat. Nr. 161–162). It has a hinged spring in a sleeve. The spring is hooked into a transverse catchplate. The volute starts where the bend of a typical knee brooch would have started and is wider than the flat foot. The end of the volute is connected to where it originally started. Brooches of this type are always decorated (Petković 2010, 143–148). Both the construction style and the material of the brooches indicate that these were probably luxurious items. While only 2% of knee brooches from Serbia are made of silver, 25% of brooches of this type found to date are made of this material (Petković 2010, 157, tab. XXVIII:1–8). One specimen is a gold-plated silver brooch with filigree decoration (Petković 2010, Kat. Nr. 913) and one is made of a combination of bronze and silver (Petković 2010, Kat. Nr. 912).

In her work Petković states that out of all examined brooches 16,15% are knee brooches. Such a high number of knee brooches shows a possible high level of mass production of this type object in this area. Much higher number of brooches of tip 20 hints that the area of Upper Moesia may be one of the production centres for this type (Petković 2010, 160). Only one brooch was found in Zugmatel (Böhme 1972, Kat. Nr. 462) and two pieces come from Lauriacum (Jobst 1975, Kat. Nr. 118–119) and Hungary (Merczi 2011, Kat. Nr. 161–162) respectively.

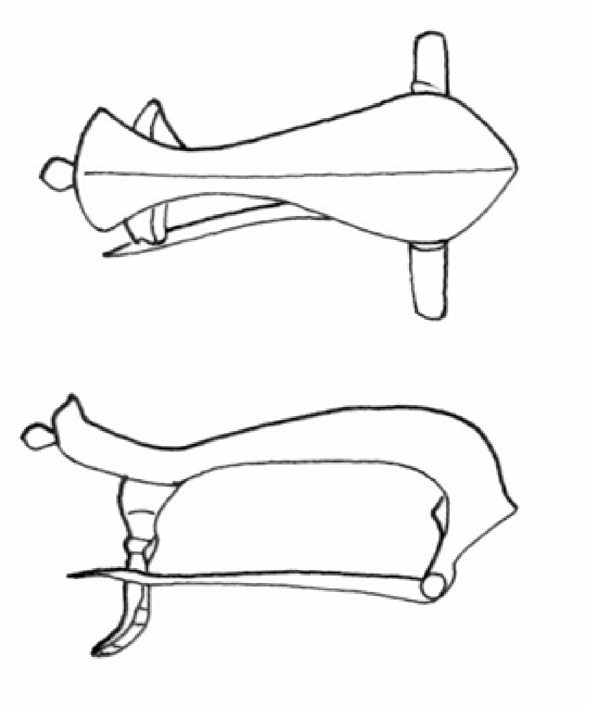

Fig.11.: Knee brooch of type Petković tip 19/B (Petković 2010, T. XXVI/3)

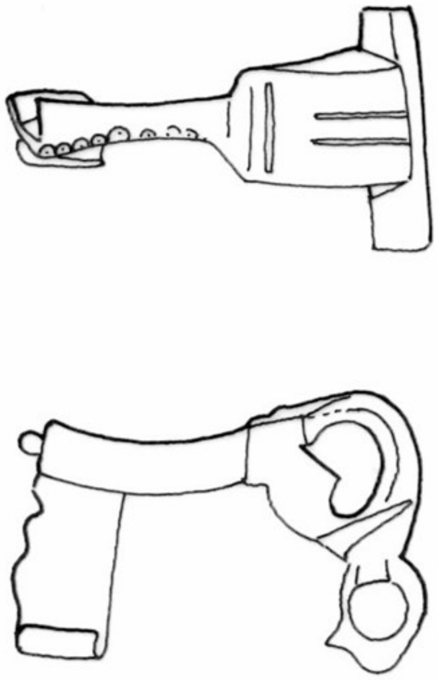

Fig.12.: Knee brooch of type Petković tip 20 (Petković 2010, T. XXVIII/1)

The last relevant work for this research is a typology of brooches from Dacia. Published in 2004 under the name *Fibulele din Dacia Romană, the* author, Sorin Cociş, provides an outlook on typology of brooches from today's Romania. Cociş collected 392 knee brooches and called them type 19. They were further divided into 6 subtypes. What is unique about his work, is that Cociş proceeded to make subtypes of subtypes. These further divisions are based on Cociş' typology of catch plates (Types 1–21), springs (Types 1–16) and hinges (Types 1–5) (Cociş 2004, 26–32).

Type 19f corresponds to Petković 20 and offers an interesting perspective. In Dacia most of the brooches with a volute bow come from legionary camps and none of them are made of precious metals or highly decorated. Cociş therefore interprets them as a strictly military subtype of knee brooches (Cociş 2004, 104–105).

Knee brooches were most widespread from the 2nd half of the 2nd century AD until the middle of the 3rd century AD, according to all researchers mentioned (Böhme 1972, 19–21; Jobst 1975, 68; Cociş 2004, 105; Petković 2010, 129). Nonetheless there are exceptions, and singular finds show early production has begun as early as the reign of emperor Hadrian (Böhme 1972, 19; Schmidt 2010, 36) and that some knee brooches were used as late as the beginning of 4th century AD (Jobst 1975, Nr. 151; Schmidt 2010, 36–37). Both types 12 and 13 have existed simultaneously and are therefore not chronologically sensitive.

3. Methodology

Before any material research, it is important to prepare a well-thought-out methodology. By setting the goals of the research and knowing its requirements, the methods to reach these goals can be carefully considered and evaluated. It as however of greater importance to know the boundaries of the selected methods. Thanks to this, a strategy can be set in advance to the start of the research. By following these steps, one should be able to ensure uniformity and the quality of the data. The intention should always be to produce a good quality data, instead of aiming for quantity. In the case of my research, traceology and X-ray fluorescence spectrometry were chosen as the best-fitting methods to reach the answers to the asked questions. Traceology will provide useful insights into the manufacturing and use-wear patterns of knee brooches, while XRF will produce valuable information about the large-scale production patterns

3.1. Traceology

Traceology is a method of examining the surface of archaeological artefacts, utilising optical magnification in the form of magnifying glasses, microscopes, 3D scanning or forensic microscopes. Thanks to this technique, the analysis is completely non-destructive. Using multiple levels of magnification, while illuminating the object by direct light from multiple angles, allows the observer to see different kinds of traces. These traces can be split into 4 main groups: manufacturing, functional, repair and post-deposition traces (Havlíková – Krištuf 2019, 461). Nonetheless one must be cautious to discern between the post deposition and recent traces. Such marks upon the surface, may have been created by a plough during ploughing of a field, or during conservation efforts. To distinguish between them, we must look at the noble patina on the surface of objects. If the traces are covered by a layer of it, they are of ancient date, but if they are on top of it, or go through it, they are recent (Havlíková – Krištuf 2019, 461). The impact of conservation on resulting traceology analysis is ambiguous. Mechanical cleaning may erase some of the finer traces, which are closer to the surface, such as scratches. It may also however uncover some new evidence, such as casting errors or damages and even decoration hidden underneath surface layers of soil or corrosion (Sych *et* *al.* 2020, 140–141). The outcome of course depends on the nature of the corrosion as well as methods of cleaning.

Traceology may be utilised on objects made from different materials. In the past, it was mostly used for examining lithics and bone tools but recently it is finding its way into archaeometallurgy as well (Fouček 2024, 18). Traceology is a useful tool revealing to us how were the studied objects produced, used and even deposited, thus the whole lifespan of the artefact from its creation until its traceological examination. It may also help us understand some aspects of ancient cultures and their worldviews, as we may assume a function of an item, but it might have served an entirely different purpose in its original environment (Caec – Mopo 2020, 172).

3.2. X-Ray fluorescence spectrometry

XRF is an abbreviation, which stands for *X-ray fluorescence.* This method utilises a source of X-rays to bombard a surface of an object or a sample taken from the object. These x-rays interact with the atoms that make up the analysed sample by removing an electron from their inner electron layers. However, this would make the atoms unstable, therefore the atoms then proceed to compensate this loss by pulling an electron from one of their outer electron layers to take the removed electron's place. This transition results in fluorescent photons being emitted during the process. Emitted photons emanate energy in form of x-rays, which is characteristic for each atom. The number of photons emitted this way and the energy they emanate, can be measured by a solid-state detector inside the XRF device (fig. 13). The device then

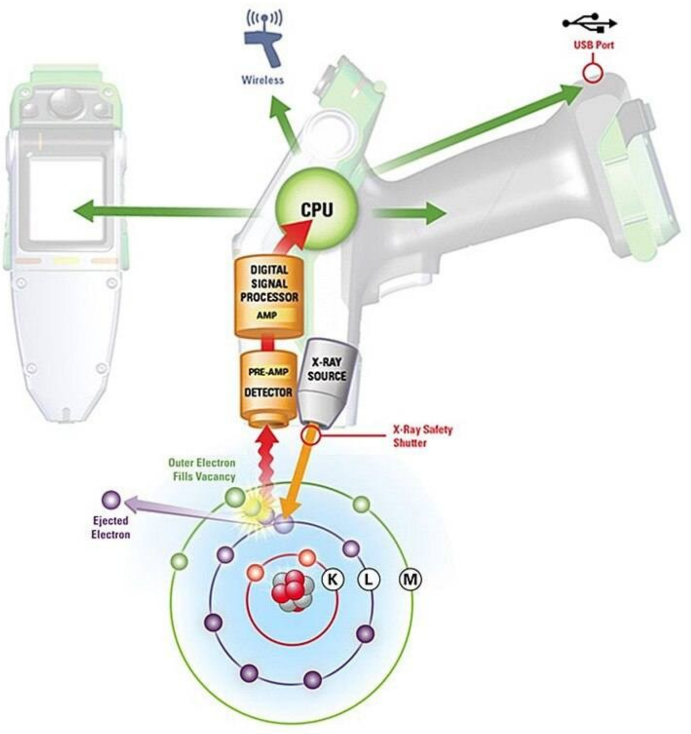

Fig.13.: Diagram depicting the principle of the X-ray fluorescence analysis

gives the user a comprehensive overview of the material composition of the analysed sample (Pollard – Bray 2014, 219).

While the theory itself is rather complicated, the process is quite easy and user-friendly. Both tabletop XRF and portable pXRF machines are highly available nowadays as they are the easiest, most popular and cost-effective option for material composition analysis. In this function they can deal with a high volume of either metal objects or geological samples in a short period of time compared to some more complicated methods (Roxburgh *et al.* 2019, 56). Another upside of this method is the ability to conduct the analysis by only scanning the surface of the object. While this is not ideal, it may help researchers get access to objects, whose invasive sampling might be otherwise out of the question. Nevertheless, the XRFs come with their own challenges as well (Roxburgh *et al.* 2019, 57).

The simple nature of operating an XRF machine (which boils down to aim/position an object, press start, read results) allows for a very quick training of new operators. Yet these operators usually lack any education in chemistry and analytics, which leads to poorly determined methodology, wrong sample preparation and misinterpretation of results (Kmošek 2017, 11; Roxburgh *et al.* 2019, 56; Fouček 2024, 21). These man-made errors stem from the limitations of the devices themselves. The primary x-ray emitters in these machines are not particularly powerful, thus they penetrate only a few tenths of millimetres underneath the surface of the object. We therefore get an information of the material composition of the surface of the object and not of its core. This might result in misleading results if the surface is dirty, heavily corroded or for some other reason diverges from the original composition of the metal core (Pollard – Bray 2014, 220; Drábková 2023, 23). Additionally, part of the return signal might be absorbed by the air path, resulting in a lower detection limit of portable devices (Kmošek 2017, 11). Another factor is the possible absorption of secondary X-rays as they leave the sample. This depends on the type of corrosion on the surface of the object, influenced by factors such as humidity, oxygen access, chemical composition and potential high values of iron hydroxides or sulphides in the soil in which the object was deposited in (Pollard – Bray 2014, 220; Roxburgh *et al.* 2019, 58).

This issue is particularly problematic when dealing with corroded copper-alloy objects. Objects made from these alloys tend to have heterogenic composition in their microstructure from the start and this problem is exacerbated by their corrosion. The corrosion forms on the surface of the objects and it may, depending on many factors, degrade the copper (decuprification) and zinc (dezincification) contents (Roxburgh 2023, 9). This degradation results in overestimation of the other alloying metals, mainly tin and lead. These processes can have severe impact on the results. For example, if dealing with a low-zinc brass, the corrosion layer may multiply the tin and lead contents by several degrees, while sidelining copper and making zinc look like an impurity, rather than a main alloying element (Roxburgh *et al.* 2019, 58).

We can minimise and negate the influence that the corrosion layer has by one of two ways. First is by completely mechanically removing the corrosion layer on part (only a few millimetres in both diameter and depth are sufficient) of the surface of the object. By conducting this method, we ought to get a clean spot, which should give us an unbiased picture of the original material composition of the object. Nevertheless, even such clean spot will still be influenced by the effects of copper and zinc degradation, because the effects of degradation gradually decrease but do not go away so close underneath the corrosion layer. One must also consider that some corrosion products might have found their way into microscopic pores and grooves of the cleaned spot and these impurities, although tiny in size, will be picked up by the XRF (Fouček 2024, 21). The second way is getting a sample of metal, from the uncorroded core of the object. This is done by drilling a tiny hole into the object and extracting the metal filings produced this way. These filings give us a clear picture of the original material composition of the object. However, obtaining them involves an invasive method which can be a big issue for curators and handers of the objects in some institutions, even though the drilling spot can be hidden by for example wax and virtually rendered invisible (Fouček 2024, 22). Least noteworthy downside of XRF regarding this research is the comparatively low sensitivity of the detector and its detection range. The device is usually only sensitive enough to be able to securely detect elements constituting at least 0,1 wt% of any given element. This is not a problem for this research, given that the research is not primarily focused on trace elements or provenance studies (Pollard – Bray 2014, 220). Lack of detection range means, that the devices usually cannot detect light elements (with atomic lower than 11). If airpath is used, the lower limit is atomic number 13, aluminium. This range can be expanded if working with a device (regardless of it being portable or not), which can create vacuum or use helium wash in its chamber. This way, the lower boundary is pushed to atomic number 11, sodium. For ancient metals and more specifically copper alloys, the detection range issue isn’t a problem, as there were no light elements deliberately used to enhance properties of these alloys. Only such addition of light elements into ancient alloys is infusion of carbon (atomic number 6) and fluoride (atomic number 9), which were added during the carburisation process while creating roman steel (Pollard – Bray 2014, 220). For this thesis, both pXRF and a tabletop XRF were chosen as suitable methods of analysis.

4. Material analysis

This chapter will provide information on how the material research itself was executed. Detailed description of how the material was worked with; the tools used during research and specifics of the conducted analyses will provide a picture on how the results were reached.

4.1. Traceology survey of selected brooches

Traceology analysis was the chosen method to try to get insight into the manufacturing methods involved. The material composition of metals has direct impact on their mechanical properties, enhancing or decreasing their workability. By comparing traces on the surface of brooches made of different alloys, we could see whether the objects were worked differently. Another thing of interest was the possibility of repairs. Repairs of such small objects might not have been viable at the time from the economic point of view.

Primary selection was done using macroscopic examination. This examination was conducted on all 84 roman knee brooches which were stored at the time at Institute of Archaeology of the Czech Academy of Sciences, Brno. Here I was also granted access to all the laboratory equipment needed to conduct a proper traceology survey. All brooches were first observed underneath a source of sharp direct light, while looking at them through a binocular microscope. During this primary examination, multiple interesting marks of different kinds were observed on the surface of the knee-brooches. For every kind of trace, several representative brooches were selected for further microscopic analysis. These brooches were selected based upon having these traces clearly observable and a layer of stable corrosion on their surface for them to be meaningful evidence (fig. 14). Severely corroded surfaces do not provide almost any traces of value (fig. 15). *Ad hoc* traceology observations with naked eye were also made at other institutions and will be marked in the catalogue.

Further analysis of the knee brooches from Moravia included imaging in forensic microscope LMI Toolscan (fig. 16). The microscope is capable of both 2D a 3D all-in focus surface imaging using a photometric stereo lighting from 8 directions. The resulting monochromatic image removes all shades and can be viewed and illuminated from 180°. Such features give us the

Fig. 14.: Unsuitable surface for traceological analysis of brooch cat. no. 44

Fig. 15.: Surface suitable for traceological analysis of brooch cat. no. 35

option of further working with the image in post-processing, enabling the user to highlight what desired features they wanted. This scanning technique has the advantage of showing a detailed topography of the object; however it can also fail to make the desired traces visible enough. Namely if the object was not cleaned properly and the plethora of traces are filled with dirt or corrosion.

Scanning was combined with microscopic imaging, using Keyence VHX 5000 digital microscope (fig.17). Keyence microscope allows the user to make coloured images with possibility of picture stitching function. The microscope has a 1/1,8-inch camera and a CMOS image sensor with a 1600x1200 pixel resolution. It allows magnifications from 20x to 200x with 25.5 millimetre working distance thanks to its Z20R/Z20T zoom lens.

In the case that the brooches were selected for microscopic imaging, they had to be de-conserved first. The knee brooches at the institute of Archaeology of the Czech Academy of Sciences, Brno, were conserved with a solution of 5% Paraloid B48N dissolved in xylen. This layer of varnish prevents the access of oxygen and other outside influences; however, it also gives the surface a glossy look, which is unsuitable for imaging. Hence the need for the de-conservation of the finds. The de-conservation was conducted by applying aceton and xylen to remove the layer of varnish. Following imaging the brooches with the Keyence microscope, they were conserved again - dried for 8 hours in an industrial dryer, to get rid of any potential humidity. After the brooches were dried, the layer of varnish was re-applied.

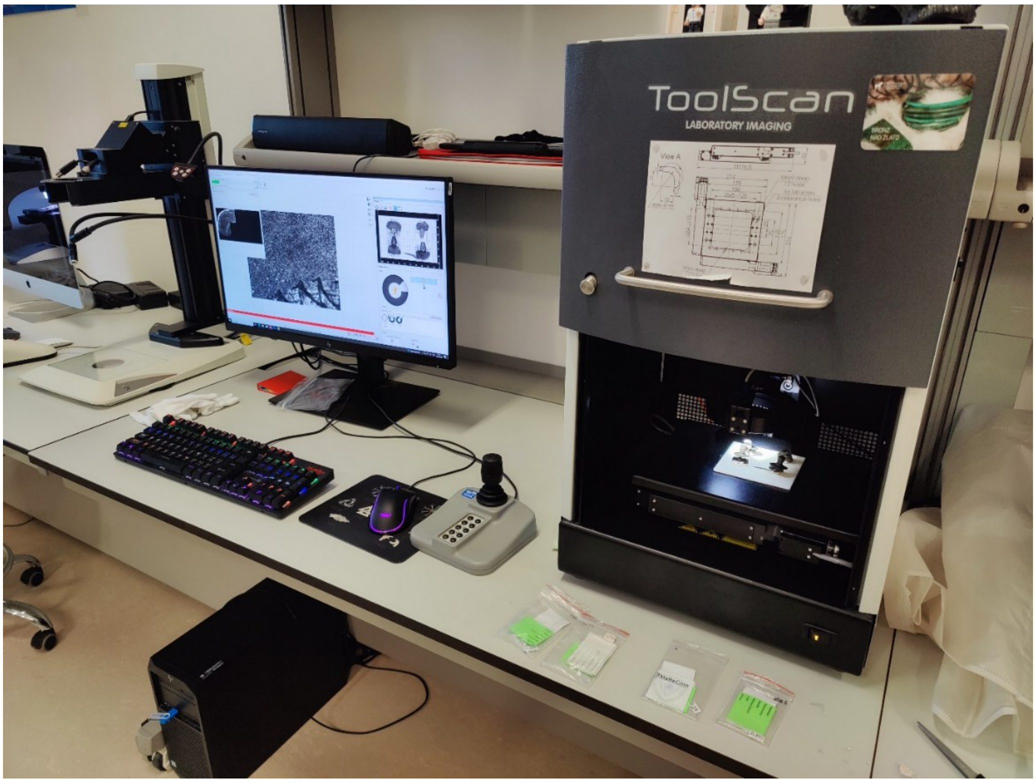

Fig.16.: LMI Toolscan forensic microscope at the Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i. (photo: M. Lelovič)

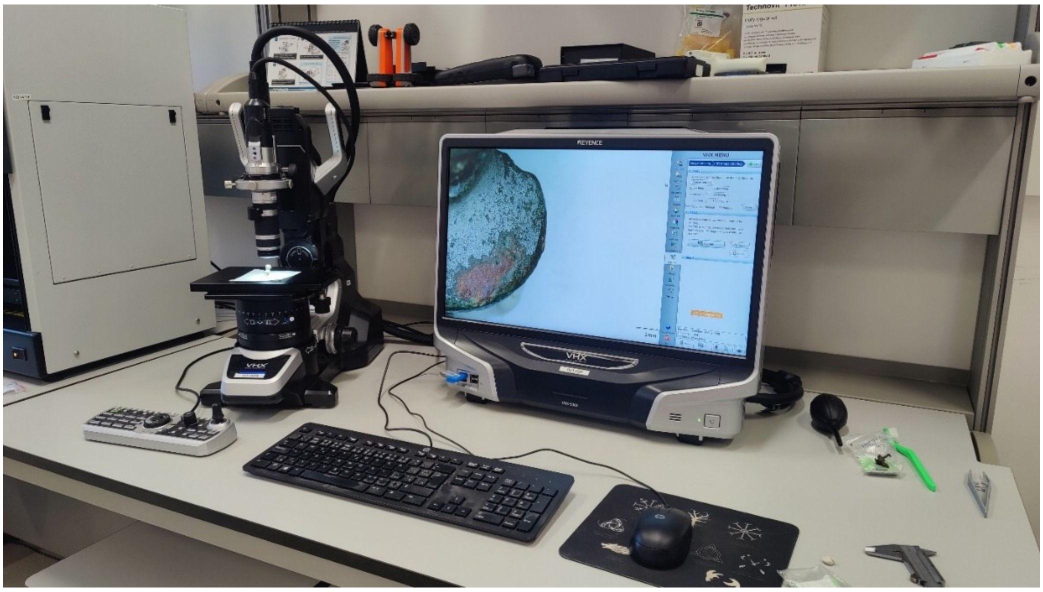

Fig.17.: Keyence VHX 5000 digital microscope at the Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i. (Photo: M. Lelovič)

4.2. X-ray fluorescence analysis

4.2.1. Portable X-ray Fluorescence

A Niton Xl3t 980 GOLDD portable XRF from the Institute of Archaeology of the Czech Academy of Sciences, Brno was used to conduct all the surface measurements of brooches (Fig. 18). The device has a silver anode and a special silicone drift detector (SDD). Furthermore, it is using Geometrically Optimised Large Area Drift Detector (GOLDD). This technology improves both the accuracy and detection ranges of the device. Factory mode *"general metals"* was used for the analysis. This mode allows for detection of all alloying and trace elements found in ancient copper alloys. It also detects any other materials present in the analysed object, which results in a need of manual filtering in post-processing.

Fig. 18.: Niton™ XL3t XRF Analyzer

The device was always used in conjunction with a lead-lined chamber connecting the pXRF to a laptop, protecting the user from radiation. All brooches were ideally measured on the bend of the bow. If the brooches were fragmented in a way which did not allow this, the place of measurement was shifted towards either the foot or the headplate. An emphasis was put upon consistently measuring the brooches form the same area of the artefact where possible, for the same amount of time and with a uniform setting for the size of focus spot. These parameters are the important factors in achieving mutually comparable results (Kmošek 2017, 11–12). The analyses were performed with 8-millimetre focus spot, aimed at the 'knee bend' of the bow, with measuring time of 60 seconds, acceleration voltage 45kV with automatic integrated evaluation of spectra.

4.2.2. Sampling of artefacts

For tabletop XRF analysis, drilled core samples were taken from 84 roman brooches stored at the time at Institute of Archaeology of the Czech Academy of Sciences, Brno. Furthermore 56 samples were taken from brooches at the Institute of Archaeology of the Slovak Academy of Sciences, Nitra. Sampling was conducted using a Proxxon MICROMOT drill with a 1mm drill bit, made from high-speed steel (HSS) and with titanium nitride coating (TiN). An appropriate spot for drilling was located on the body of each brooch. Such spot was selected to be on a discreet part of the brooch. This part had to be thick enough to warrant a drilling which would provide enough metal filings for a worth-while analysis, while not jeopardising the integrity of the brooch. Therefore, most drillings were undertaken on either the bottom part of the bow or on the foot of the brooches (fig. 19). The drilling was done in two stages. First part was drilling out the corrosion layer on top of a brooch. Inclusion of this corrosion in the sample would have distorted the result of the analysis (see chap. 3.2.). Second stage was drilling of the sample itself. Depending on the thickness of the drilled part, the depth of this intervention was in a range of 1–3 millimetres. In relation to the depth, the weight of obtained sample ranged between 10–40 milligrams (fig. 20). The fillings were deposited in a plastic Eppendorf test tube with a stopper and properly marked.

Fig. 19.: Hole 1mm in diameter in the bow of the brooch after sampling, captured by Keyence VHX 5000

Fig. 20.: Size of the obtained sample

4.2.3. Tabletop Energy Dispersive X-ray Fluorescence

All the drilled core samples were analysed by a tabletop ED-XRF (Energy Dispersive X-ray Fluorescence) (fig. 21). The device was ElvaX Pro at the Institute of Archaeology of the Czech Academy of Sciences, Brno. It includes silver anode and an SDD.

Samples were measured in a testing tube through mylar foil 6 µm in thickness (fig. 22). Once in the XRF the collimator was set to 7 millimetres or 5 millimetres in diameter depending on the size of the sample. A single 120 second measurement time at 45kV and 270 μA was used. Factory calibration mode *Cu* was used. The evaluation of spectra was done individually in Elvatech software primarily following elements usually present in ancient copper alloys: Cu, Pb, Sn, Zn, As, Fe, Sb, Ni, Ag, Au, Co, Bi, Ti.

Fig. 21.: ElvaX Pro tabletop XRF analyzer

Fig. 22. Samples in Eppendorf test-tubes prepared for XRF analysis

4.2.4. Data evaluation

Resulting data from both devices were imported to Microsoft Excel, where they were normalised for further study. All elements, which were not the main admixtures of ancient copper alloys were defined as soil residues present in the noble corrosion layer and filtered out, such as: V, Cr, Mn, W, Se, Zr, Pd, Cd, Ru, Mo, Nb, Al. The data were normalised, and a preliminary evaluation was done in Microsoft Excel, using quantitative sorting, histograms and XY plots. This evaluation helped uncover a mistake made during the export of the data from the tabletop XRF, which was immediately rectified. While these preliminary evaluations are not essential, they help with identifying interesting patterns in the material, which could be further examined and later visualized by other tools.

Evaluation and visualisation of the results was done in the PAST statistical programme. Here the main tools used for evaluation were the principal component analysis (PCA), Ternary diagram plots, violin-box plots and XY plots. Ternary diagrams are a useful tool for an easy visualization of quantitative data. However, it only shows ratios of the three compared elements and may therefore not perfectly reflect reality. It is therefore useful to combine it with multivariate statistical analyses, preferably the PCA with a correlation matrix. PCA can also incorporate copper in the evaluation. With copper being the main constituent of the analysed objects, it puts the main alloying elements into another, useful perspective.

5. Results

In total 148 drilled core samples and 267 surface measurements were acquired. This relatively large sample allowed for a comprehensive study of the material composition of the brooches. By analysing the core samples and surfaces of the brooches by two different devices, these data also allow for a comparison of these methods. Additionally, 27 brooches were selected as displaying interesting marks, which were imaged using the Keyence and Toolscan microscopes. These marks produced some interesting insights, as well as a data set for comparison.

5.1. Problems of the material sources

During the research, several problems arose with getting access to the knee brooches and then with their analyses. The biggest issue was acquiring permission to access the brooches from inside of the Roman provinces. Three sites located in Austria, Carnuntum, Lauriacum and Vindobona were chosen as ideal for the research. All these sites have both a legionary fortress and an adjacent civilian town, providing the opportunity to compare material from military and civilian contexts. However, I was only granted access to a collection of Roman-provincial knee brooches from Carnuntum. These are deposited in Kulturfabrik Hainburg. Moreover, even though it was possible to gain access to the brooches from Carnuntum, many of these lacked find contexts. The pieces with verified contexts came from the 'Legionslager' area of the site, with none of the pieces found in the 'Zivilstadt'. The goal of analysing roman-provincial knee brooches from the civilian contexts from the roman sites inside of the Roman Empire was therefore not achieved.

Time constraints also limited the amount of work which was possible to do. For example, in SAV Nitra, sampling and documentation took place over a three-day period. In Carnuntum, the situation was even more hectic, as the time allocated for the knee-brooch research was a single day. In both cases, prioritisation had to take place, resulting in an unsatisfactory state of documentation. Some of the brooches therefore do not have photographs or detailed descriptions associated with them.

Another hurdle during the research, was that drilled core samples were only taken from brooches in Brno and Nitra. In Carnuntum however, the only allowed method of analysis was surface measurement using pXRF. Due to this, the brooches in Brno and Nitra were also measured from the surface by the pXRF. This was done to enable an unbiased comparison of material composition of brooches from those sites and the ones from Carnuntum. As a benefit a set of measurement made by two different techniques allows for a methodological comparison of results. These results were examined in comparison to one another showing interesting disparity.

A factor which impacted the results of the pXRF surface analyses, was the state of conservation of some brooches from Kulturfabrik Hainburg and SAV Nitra. Some of the brooches from Hainburg were not completely cleaned having soils residues on the surface of the brooches (fig. 23). The selection of brooches was therefore limited to only the sufficiently cleaned knee brooches with at least part of the surface free of soil, affecting and lowering the possibilities of representative selection. While the pXRF would be able to pass through the soil on the surface of the brooches, it would also get return signals from it. The results would therefore also include the elements contained in the soil, compromising the analysis.

A portion of the roman-provincial knee brooches from Nitra were previously cleaned via chemical treatment, instead of a mechanical one. The inorganic acid used, while effective in dealing with the corrosion, also aggressively removed lead from the surface layers of the brooches. Phosphoric, sulphuric or hydrochloric are some of the acids used in the past for cleaning copper archaeological artefacts. Especially acetic acid is aggressive towards lead (Drábková 2023, 56). Such treatments lead to complete removal of corrosion products, which is not desirable by today’s standards. In present day, the goal of conservation is to get to a layer of noble patina on the surface of copper-alloy objects, when possible (Drábková 2023, 44). The removal of lead from the surface of the brooches was discovered while comparing the drilled core samples analysis and the surface analysis. The surface analysis should be displaying higher levels of lead, as discussed in chapter 3.2. This was not the case however, and the cores displayed lead levels several times higher, than the surfaces. The surfaces of the brooches were also devoid of any corrosion products typical for copper-alloy objects and displayed marks of acid etching (fig. 24). Such treatments also remove most of the delicate traces on the surface of the objects, rendering any future efforts for traceological analysis almost useless. Therefore, one has to be aware not only of the limitations of the selected method of analysis of material composition, but also of the possible impact of conservation methods used while preserving the artefacts. Moreover, an approval was given to sample only knee brooches coming from metal detector surveys. Brooches from excavations were only analysed via surface measurements by a pXRF. Such restriction has also made the selection of material subjective.

In conclusion, while the obtained sample size is sufficient, the gathering of material proved much more of a challenge than expected. The inability to gain access to more Austrian sites made the acquisition of data from Roman civilian contexts impossible to achieve. Moreover, the artefacts which were accessed had to be selected subjectively, to either meet the terms of agreement for access or because of the state of conservation. While this forced selection of material did not impact the research results significantly, the inability to sample all the knee brooches make the interpretation of results troublesome. The subjectivity of material selection also makes a typological comparison of separate areas impossible. The roman-provincial knee brooches in Carnuntum not only displayed more typological variation but were also more decorated, than their counterparts from the *Barbaricum*. The pieces from Carnuntum also show an interesting deviation in material, despite only being analysed via pXRF surface analysis.

Fig. 23.: An incompletely cleaned brooch with soil residues, cat. nr. 213, Carnuntum (Photo: Martijn Wijnhoven)

Fig. 24.: Knee brooch etched by acid, cat. nr. 176, Iža-Leányvár (Photo: The institute of Archaeology of the Slovak Academy of Sciences, Nitra)

5.2. Traceology

Traces on the surface of all four categories (manufacturing, functional, repair and post-deposition) can be observed on the brooches from Moravia, Slovakia, Austria and Bohemia. Offset structural elements, cracks from casting, non-polished casting flashes and traces of grinding are all marks left on the surfaces of the objects from the manufacturing stage. The offsetting of some elements, or whole bows of the knee brooches, is a consequence of misalignment of the two halves of the moulds during casting. While advanced, the two-part moulds were not a perfectly precise method of casting. While creating the impression in the clay, the 'bottom' half of the mould could end up with a deeper impression of the casting pattern, than the 'upper' part, which was pressed on top. Before casting two halves of the moulds were simply sealed by more clay and tied together before pouring in the metal (Bayley–Butcher 2004, 27). It is therefore possible, that the parts of the mould could still move a little. Lastly, the two pieces could have simply been incorrectly put together, resulting in an uneven casting. The misalignments can be for example observed at knee brooches cat. no. 11 or 82 (fig. 25; 26).

Casting flashes are indicators of the joins of the moulds. They were usually removed by polishing but can be still relatively frequently observed on the surface of the brooches. The casting flash could have been retained to give the brooch a different appearance or because it could have been simply too time consuming to remove it. Furthermore, the casting flash can be an indication of mould misalignment as well. Examples of knee brooches which retained their casting flashes are cat. no. 47; 58 (fig. 27; 28).

Occasionally, relatively large cracks on the surface of the brooches covered by noble patina may be observed on the bodies of the knee brooches. The cracks were caused by pockets of air, unable to escape quickly enough during the pouring of the metal into the mould (Henry–Bewer 2014, 51). These fractures are not of recent origin, as attested by the patina. Furthermore, their size in proportion to their bodies do not point toward mechanical damage. Knee brooches cat. no. 77 and 82 display these cracks on their surfaces (fig. 29; 30).

After the casting the brooches were further worked. The process of removing the excess metal by polishing and grinding left marks all over the surface of the brooches, from headplates to feet. The polishing marks are a most common trace on the surface of the knee brooches. The bow and the head plate of cat. no. 40 and the catch plate and foot of cat. no 56 are the most prominent examples (Fig. 31; 32; 33; 34).

Fig. 25.: Unevenly cast headplate, cat. no. 11, captured by Keyence VH 5000

Fig. 26.: Offset catchplate, cat. no. 82, Captured by Keyence VH 5000

Fig. 27.: Visibly misaligned casting flash on the bow of cat. no. 47, captured by Keyence VH 5000

Fig. 28.: Casting flash on the body of cat. no. 58, captured by Keyence VH 5000

Fig. 29.: A cavity in the back of the bow created during casting cat. no. 77, captured by Keyence VH 5000

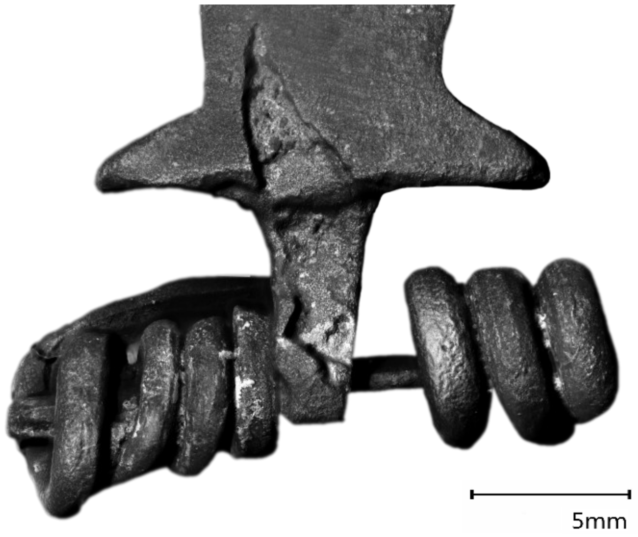

Fig. 30.: A crack in the back of the bow and the spring socket of cat. no. 82 created during casting, captured by LMI Toolscan

Fig. 31.: Traces of polishing on the back of the bow of cat. no. 40, captured by Keyence VH 5000

Fig. 32.: Traces of polishing on the headplate of cat. no. 40, captured by LMI Toolscan

Fig. 33.: Traces of polishing on the catchplate of cat. no. 40, captured by LMI Toolscan

Fig. 34.: Traces of polishing on the back of the foot of cat. no. 40, captured by LMI Toolscan

A prominent aspect of the roman-provincial knee brooches is the decoration. The headplate is usually the only decorated part of the brooch. This is the case with most of the Moravian brooches. The decoration was made by tremolo chasing technique. Chasing is done with a blunt tool called tracer. Using this technique, the metal only deforms, pushing it out of the incisions, instead of removing it (Bayley–Butcher 2004, 30). Headplate of brooch cat. no. 40 offers a look at the traces left by the decorative process (fig. 35). Other possible way the headplates could have been decorated was by putting a silver wire into a notch in the headplate. Brooch cat. no. 59 is the only brooch with a notch on the edge of the headplate enabling such a decoration technique (fig. 36).

However, brooches with decoration on their feet, bows, and even catch plates also exist. Only three Moravian brooches, cat. no 14, 22 and 75 have a decoration besides the headplate, specifically on their feet (fig. 37; 38). These more decorated brooches appear much more frequently in Slovakia and Austria. For example, brooches form Slovakia cat. no. 125; 127 or Austria, cat. no. 193; 195 have their feet decorated. The feet of the brooches are decorated either by additional construction features, seemingly preferred in Slovakia, or by chased line decoration. Knee brooch cat. no. 88 has a punched circle decoration on the bow. Cat. no. 92 and 195 have chased line decoration on their bows right above the spring, despite not having a headplate. A crest and two knobs on either side of the bow adorn brooch cat. no. 100. An interesting décor are canelures on the whole body and spring sleeve of brooch cat. no. 202.

Another form of visual enhancement of the brooches was tinning. This treatment gave the brooches a silvery look, by applying a very thin layer of tin or lead-tin alloy coating. The coating was applied by one of two ways. Either dipping the brooches in molten tin or tin-lead alloy, or by heating up the brooch and rubbing it with a rod of tin or tin-lead alloy (Bayley–Butcher 2004, 43). This procedure created a few micrometres thick layer of tin on the surface of the brooches, as can be for example observed on brooch cat. no. 78 (fig. 39). The same lead-tin alloy could have been used as solders as well. The only solder encountered on roman-

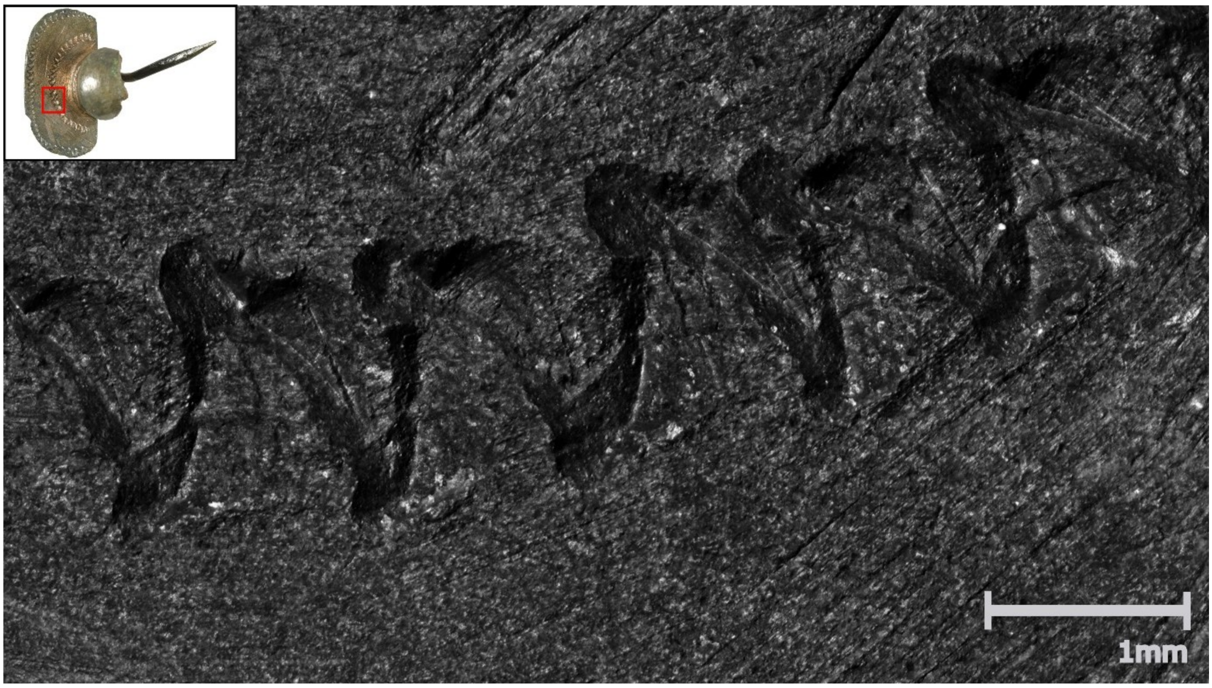

Fig. 35.: Traces of the tool used to create the tremolo chased decoration on the headplate of cat. no. 40, captured by LMI Toolscan

Fig. 36.: The notch on the headplate of cat. no. 59 for a decorative silver wire, captured by Keyence VH 5000

Fig. 37.: Hammered-out foot with chased decoration, cat no. 14 (photo: The Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

Fig. 38.: The notch on the headplate of cat. no. 59 for a decorative silver wire, captured by Keyence VH 5000

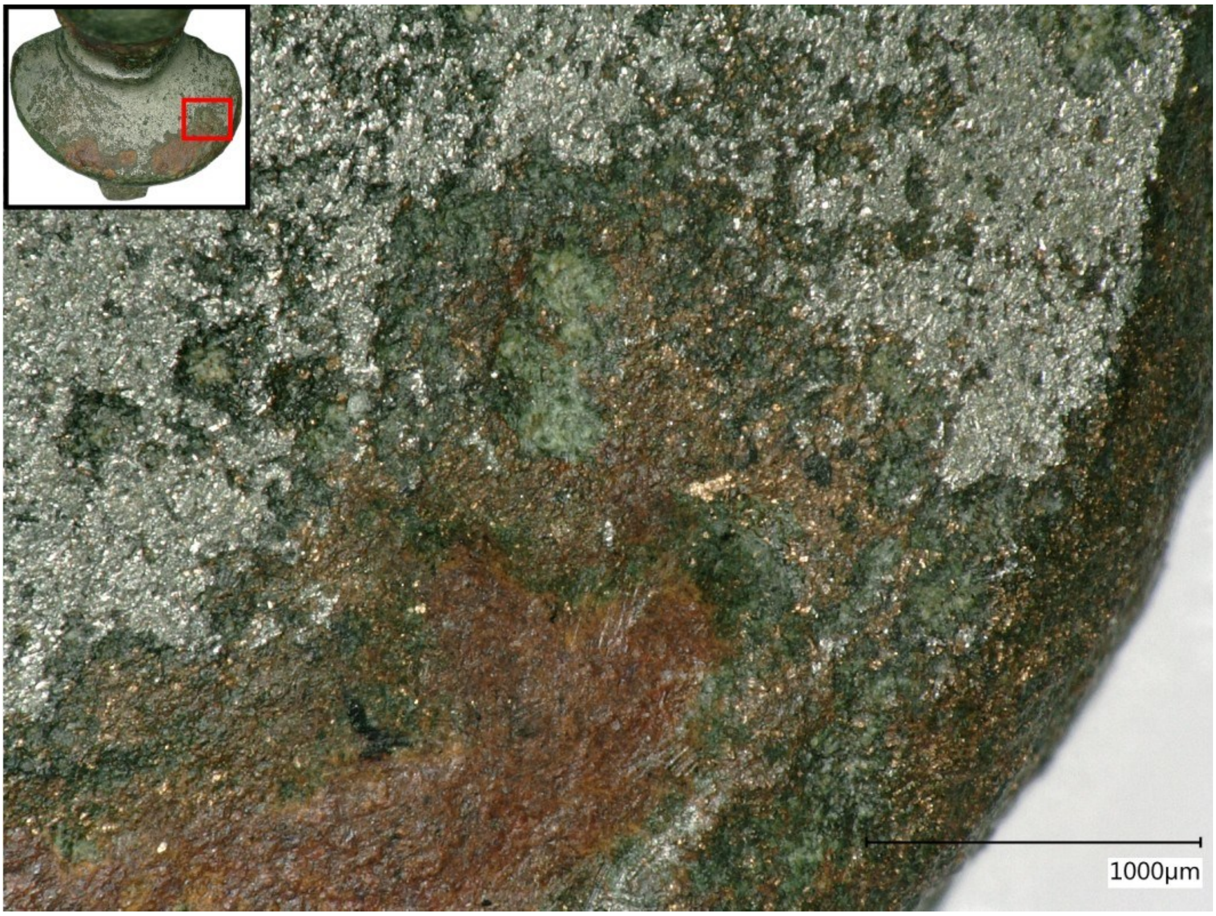

Fig. 39.: Tinning on the headplate of cat. no. 78, captured by Keyence VHX 5000

provincial knee brooches during this research are on brooch cat. no. 207 (fig. 40). Here an additional plate is soldered onto the transversely positioned catch plate. The exact material composition of the solder was unfortunately not measured by a pXRF device.

Knobs which appear on the feet of some brooches can be of two characters. They are either an additional decorative aspect of the brooches, or they can be a remnant of the casting. As discussed in chapter 2.4., the sprue cup either connected to the foot or the socket for the spring. While knobs can be interpreted as simply remnants of the casting if the sprue cup connected to the foot, that is not the case if it connected to the socket. If that was the case, the knobs had to be part of the original casting pattern and were therefore a desired element of the brooch. The fact that the knobs were deliberately added for decoration is attested by a casting pattern for a Jobst 13C knee brooch from Flavia Solva (fig. 41). Moreover, I would argue, that the decoratively shaped knobs were a deliberate addition, as in the case of cat. no. 54. (fig. 42), while the simple ones in form of rods or protrusions are remnants of casting the brooches from their feet, best represented by cat. no. 42 (fig. 43).

Functional traces include incisions on the bows and headplates of the brooches, marks of catchplate wear or breakages, ranging from springs and headplates to feet and catchplates. These marks are a result of the usage of the brooches. The springs are the most commonly broken parts of the brooches as they have undergone constant stress of usage. These damages can be recognised as ancient in origin thanks to the noble patina covering these marks. In the case that it was the catchplate which broke it could have been repaired. The catchplates were relatively thick. If the break was made at least a few millimetres from the foot of the brooch, the remaining metal could have been heated up and hammered out into shape of a thin catchplate (fig. 44). No less than 17 of the 274 examined roman-provincial knee brooches had their catchplates hammered back into their original shape after a defect. The knee-brooches were not spared of recent damages as well, however. Deep gushes on the bows, broken springs or breakages of headplates, displaying the original yellow-ish colour (fig. 45) of the original material may be attributed to recent times. These damages could be the results of deep ploughing, the artefacts being hit while excavating, or improper handling and storage.

Fig. 40.: Solder on the catchplate of cat. no. 207 (Photo: M. Wijnhoven)

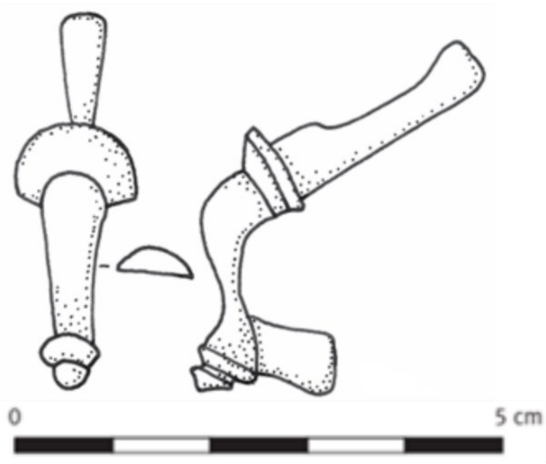

Fig. 41.: Casting pattern for a Roman-provincial knee brooch, Flavia-Solva (Cociș 2019, Pl.131/71)

Fig. 42.: Decorative knob, cat. no. 54, captured by Keyence VHX 5000

Fig. 43.: Retained casting knob, cat. no. 42, captured by Keyence VHX 5000

Fig. 44.: Hammered catchplate, cat. no. 37, captured by Keyence VHX 5000

Fig. 45.: Tinning on the headplate of cat. no. 60, captured by Keyence VHX 5000

5.3. pXRF surface analysis results

As mentioned in chapter 3.2., the pXRF is more of a tool to give the operator a rough idea of what he is dealing with. It had been used only to allow comparison between brooches from Carnuntum and the artefacts from other sites. As can be seen in fig. 46, the results did not create any significant clusters solely based on their primary alloying elements. A PCA graph has shown the same results (fig. 47).

No significant clustering occurred even after considering all possible ancient factors. The type of site the brooches were found at, of what culture were the residents of the site, or the typology of the brooches themselves. Only one relatively big cluster of brooches (marked cluster 1 on fig. 46; 47) with very low lead content could be seen. The issue of exaggeration of tin and lead by surface pXRF analysis was discussed in previous chapters. After the possibility of incorrect methodology was ruled out, the brooches themselves were re-examined. Only

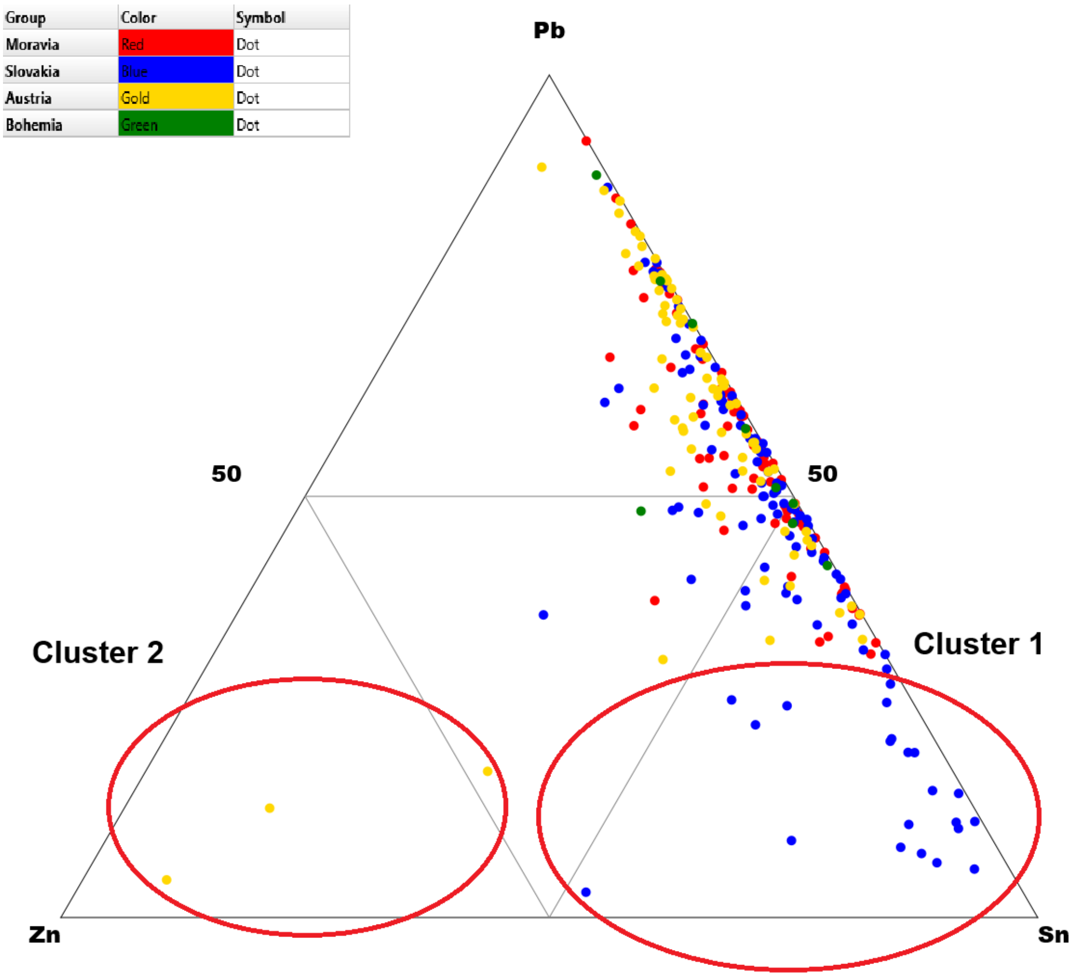

Fig. 46.: Ternary diagram of pXRF surface analysis results, coloured according to the area of origin of the analysed brooches

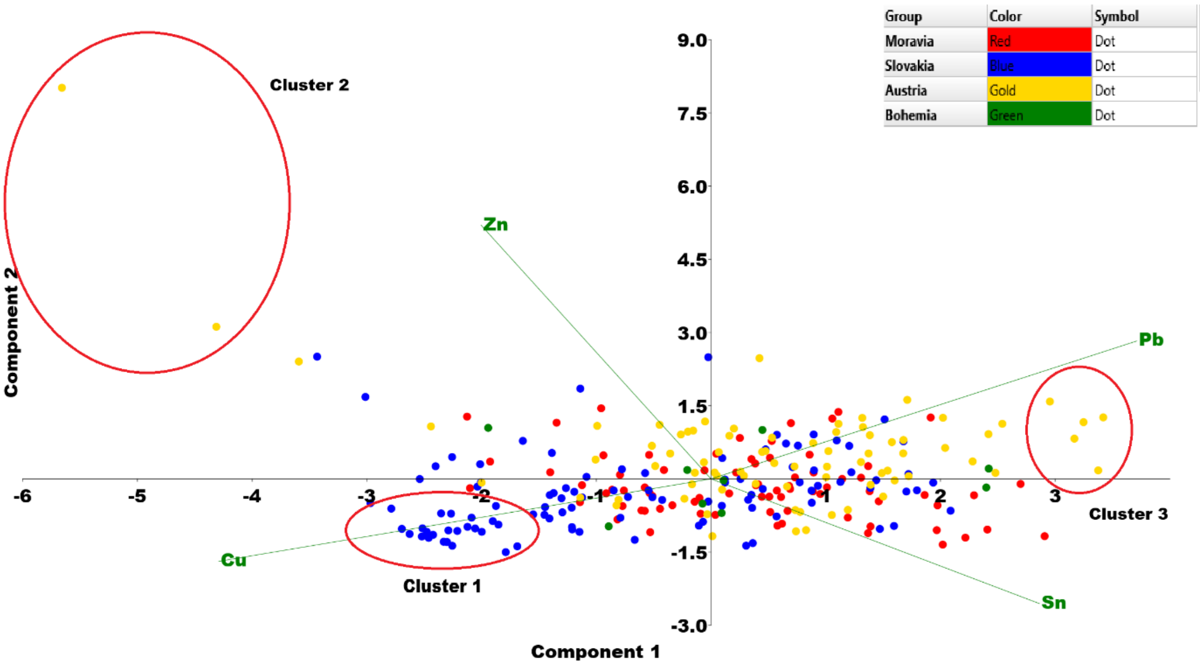

Fig. 47.: PCA graph of pXRF surface analysis results, coloured according to the area of origin of the analysed brooches

after considering the institution at which the roman-provincial knee brooches were deposited at, an explanation was found for the low-lead content cluster. All the brooches from cluster 1 are deposited at the Institute of Archaeology of the Slovak Academy of Sciences in Nitra. The state of conservation of some of these brooches, as discussed in chapter 5.1., was the issue. Almost every brooch from cluster 1 bear marks of acid etching on their surface and they were in some cases completely stripped of the corrosion layer (fig. 48).

Cluster 2 is a group of three high-zinc brooches, cat. no. 194, 195 and 202, from Carnuntum. Cat. no. 194 and 202 have their levels of lead and tin under 2.3%, while having their zinc values over 11%. This makes them the only two brass specimens out of the 273 surface measured brooches. They are brass beyond any doubt, even though they were measured from the surface. The lead and tin values would presumably be even lower, if their drilled core samples were to be analysed. Interestingly enough, brooch cat. no. 202 is one of the most decorative pieces encountered, boasting a fluted decoration all over the body. This extraordinary decoration also covers the spring sleeve of the brooch. The other brooch, cat. no. 195, has lead and tin values over 3% and 6% respectively, therefore “only” making it a leaded tin-brass object.

Cluster 3, which only appears in the PCA graph (fig. 47), again, consists only of brooches originating from Carnuntum. All of these brooches have extreme levels of both lead and tin.

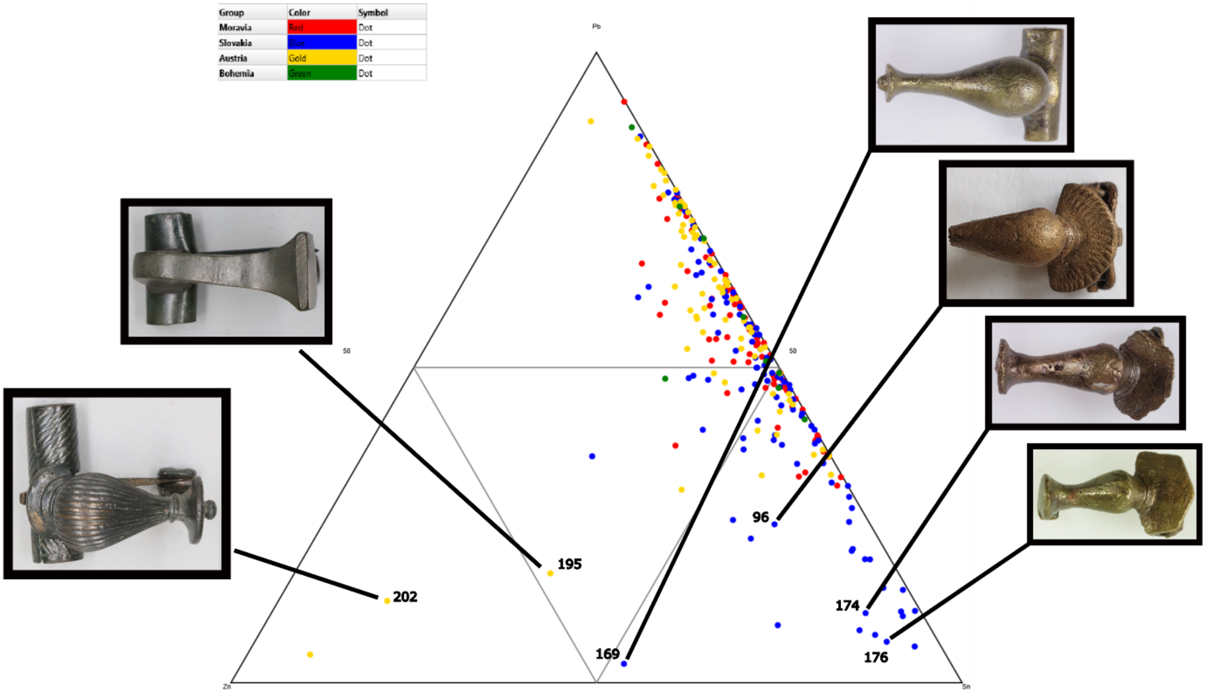

Fig. 48.: Ternary diagram of pXRF surface analysis results, coloured according to the area of origin of the analysed brooches, with the Slovak low-lead, acid-treated knee brooches (right), and the brass and high-zinc knee brooches from Carnuntum (left)

Lead in these brooches is ranging from 32% to 58%, while tin can be anywhere between 12% to 35%.

Generally, it can be said, that according to the pXRF results, the Austrian brooches have higher lead values, while also boasting some zinc-rich specimens. Such results from surface measurements are important, as zinc values are lower on the surface, therefore there may be even more brass brooches from Carnuntum. The knee brooches from Slovakia on the other hand seem to have much higher tin values. As discussed previously however, results of the pXFR measurements of the knee brooches from Slovakia cannot be taken at face-value. Moravia and Bohemia are showing an apparent equilibrium, without a clear material preference.

A histogram is a useful tool which helps with a very simple visualisation of the quantitative data. A histogram representing the lead contents in the brooches (fig. 49) is almost shaped like a Gaussian distribution. Nonetheless the start is heavily influenced by the improperly conserved knee brooches from Slovakia. Most of the brooches contain at least 8% lead, with the average being between 20% and 37%. Tin histogram (fig. 50) has uncharacteristic second peak, however, this cannot be linked to the Nitra brooches. Just like lead, most of the knee brooches contain above 7% of tin. The average is 7% to 22%. Lastly zinc (fig. 51) has a sharply declining tendency right from the start. This translates to the overwhelming majority of knee brooches having extremely low admixtures of zinc, under 2.5%. These histograms allow for a conclusion, that the Roman-provincial knee brooches were made of leaded bronze, with possible low zinc admixtures. These admixtures of low levels of zinc, cannot be conclusively interpreted as intentional move by the workmen, as such small values may be the result of admixture from the ore sources or recycling material. There are a few zinc-rich pieces, but only two of them are pure brass. A preference for material from which the Roman-provincial knee brooches were made is becoming apparent.

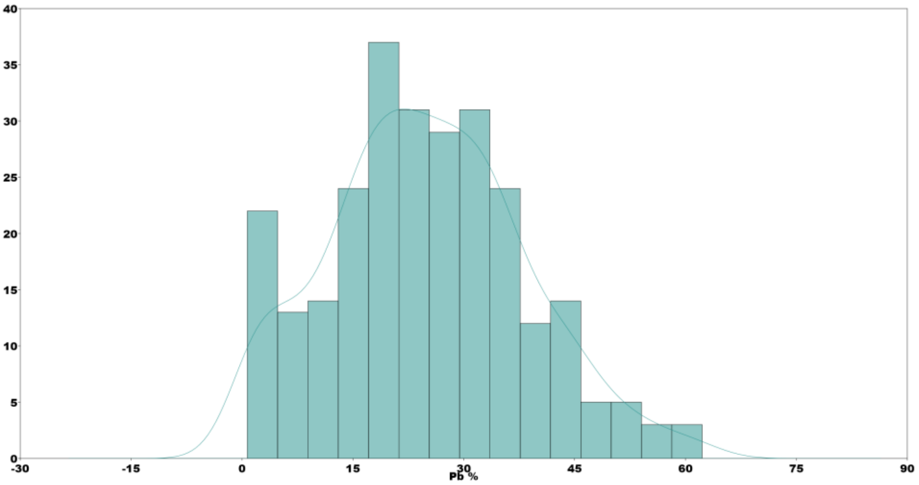

Fig. 49.: Histogram of lead contained in the brooches according to the pXRF measurments

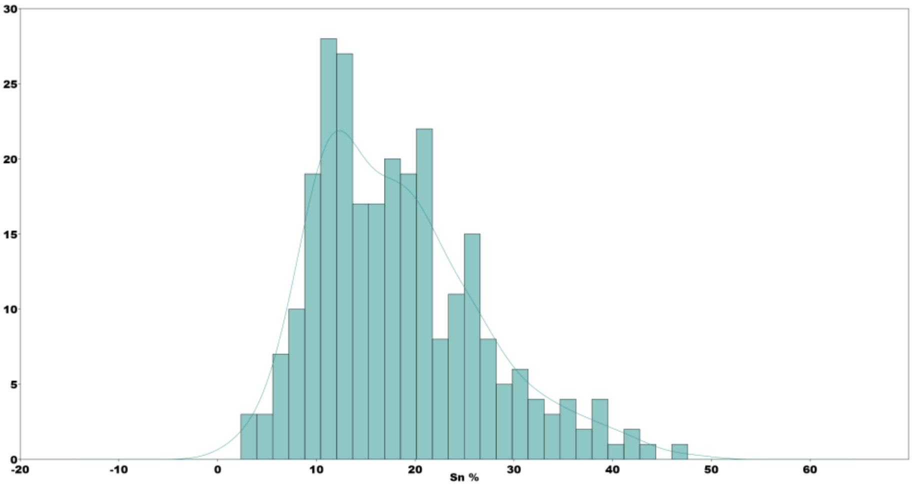

Fig. 50.: Histogram of tin contained in the brooches according to the pXRF measurments

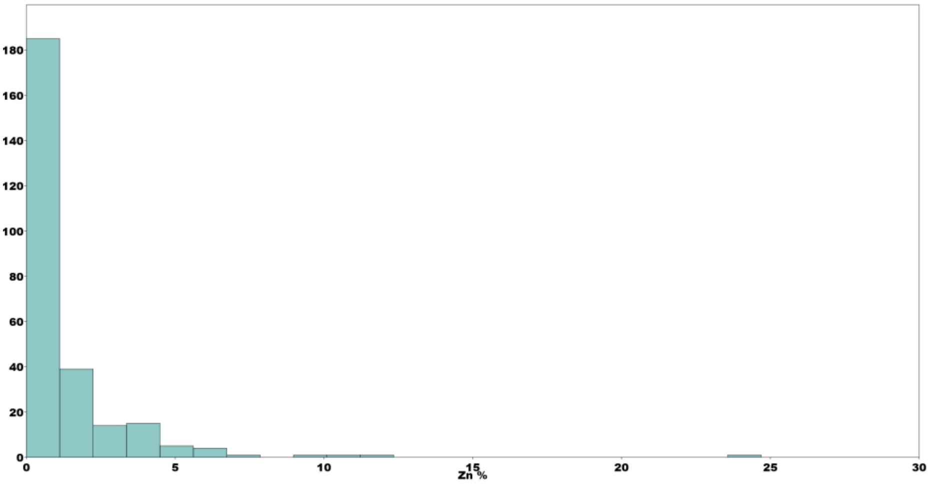

Fig. 51.: Histogram of zinc contained in the brooches according to the pXRF measurments

5.4. ED-XRF drilled core sample analysis results

The results of XRF measurements of drilled core samples give us more promising results. At least in their clarity and material clustering. As can be seen in fig. 52, the drilled core samples produced four distinct material clusters. Cluster 1 consists of purely leaded tin bronze brooches. They are also almost without any addition of zinc (below 1.1%). Brooches of this cluster are very heavily leaded, generally keeping lead levels above 20%, while tin itself was added only as the bare minimum amount of 2% in some cases. The 2% amount of tin is an artificial bar, when the copper alloy object may start to be considered as tin bronze. Best example of this is brooch cat. no. 108, which has the tin-lead ratio of 1:14.2 (2,71 % Sn : 38,71 % Pb). Here we must take into consideration, that the high lead amounts may have caused the other alloying metals to be artificially lower in the measurements. Cluster 2 comprises of leaded tin bronze as well, however it has a higher tin amount, than the previous group. Furthermore, zinc starts to play a significant role, with most of the brooches having between 1-4%, going as high as 6%. Cluster 3 has the tin-lead ratio almost equalised, keeping it between 1:2–1:1. Zinc keeps fairly low levels in this group, with the brooches containing anywhere between 0–2%. Cluster 4 is the single cluster of brooches, where zinc reaches almost the same amounts as lead and tin do. While the brooches do contain anywhere between 5-10% of zinc in this group, due to similar amounts of tin and lead they cannot be classified as pure brasses.

Interesting fact is, that not all the brooches from cluster 4, are extraordinary (fig. 53). Four out of six of the brooches are either Jobst 13C or Jobst 13D type, so the most common types. One of the brooches, cat. no. 106, is type Jobst 12C, which is the same as cat. no. 195 from Carnuntum. This brooch has also shown high zinc value, even though it had been measured by a pXRF. The other brooch, cat. no. 118, is type Petković 19/A, which is not so commonly observed in the middle Danube region. This rarity is attested by the fact, that this is the only brooch of this type encountered during this research.

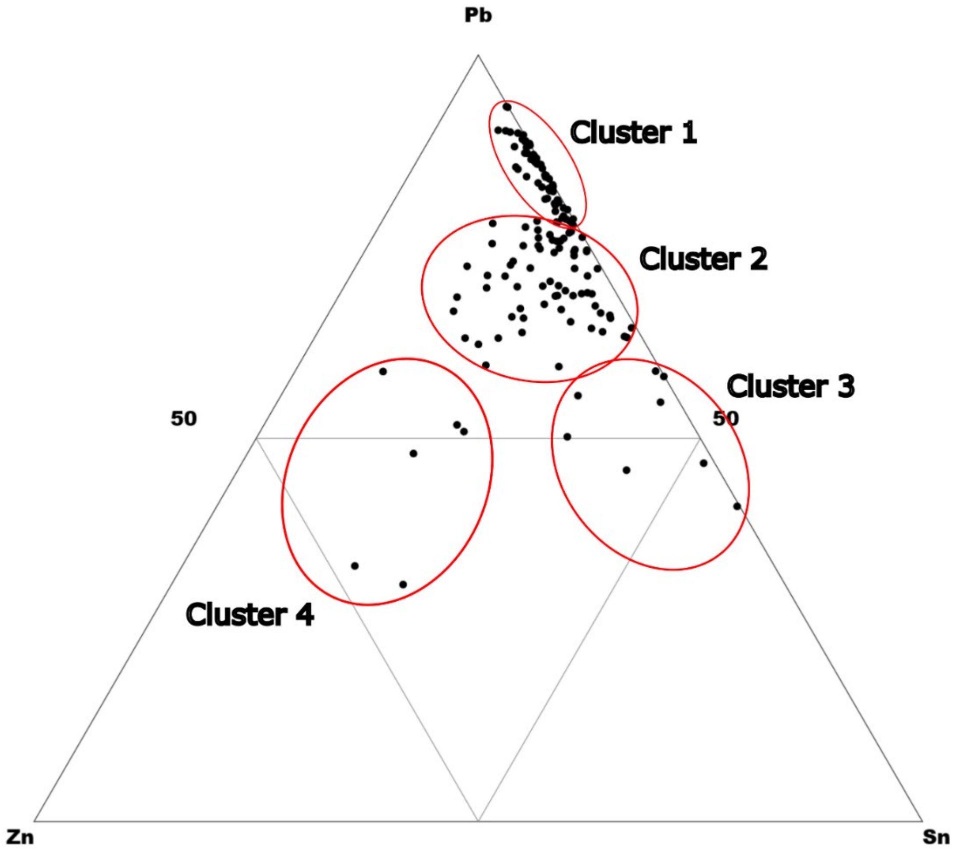

Fig. 52.: Ternary diagram with clusters of brooches of similar material composition

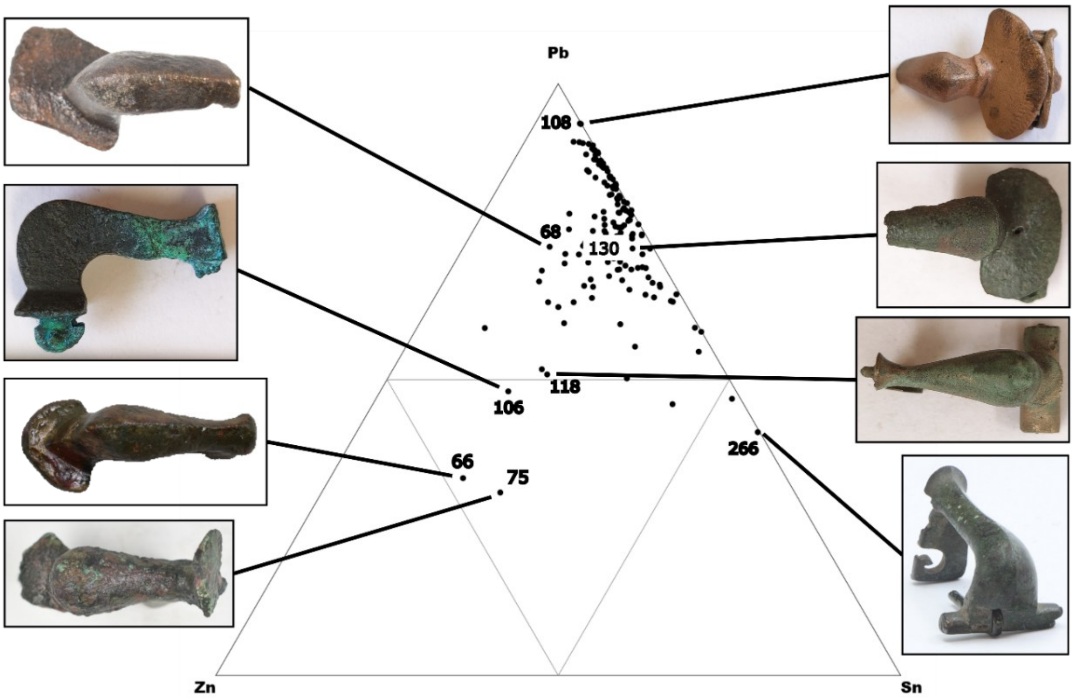

Fig. 53.: Ternary diagram of main alloying elements analysis results from drilled core samples, with associated brooches

The clusters again, do not seem to corelate with any ancient criteria. Whether it is the culture of site of origin (fig. 54), area of provenience (fig. 55) or typology (fig. 56), no apparent clusters can be observed. However, if we look only at the two seemingly most prevalent types in the Middle Danube region, Jobst 13C and Jobst 13D (94 samples out of 148 brooches are from these two types), an interesting pattern emerges (fig.57). For the undecorated Jobst 13C type, the preferred material seems to be the tin bronze with equalised tin-lead content, with occasional zinc admixture. An opposite is true for the decorated Jobst 13D, which were preferably manufactured out of the very highly leaded tin bronze, with almost no zinc contents. Such trends could not be observed when comparing the results of other types, due to low sample size of these other types. This sample size is the result of inability to access knee brooches from Austria and by the fact, that some types of brooches were simply not preferred in the area of study, making them exceptional finds.

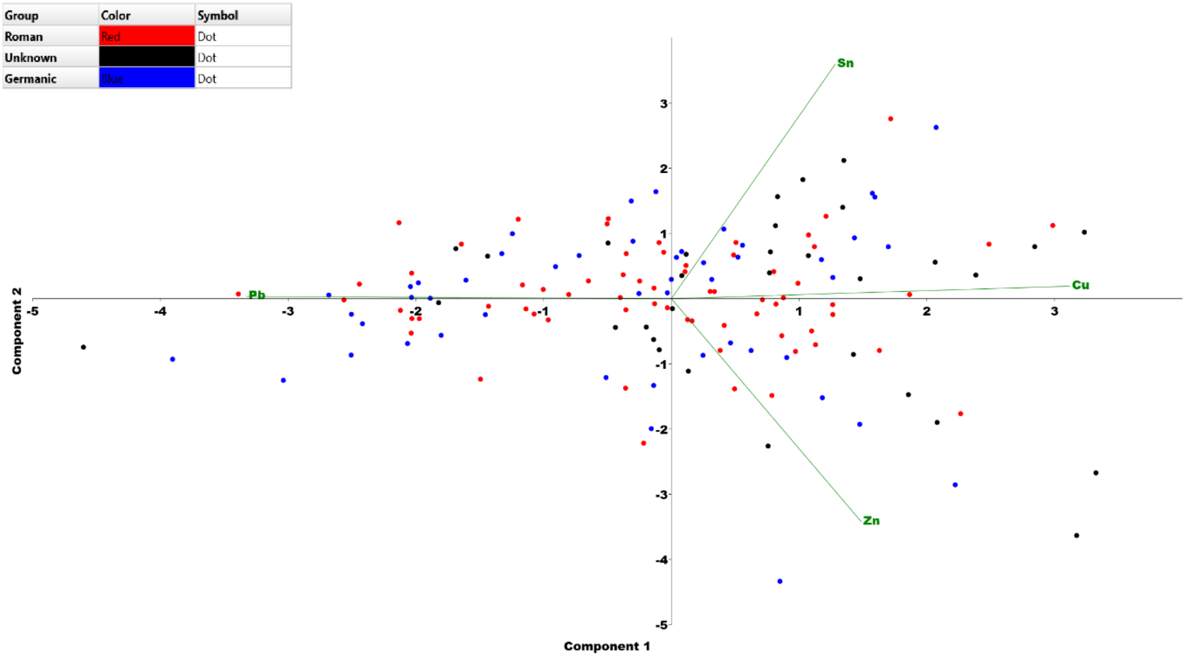

Fig. 54.: PCA graph coloured according to the culture residing on the site the brooch was found on

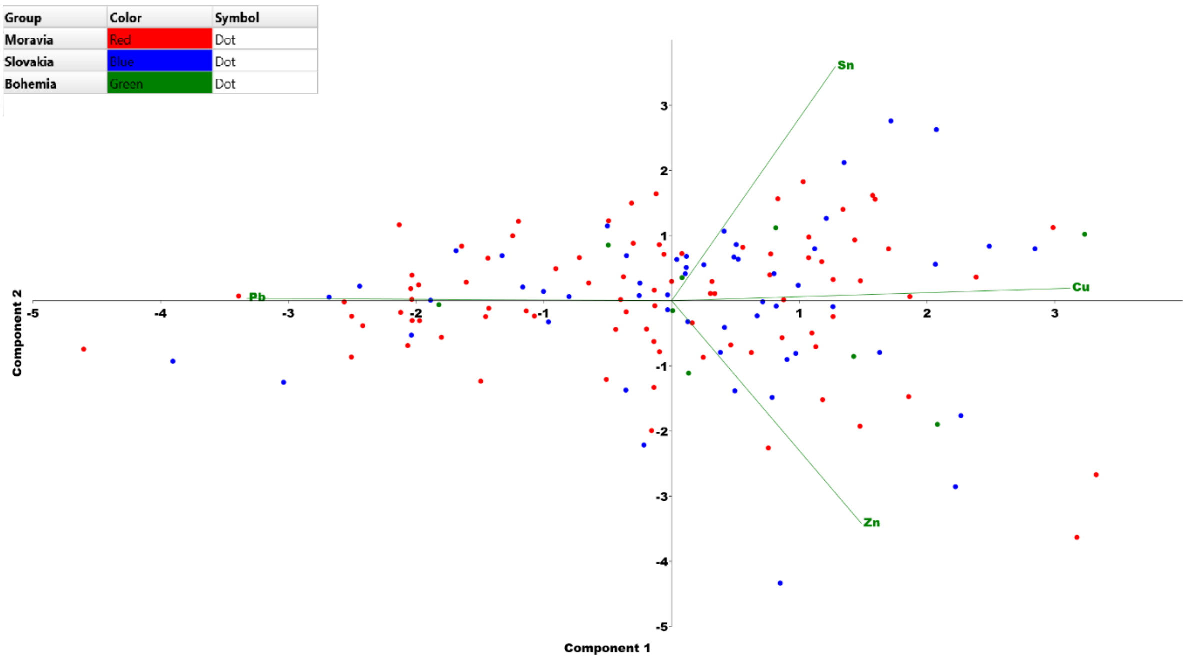

Fig. 55.: PCA graph coloured according to the general area of origin of the brooches

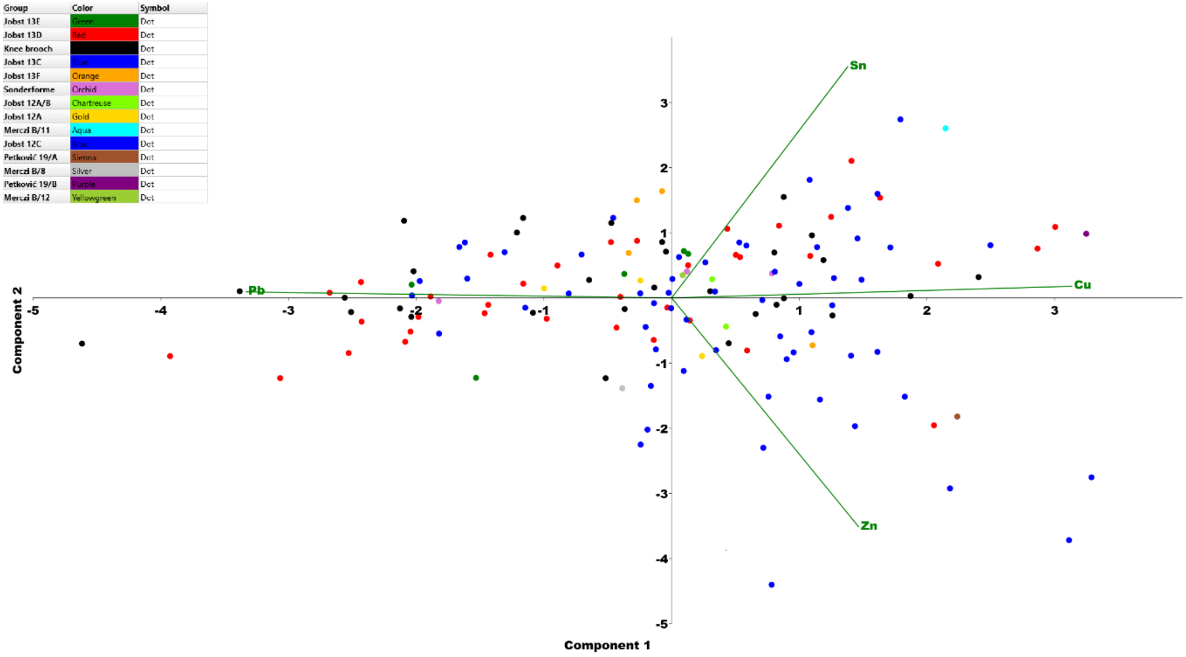

Fig. 56.: PCA graph coloured according to the typology of brooches

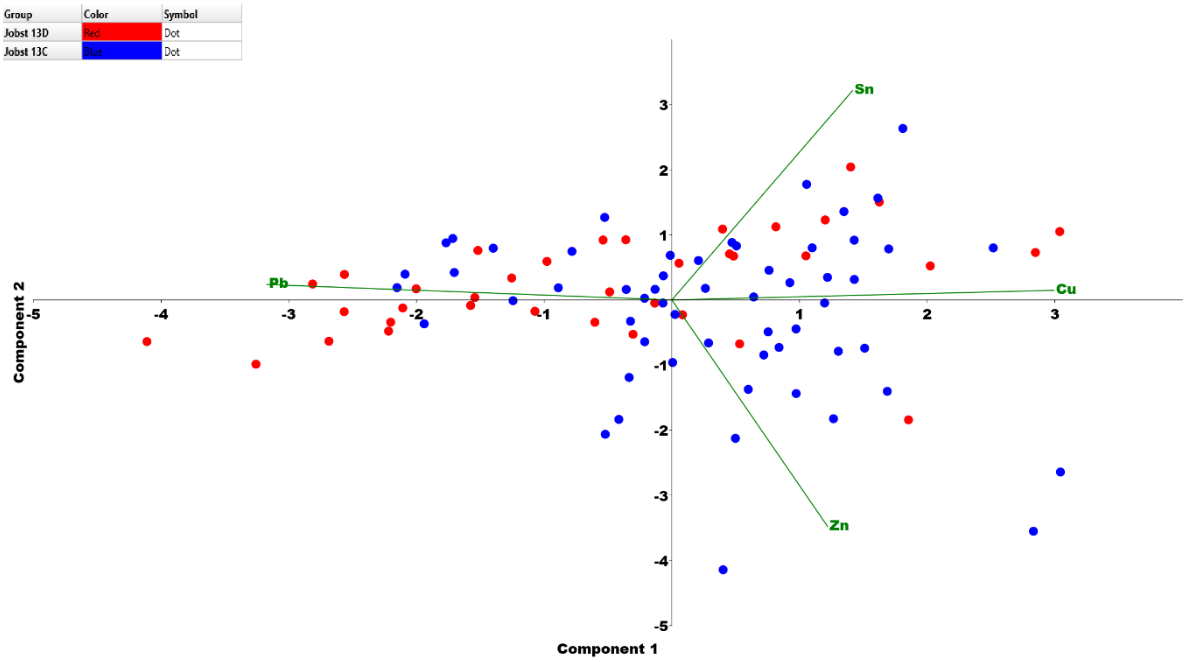

Fig. 57.: PCA graph comparison of material composition of type Jobst 13C and Jobst 13D knee brooches

The analyses of drilled core samples also enabled a basic trace element patterns evaluation. While XRF itself does not allow for a provenance study, it can provide information about trace elements patterns of general groups. The knee brooches should cluster not only based on the main alloying elements, but on the insignificant ones as well. Trace elements are in this case Sb, Ni, Ag, As, Fe, Au, Co, Bi and Ti. Iron was left out of the evaluation, due to it being more of an indicative sign of level of refining. Bismuth and arsenic naturally occur in lead ore, therefore their amounts are very closely tied to the lead content. They were therefore excluded from the evaluation as well. Lastly, titanium, nickel and gold were rejected as indicative of the ore batches pattern due to their very low to null content in the analysed samples. These negligible levels cannot be considered as indicative of the batch of ore they came in. Only antimony, silver and cobalt remain as relevant trace elements of interest. As we can see however, the results again do not create any distinguishable groups (fig. 58). This remained the fact even after again considering all trace elements contents available.

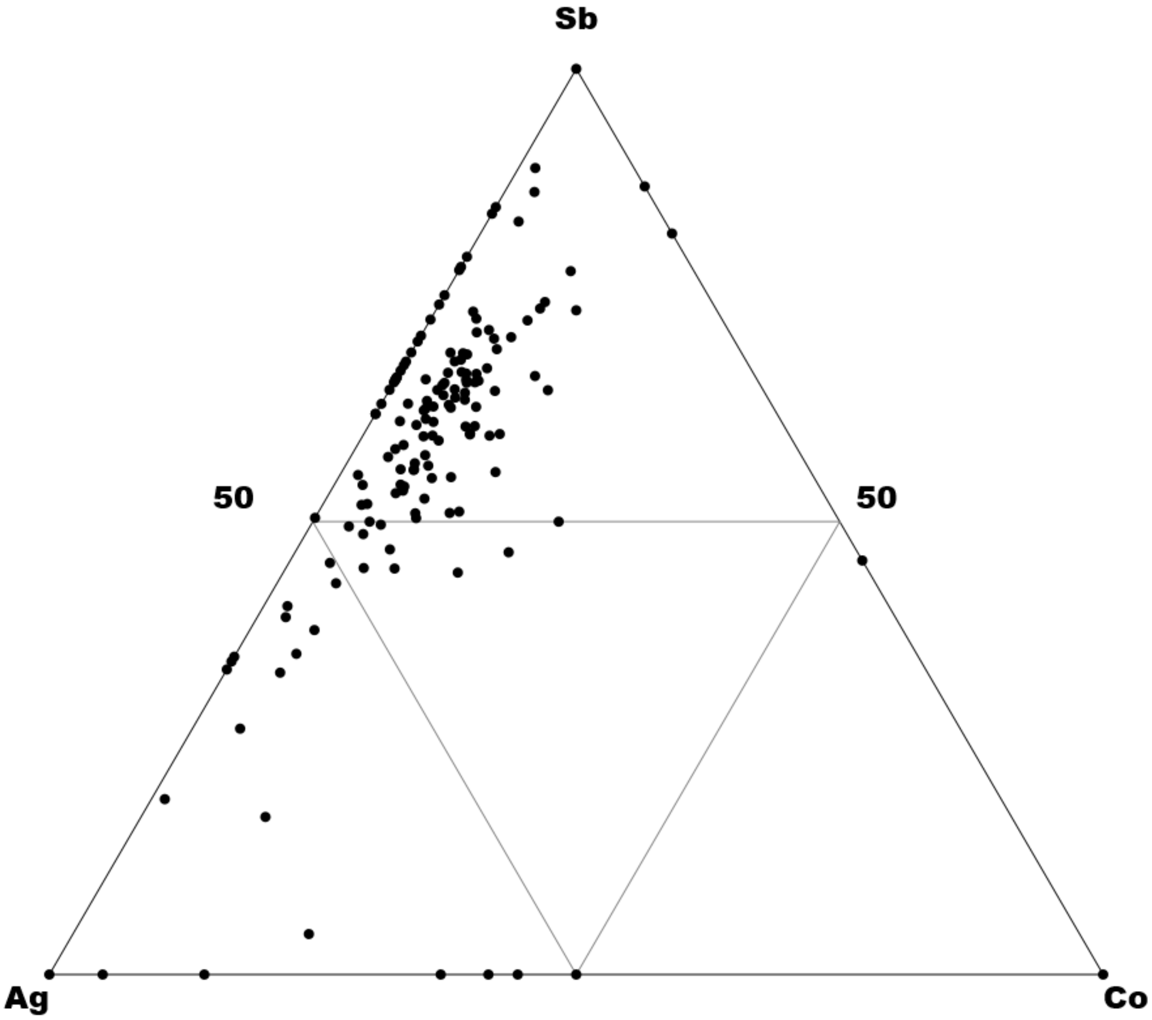

Fig. 58.: Ternary diagram comparing the trace elements measured by the ED-XRF

While the results of the trace elements analysis are rather negative in nature, they are still providing some information of the larger picture of the knee brooch production. By not creating any homogenic groups based on the trace elements, we can see a large diversity of source of the metals. Such diversity could be interpreted in one of two ways. First possible answer is that the craftsmen simply used ores from a wide variety of sources. Such an explanation is supported by the fact, that the brooch production seems to be decentralized and based around small regional workshops (Southern 2006, 78; Kehne 2007, 329). Second theory is that recycled material was frequently used for the production of Roman-provincial knee brooches. This mixing of material from several sources would result in ambiguous results of trace element pattern analysis.

Thanks to the drilled core sample analysis, the general material composition of the knee brooches can be characterised with a high degree of accuracy. 142 out of 148 sampled brooches are made of leaded tin bronze. The remaining six brooches are made of leaded tin brass. The lowest lead amount in the brooches is 4%, with the average being between 13.5–23%. In the histogram (fig. 59) a second peak of lead appears between 26.5–33%. Tin is always present as well, with the lowest admixture amount of at least 1.8%. The average tin amount in a Roman-provincial knee brooch is between 3.5–6%, as reflected by the tin histogram (fig. 60). Zinc, just like in the case of the pXRF results, seems to be an unintentional inclusion in most of the brooches as represented by the first peak of the zinc histogram (fig.61). However, as suggested by the following three peaks, some brooches contain an admixture of zinc anywhere between 2.7%–8.2%. A comparison of the average amounts of the main alloying elements, reflecting these values can be seen in the violin and box plots (fig. 62, 63).

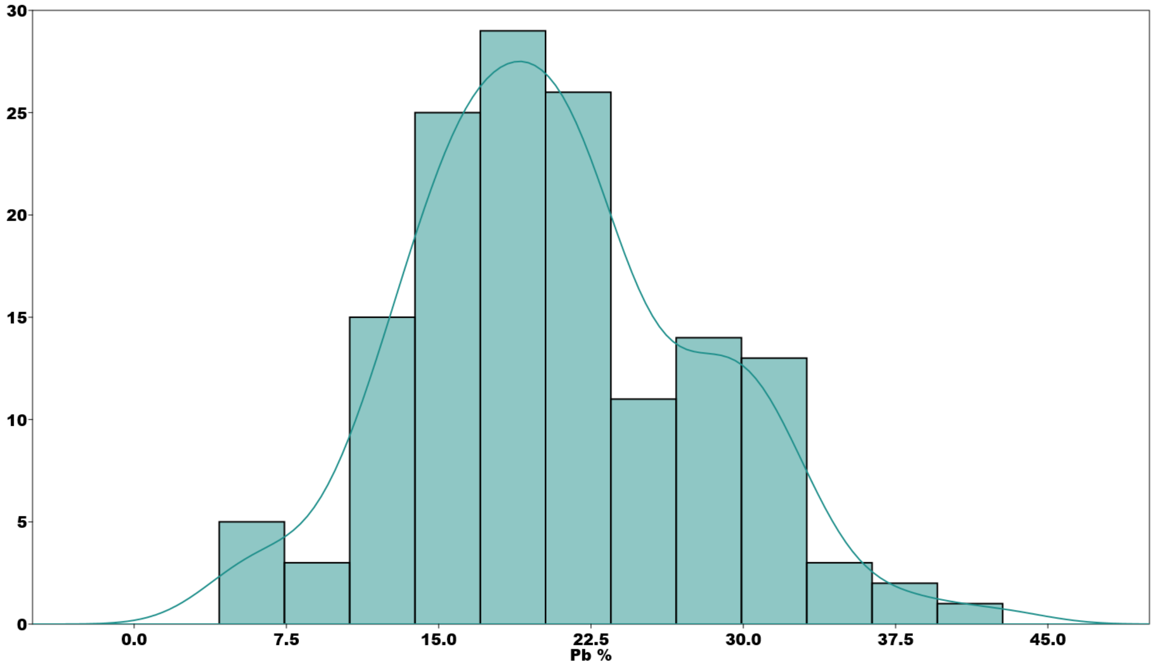

Fig. 59.: Histogram of lead amounts detected by the ED-XRF

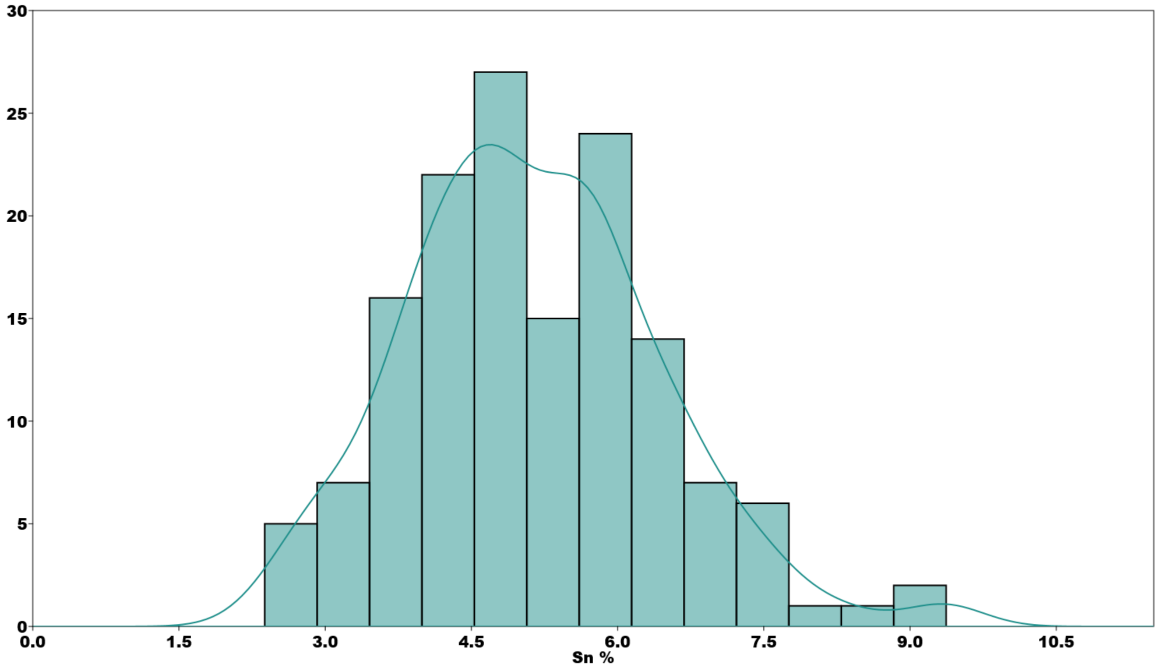

Fig. 60.: Histogram of tin amounts detected by the ED-XRF

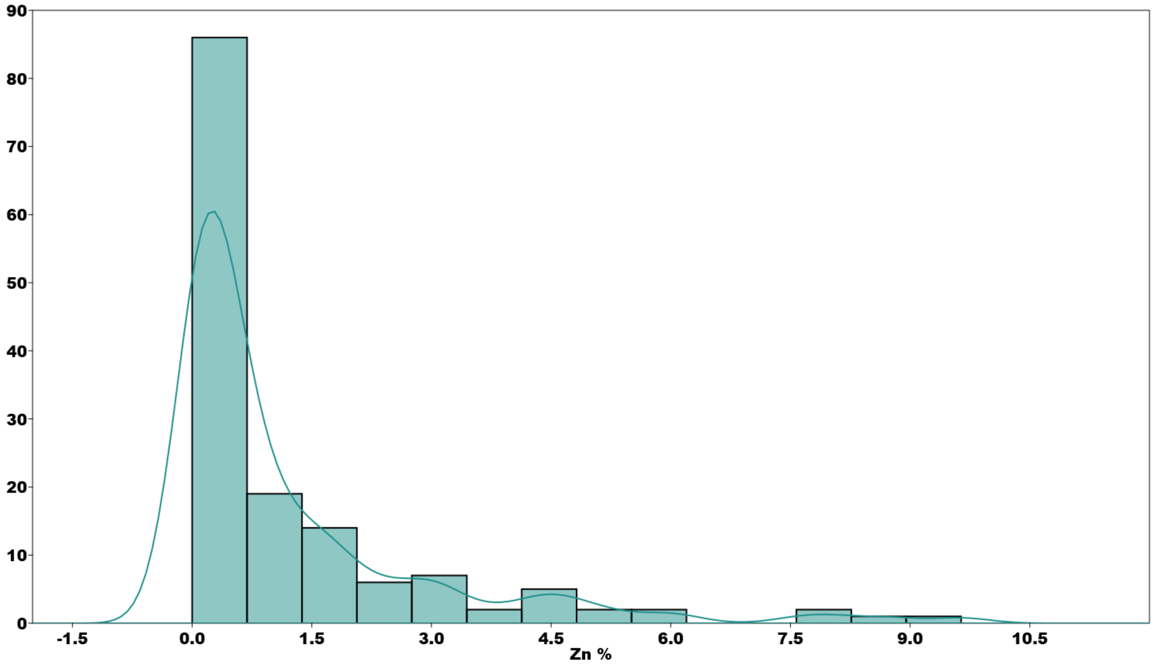

Fig. 61.: Histogram of zinc amounts detected by the ED-XRF

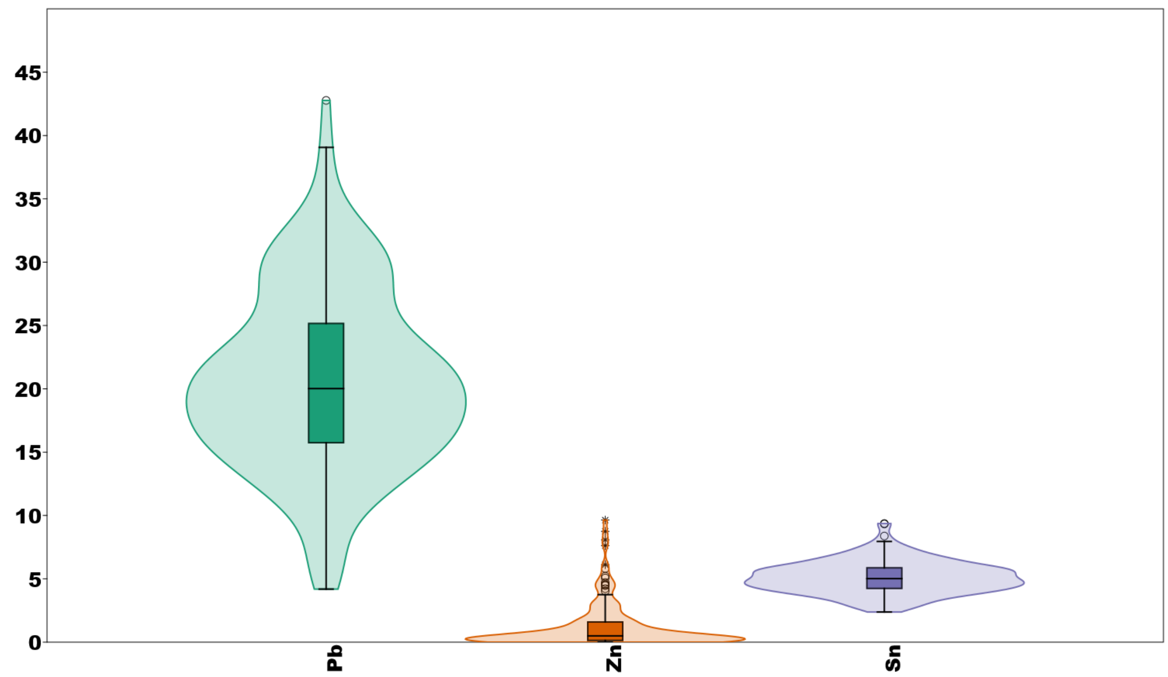

Fig. 62.: Violin and box plot comparing the main alloying elements measured by the ED-XRF

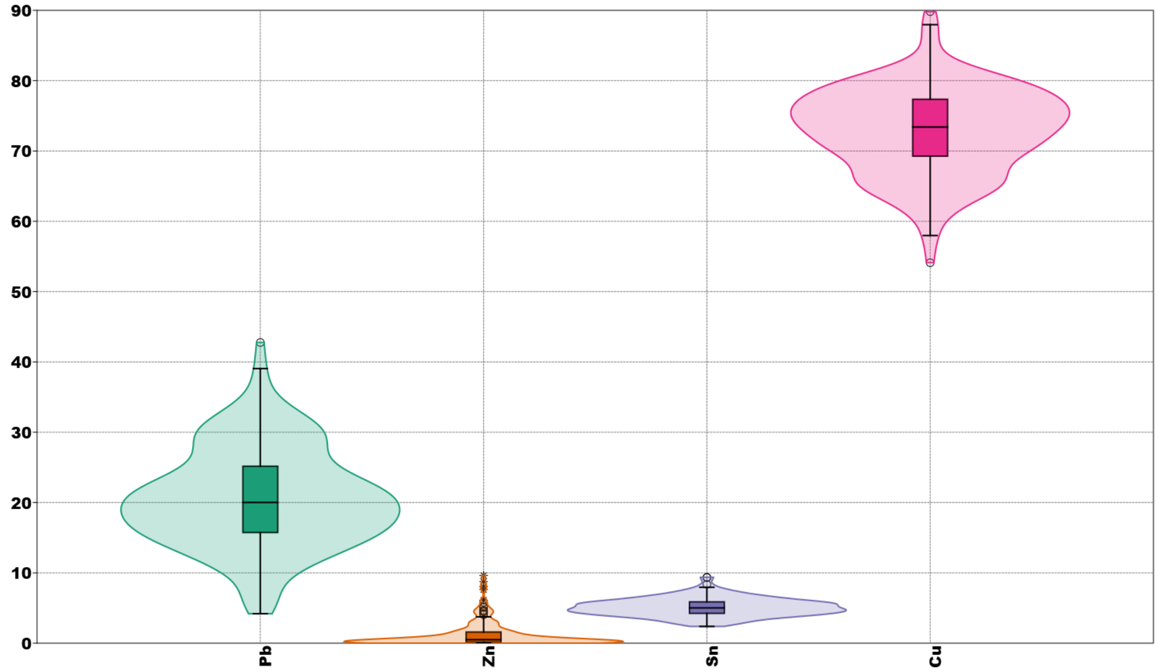

Fig. 63.: Violin and box plot comparing the main alloying elements, with consideration of copper, measured by the ED-XRF

6. Discussion

During the course of the research, several interesting questions arose from the material itself and the results of the analyses. Moreover, overcoming of methodological challenges posed by the analysed material or restrictions imposed by the lending institutions, allows for a comparison and evaluation of selected methods and methodology. Lastly, further research direction can be discussed, to enhance and expand the research.

6.1. Implications of material homogeneity: sign of craftsmen skill or state control?

As demonstrated, the Roman-provincial knee brooches display a very high degree of uniformity in their material composition. Both methods of material analysis attest the preferential use of heavily leaded tin bronze when crafting the knee brooches. Only two brooches from Carnuntum out of 257 examined brooches can be considered pure brass artefacts. Some admixtures of zinc are present, however they mostly only supplement and enhance the main tin-lead-copper alloy properties. Only in a few cases could we consider the artefacts as heavily leaded tin brasses.

Such a high degree of uniformity begs the question: “How was this achieved in ancient times?” The most probable answer is that the craftsmen had a high degree of control of the type of alloy they wanted to produce. Moreover, research on other types of objects (locks, toiletries, military camp equipment) suggests, that subtle associations were perhaps in place, regarding object typology and their ideal alloy composition (Dungworth 1997, 906–907; Roxburgh *et al.* 2016, 420). The control of craftsmen could also extend toward recycled material. Scrap metal which was to be recycled would have been identified primarily by its colour. Furthermore, some other ‘tests’ may have been in place to find out what alloy the craftsmen were dealing with. By approximately knowing what kind of alloy they were recycling, the craftsmen could produce desired alloys with a relatively high degree of precision (Dungworth 1997, 907).

Other possible answer is that of centralization. The Roman Army could have organised a centralised production of knee brooches for its soldiers, or the Roman Empire may have exerted control over distribution of raw material. The centralisation theory is regarded as less probable by contemporary researchers (Roxburgh *et al.* 2016, 420). It could be argued that the theory about the centralised production could be disproved by the numerous finds of workshops outside of Roman military sites, with finds of casting patterns, moulds and unfinished castings of the knee brooches (Schmid 2010, 34; Cociş 2019, 35–67). We can speculate however, that these local workshops could have simply fulfilled state or military orders, as modern militaries also order equipment from private companies. Such a *modus operandi* would hold up considering the specifically local types of knee brooches. The local workshops, upon receiving an order from the military, would simply produce the brooches in their local tradition. Moreover, even if there was no centralised distribution of knee brooches to the soldiers, this does not rule out the possibility of state control over raw material resources.

6.2. Impacts of mass production on the material composition and production patterns

The homogeneity of material composition may also be considered as another confirmation of the mass production of Roman-provincial knee brooches. As the hundreds of finds of knee brooches from the Limes area attest, they were a highly sought-after item. If the craftsmen were to satisfy the demand, they would need a standardised procedure to follow to achieve an optimal level of efficiency. This meant, perfecting the composition of the alloy, which had to have ideal properties for the type of object they were supposed to be moulded. By standardising the material composition, the craftsmen knew exactly what to expect in regard to the behaviour of the alloy during and after the casting. Therefore, instead of having to constantly adapt to new circumstances, the craftsmen desired to simplify their work as much as possible, to achieve the best results at a large scale with as few problems as possible. By not altering the material composition, unexpected defects could be avoided. This desire for standardisation can be seen in every step of the production process described in chapter 2.4. From creating the casting patterns, to creating re-usable two-piece moulds, ending with standardisation of the material composition. Everything aimed at streamlining the process of production, making it as efficient as possible.

The level of mass production and possible demand is further illustrated by traceology marks. It is not uncommon for finished brooches to display traces of faulty casting or improper refining after casting. These brooches were however still finished and worn, as demonstrated by fig. 25–30. All of these brooches, while defective in one way or another, were still worked after the casting (as attested by the polishing traces) and were equipped with a spring. Especially the spring is a testament to the brooches' active use. The springs were added after the body of the brooch was cast and further worked, therefore it would not have been added, if the brooch was not to be actively used. So even though the brooches were 'imperfect' they were still purchased and actively used and appreciated by their owners.

6.3. Methodological challenges and the importance of awareness of their impact on selected methodology

As mentioned in chapter 3, the researcher should be aware of the limits of the methods selected for research. The accuracy and dependability of the results acquired via the surface measurement with the pXRF has been discussed in chapter 3.2. What may not be accounted for, is the state of the artefacts themselves.

In Nitra some of the brooches were of bright yellow colour, displaying their original look. Originally, I ascribed this to aggressive mechanical cleaning. However, a possibility of chemical cleaning was brought to my attention. Such a possibility did not occur to me, as this method of conservation is no longer used. The impacts of this approach to conservation on the copper-alloy objects, has been discussed in chapter 5.1. The result of such treatment is almost complete depletion of lead on the surface of the brooches. As a result of this depletion, tin and copper show much higher values (tab. I.). These artificially enlarged values at the expense of lead then provide false results. In this case, the brooches would be interpreted as almost pure tin bronze, with very low lead admixtures.

If the chemical treatment was not brought to my attention and were it not for the core samples for comparison (fig. 64), these brooches may have been misinterpreted. Their interpretation would have been as a special group of knee brooches, as they would be the only ones with very low lead admixtures, when compared with the rest of the results (fig. 46). Such misinterpretation may have shifted the final conclusions of the research, and possible future considerations. This event only further stresses the importance of getting acquainted with selected methods and possible outside influences.

Cat. no.	Pb surface	Pb core	Zn surface	Zn core	Sn surface	Sn Core	Cu surface	Cu core
96	3,1	30,52	1,6	1,10	7,7	4,12	87,5	64,25
99	1,7	32,66	0,4	0,20	12,8	4,89	85,1	62,24
101	2,1	17,36	4,8	4,46	16,3	5,70	76,8	72,47
112	2,5	34,97	1,9	1,03	6,6	2,77	88,9	61,24
114	1,8	21,14	2,1	1,61	17,2	5,54	79,0	71,71

Tab. I.: Comparison of the absolute values from surface and drilled core samples analysis

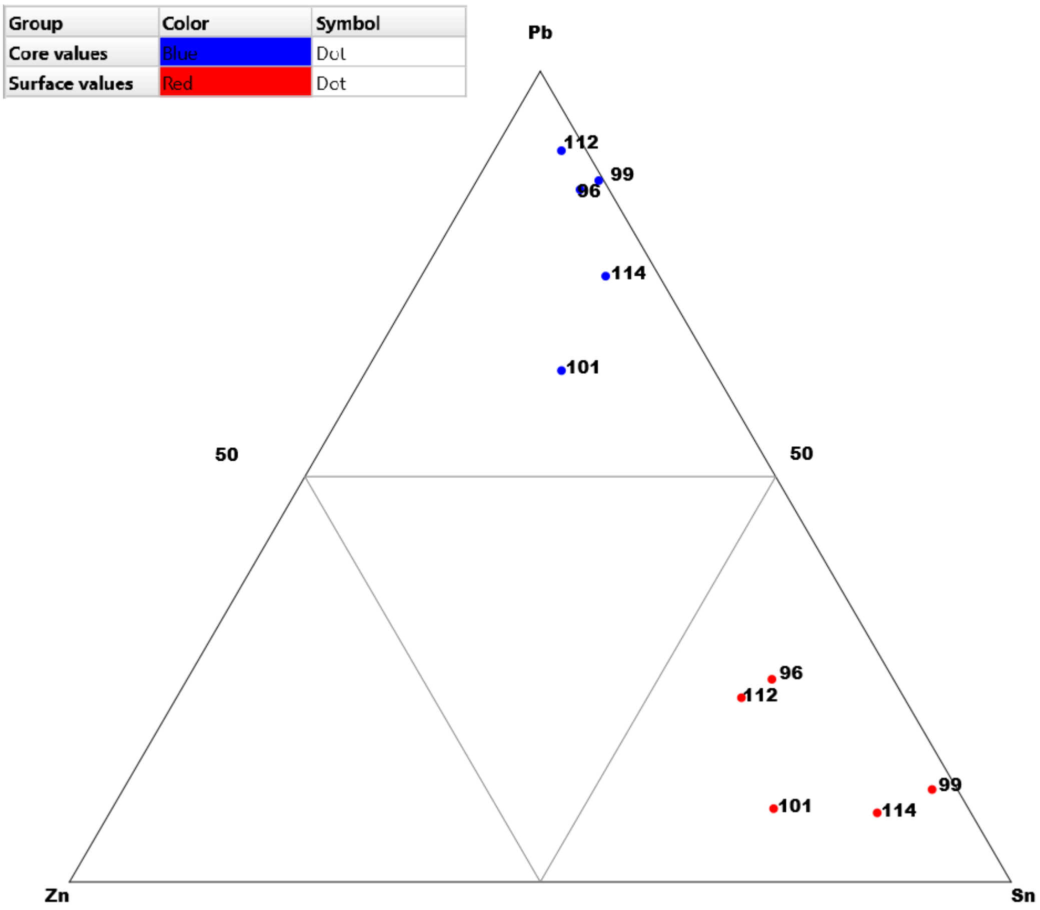

Fig. 64.: Ternary diagram comparing values from surface and drilled core samples analysis

6.4. Comparison of methods: to drill or not to drill?

In archaeology, there is an ongoing discussion whether the drilling or any other form of artefact sampling (for example sampling for metallographic analysis) is a worthwhile trade off, for the damage to the object. These damages are oftentimes unacceptable to the curators in museums and repositories, or to private collectors (Roxburgh *et al.* 2016, 411). Therefore, pXRF rose to the forefront of material analysis is the ideal non-destructive material analysis method. However, as demonstrated on the case of the Slovak brooches above, it cannot be always depended upon, even if its shortcomings are considered. In chapter 3.2. the various shortcomings of the surface layer measurements were mentioned. By comparing the pXRF measurement results with the drilled core sample values, the severity of these shortcomings can be verified and quantified.

Firstly, the effects of decuprification and dezincification of the surface can be compared to the core material composition values. Copper devaluation on the surface of the brooches is very well demonstrated by fig. 65. This histogram compares the two series of measurement to one another. As can be seen, the core copper values in the knee brooches according to the surface measurements are anywhere between 25% to 90%. The average value of copper should be between 40% and 60%, with extremes in copper values going both ways. However, the real values are far more constant and have a much lesser spread. The overwhelming majority of knee brooches keeps their copper content between 68% and 82%. When looking at the histogram, we can see that the real values would be considered as outlying extremes, if taken from the surface measurement perspective.

Dezincification is harder to observe on the Roman-provincial knee brooches. The brooches have a generally low zinc content; therefore, the impact of dezincification is hardly noticeable in most cases (fig. 66). It would appear, that the surface measurements have detected more low-zinc pieces. This is not the case however, as the pXRF failed to detect the zinc-rich brooches (above 7.5%), artificially reducing their zinc content. They would therefore be closer to the 0 sum of the histogram. The issue of dezincification can be best demonstrated by examining ten of the most zinc-rich specimens according to drilled core sample measurements (fig. 67; tab.: II). Here we can see that the zinc devaluation can vary in its severity, lowering the zinc amount by “a few percent” or by several orders of magnitude. The worst case scenario is represented by brooch cat. no. 106, which is a leaded tin brass brooch, with the zinc value of

7,62%. However, if the pXRF results were taken at face value, it would be classified as pure leaded tin bronze, as it has a zinc value of 0,8% on the surface.

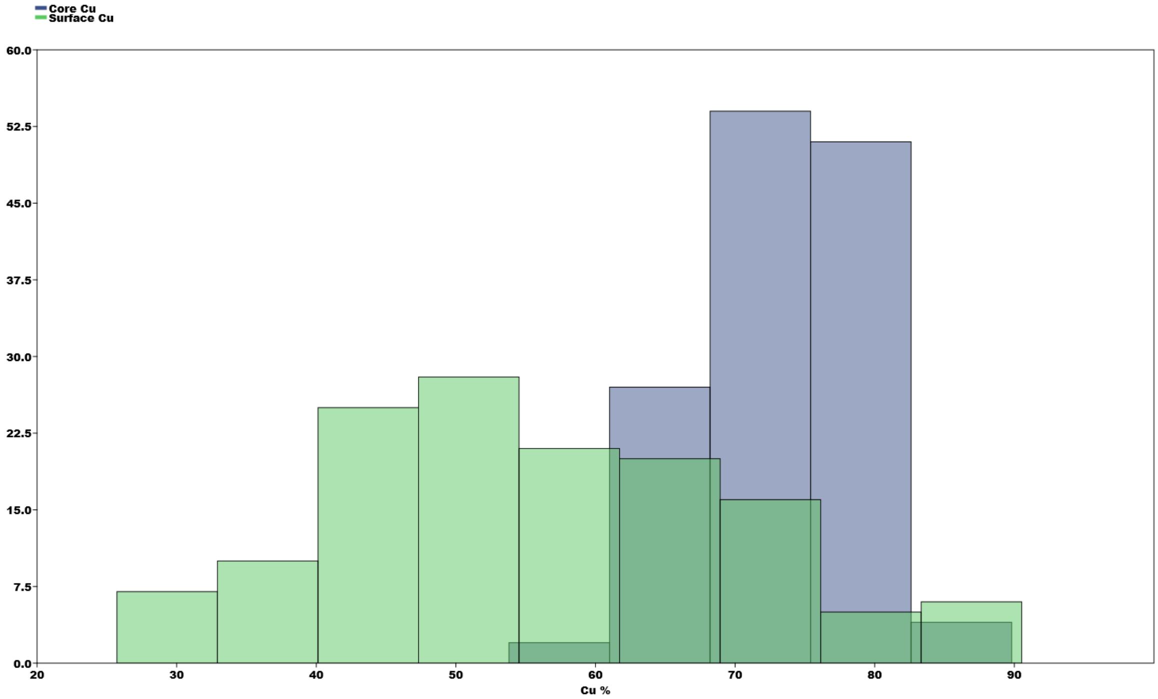

Fig. 65.: Histogram comparing surface and core values of copper

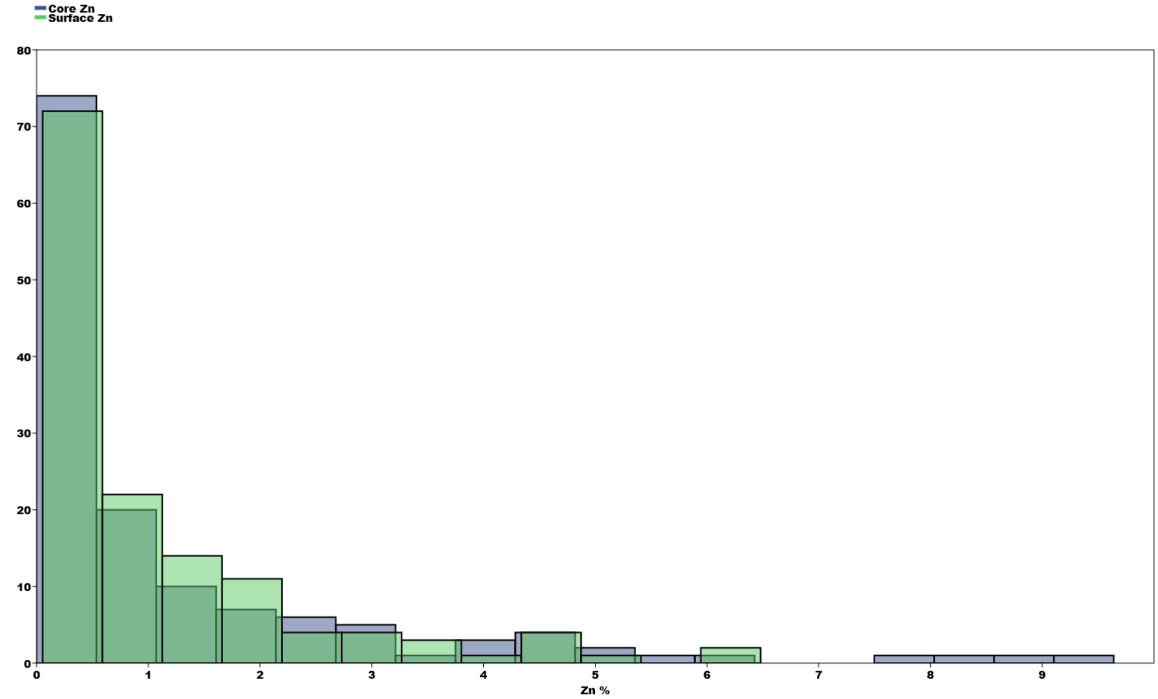

Fig. 66.: Histogram comparing surface and core values of zinc

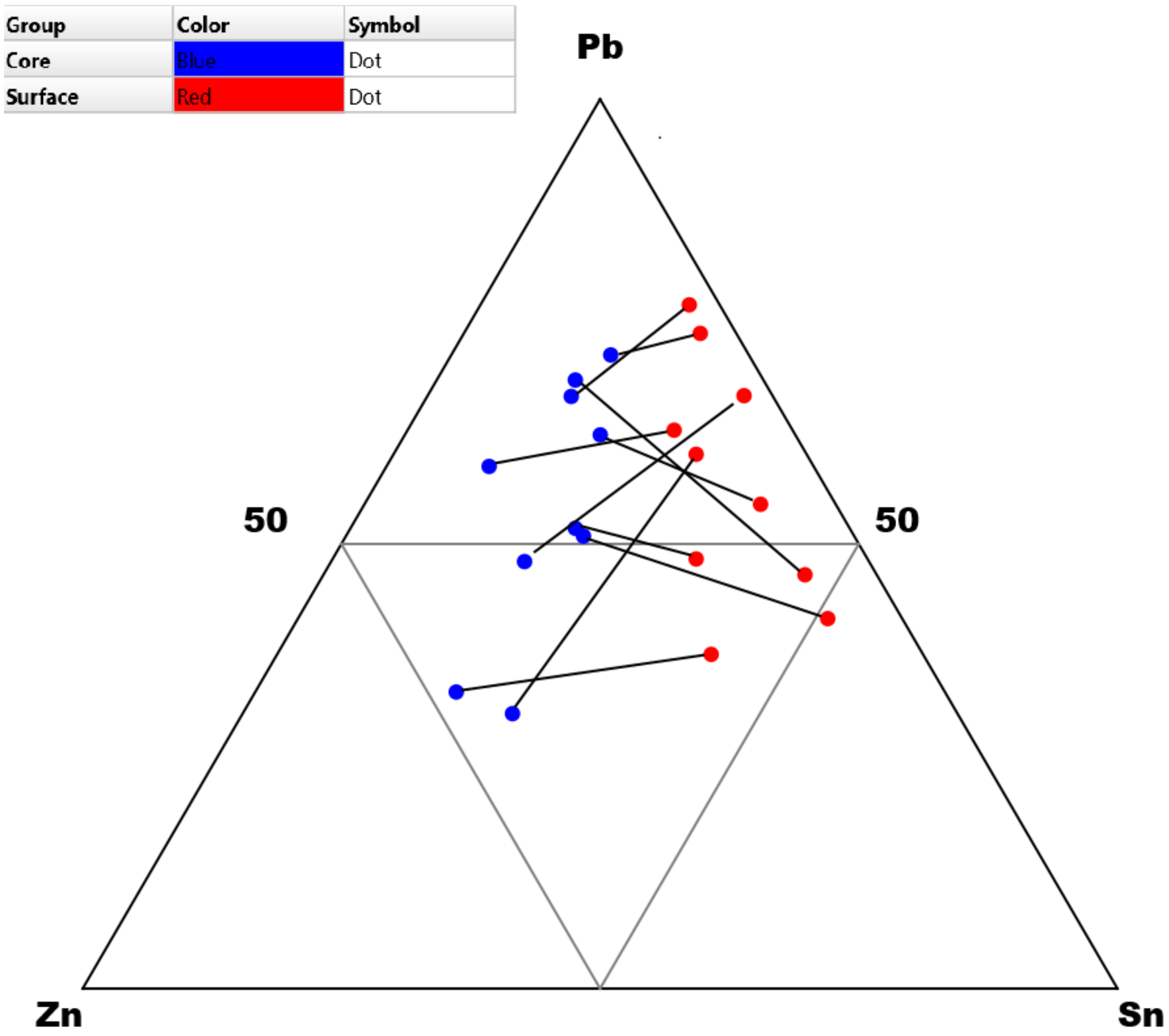

Fig. 67.: Ternary diagram comparing the surface and core Zn values of the 10 most zinc-rich brooches according to drilled core sample analysis

Cat. no.	39	49	66	73	75	102	106	118	126	272
Zn core	4,57	5,07	8,75	4,71	8,08	9,64	7,62	5,21	6,12	5,82
Zn Surface	2,1	1,6	6,1	2,2	2,7	6,4	0,8	3,6	4,8	4,9

Tab. II.: Comparison of absolute Zn values from surface and drilled core sample measurements

The above-described surface devaluations of elements result in artificial enlargement of tin and lead values in the pXRF surface measurements results. Tin benefits by far the most from the devaluation of copper and zinc values. It is overestimated by several orders of magnitude as shown by the tin histogram (fig. 68). While in reality, the tin value in the brooches falls between the low of 1.8% and the absolute maximum of 12%, the surface measurements blow these values out of proportion. The pXRF measurements suggest the severity of overestimation can be again best demonstrated by directly looking at the absolute values (tab. III.). Here we can see, that the tin is reaching almost ten times its real value on the surface as opposed to its real amount in the core of the brooches.

Lastly, lead is the second beneficiary of dezincification and decuprification. While the overestimation of real values does not reach the levels of tin, it still does take place (fig. 69). The real values are once again multiplied but in the case of lead usually “only” by a factor of two, with maximum being factor of three.

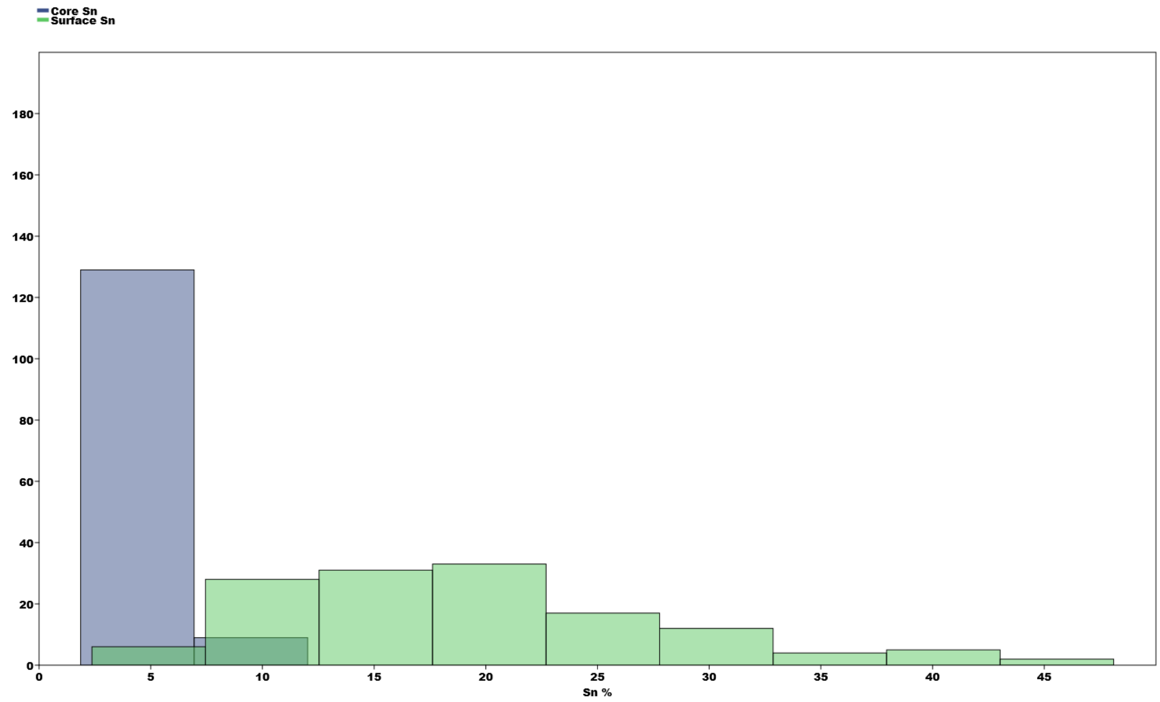

Fig. 68.: Histogram comparing surface and core values of tin

Cat. nr.	3	16	31	35	47	51	58	67	70	267
Sn core	4,02	2,92	5,85	7,40	5,63	7,05	4,54	4,86	5,60	4,24
Sn surface	35,07	33,95	39,1	43,1	47,6	42,4	37,5	38,9	41,7	36,9

Tab. III.: Comparison of absolute Sn values from surface and drilled core sample analysis

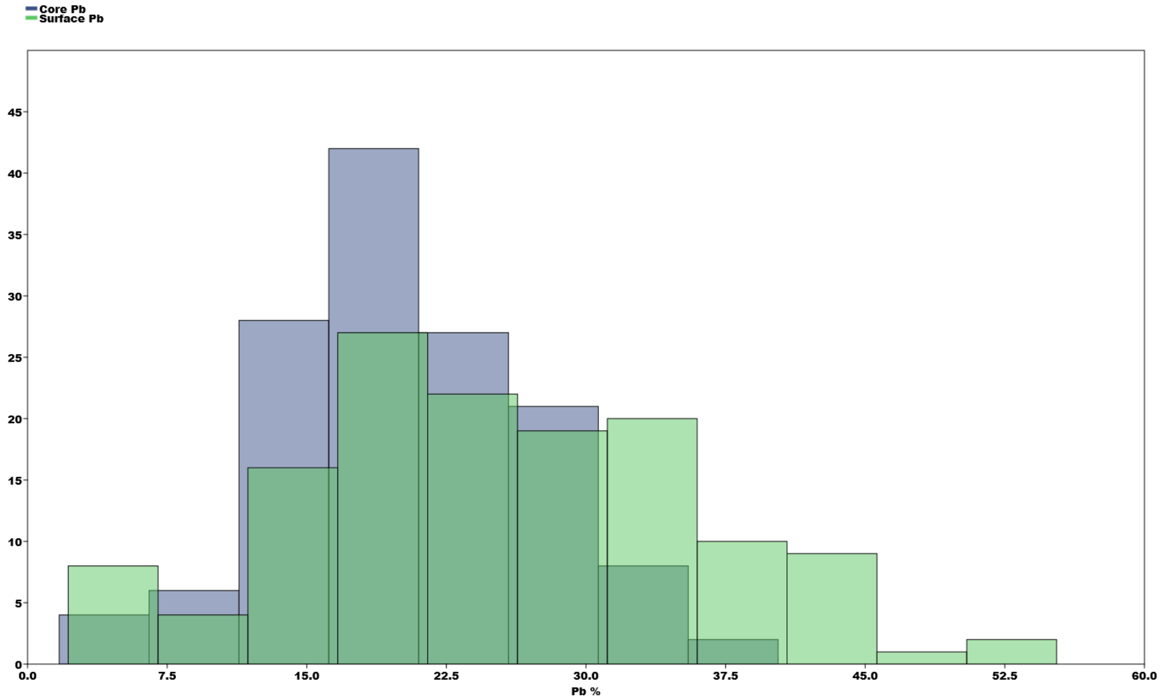

Fig. 69.: Histogram comparing surface and core values of lead

As demonstrated, there are too many variables to consider for the pXRF measurement results to be interpreted with any degree of reliability. The overestimation of certain elements, while devaluation of others cannot be reliably quantified and compensated for. Any surface measurements should therefore not be taken at their face value, and when possible, drilled core samples should be taken, to provide good quality material analysis data.

6.5. Future research

While the research question itself could not be properly tested and answered, the final results and interesting new insights do offer future research incentives. The main way the data would be enhanced would be by obtaining new quality data. By quality data one should understand knee-brooches with verified find contexts. The sites of interest should be sites in the Roman frontier zones. Especially the *cannabae* and *vici* in the vicinity of military installations would provide data of interest. The knee brooches from civilian contexts would broaden the perspective on the material composition of the brooches, as there does not seem to be any difference between the brooches from Roman military and Germanic settlement contexts. While the material composition data from Carnuntum were obtained by an inferior method and the brooches lack the find contexts, some slightly different trends in the bulk production can be observed. Furthermore, the two purely brass brooches, without an equivalent in the Barbaricum, suggest that a different *modus operandi* of the brooch production may have taken place inside of the Roman provinces.

The dataset would also benefit from more typologically diverse sample collection. The bulk of the examined brooches were of the Jobst 13C and Jobst 13D types. Fig. 53 has shown that there was a preference of material for the decorated and undecorated brooches. With the rest of the examined brooches being of types however, which occur as single pieces in the area of study, it is hard to make similar comparisons. By obtaining more diverse typological sample, more nuances could possibly be observed within the Roman-provincial knee brooch production. Here, the Roman sites which were occupied in the long term (unlike the temporary camps in the Barbaricum), would provide such types. While the selection of brooches for analysis was constrained by the state of conservation, in general, it can be said that Carnuntum had a much wider typological diversity of knee brooches. This diversity can be expected on other sites as well.

Lastly, obtaining data from find contexts deeper into the interior of the Empire could also be of interest. Firstly, the brooches would be with a high degree of probability coming from a civilian context. In the 2nd and 3rd centuries, bulk of the Roman army was station at Limes Romanus, guarding the borders from external threats. Any brooches would therefore probably be of civilian origin. Secondly, brooches from the interior could potentially be of different material composition. A hypothesis is offered, that the craftsmen from the interior would not adhere to the “standard” of the craftsmen in proximity to the Limes. Therefore, a series of knee brooches of different material composition could have emerged.

7. Conclusion

This thesis had the goal of answering the research question, of whether the material composition of Roman-provincial knee brooches changes depending on their find context. While they are generally regarded as an item exclusively associated with the Roman army, their diffusion into Roman civilian settlements and Germanic settlements suggests otherwise. The hypothesis was to be tested by conducting a relatively large-scale sampling campaign. The sampling would involve getting drilled core samples, providing reliable material composition information. This campaign was to encompass the Middle Danube area, due to material accessibility and geographical proximity.

The thesis started with setting the brooches into to context of the Roman dress, and its role in it. A concise historical and archaeological overview of the middle Danube area followed, providing the background behind the diffusion of the knee brooches all along the area of study. The knee brooches, already a very popular dress accessory was carried into the areas of modern-day Czech Republic and Slovakia by Roman soldiers participating in the Marcomannic wars. Following this, a detailed description of the manufacturing process of the brooches was provided, providing background for the traceology and material analysis study. Lastly, an overview of the typologies was given to

The following two chapters described the methods and methodology chosen to answer the research question. The methods chosen were traceology, pXRF surface analysis and ED-XRF drilled core sample analysis. All the utilised methods were characterised in detail, providing the reasoning behind their use, while also making the reader aware of their possible shortcomings. Information were provided on how the selected methods were utilised, and how the analyses were conducted.

Results were summarised in the following chapter. The issues with the material sources were described and addressed. Traceology analysis mainly provided insight into the production processes and its issues. An observation was made that the knobs, described in the literature as purely cosmetic element of the knee brooches, could have in some cases be remnants of the casting. The two datasets resulting from utilisation of two *X-ray fluorescence* methods had been described and evaluated.

Discussion addressed the results of the conducted analyses and considered their broader technological and socio-cultural connotations and implication. Furthermore, datasets of two different methods allowed for their direct comparison, pointing out the inadequacies of the pXRF surface analysis method. Lastly future directions for the research material composition of Roman-provincial knee brooches were suggested.

In conclusion, the research question could not be answered due to lack of material from the Roman civilian contexts. Therefore, one of the three suggested material groups is completely missing from the dataset. This was due to the unexpected difficulties with getting access to material from Austrian sites, except for Carnuntum. Nonetheless the thesis provided interesting data, showing only on the brooches form Roman and Germanic sites, that material preference based on the supposed customer does not seem likely. With exception of a few brooches, most are made of highly leaded tin bronzer. However two brooches from Carnuntum with unknown find context do indicate the possibility of brooches made of pure brass. Furthermore, the methodological comparison had brought new data towards the discussion of the usefulness of pXRF surface measurements in comparison to the drilled core samples.

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9. Sources of images

Fig. 1.: A funerary monument depicting a woman wearing two Doppelknopffibeln on her shoulders and two knee brooches at the centre of the dress as decorations, Neumarkt im Tauchenland, Austria (Ivleva 2017, fig. 4.2.)

Fig. 2.: A funerary monument depicting a roman male (on the right) wearing a knee brooch on his right shoulder, Brâncovenești, Romania (Cociș 2004, Pl. CLXXVII/1a)

Fig. 3.: A typical roman-provincial knee brooch, type Jobst 13C, Račice-Pístovice (photo: The institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

Fig. 4.: Map depicting the Germanic incursions and Roman counter-offensives during the Marcomannic wars (https://www.lovecpokladu.cz/club-articles/22495/4.jpg, visited: 09.05.2025)

Fig.5.: Map of sites providing Roman-provincial knee brooches for research (author: N. Mořkovská)

Fig. 6.: Difference in colour between brass and tin bronze (generated by Chat GPT AI)

Fig. 7.: Unfinished casting of a knee brooch with the sprue cup connected to the socket of the brooch of the brooch (Cociș 2019, Pl.120/17)

Fig. 8.: Unfinished casting of a knee brooch with the sprue cup connected to the foot of the brooch (Cociș 2019, Pl.149/157)

Fig. 9.: Illustration of brooches in the casting moulds (author: M. Grňová)

Fig.10.: Brooches cat. no. 38 and 40 of type Jobst 13C (left) and Jobts 13D (right) (photo: The Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

Fig. 11.: Knee brooch of type Petković tip 19/B (Petković 2010, T. XXVI/3)

Fig. 12.: Knee brooch of type Petković tip 20 (Petković 2010, T. XXVIII/1)

Fig. 13.: Diagram depicting the principle of the X-ray fluorescence analysis (https://wpstaq-ap-southeast-2-media.s3.amazonaws.com/portableas/wp-content/uploads/media/1564961314572.jpg, visited 09.05.2025)

Fig. 14.: Unsuitable surface for traceological analysis of brooch cat. no. 44

Fig. 15.: Surface suitable for traceological analysis of brooch cat. no. 35

Fig. 16.: LMI Toolscan forensic microscope at the Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.

Fig. 17.: Keyence VHX 5000 digital microscope at the institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i. (Photo: M. Lelovič)

Fig. 18.: Niton™ XL3t XRF Analyzer (photo: M. Lelovič) (https://www.thermofisher.com/TFS-Assets/CAD/product-images/F85667~p.eps-650.jpg, visited 09.05.2025)

Fig. 19.: Hole 1mm in diameter in the bow of the brooch after sampling, captured by Keyence VHX 5000

Fig. 20.: Size of obtained sample

Fig. 21.: ElvaX Pro tabletop XRF analyzer (https://elvatech.com/wp-content/webpc-passthru.php?src=https://elvatech.com/wp-content/uploads/2018/01/pro2.png&nocache=1, visited 09.05.2025)

Fig. 22.: Samples in Eppendorf test-tubes prepared for XRF analysis

Fig. 23.: An incompletely cleaned brooch with soil residues, cat. no. 213, Carnuntum (Photo: Martijn Wijnhoven)

Fig. 24.: Knee brooch etched by acid, cat. no. 176, Iža-Leányvár (Photo: The Institute of Archaeology of the Slovak Academy of Sciences, Nitra)

Fig. 25.: Unevenly cast headplate, cat. no. 11, captured by Keyence VH 5000

Fig. 26.: Offset catchplate, cat. no. 82, Captured by Keyence VH 5000

Fig. 27.: Visibly misaligned casting flash on the bow of cat. no. 47, captured by Keyence VH 5000

Fig. 28.: Casting flash on the body of cat. no. 58, captured by Keyence VH 5000

Fig. 29.: A cavity in the back of the bow created during casting cat. no. 77, captured by Keyence VH 5000

Fig. 30.: A crack in the back of the bow and the spring socket of cat. no. 82 created during casting, captured by LMI Toolscan

Fig. 31.: Traces of polishing on the back of the bow of cat. no. 40, captured by Keyence VH 5000

Fig. 32.: Traces of polishing on the headplate of cat. no. 40, captured by LMI Toolscan

Fig. 33.: Traces of polishing on the catchplate of cat. no. 40, captured by LMI Toolscan

Fig. 34.: Traces of polishing on the back of the foot of cat. no. 40, captured by LMI Toolscan

Fig. 35.: Traces of the tool used to create the tremolo chased decoration on the headplate of cat. no. 40, captured by LMI Toolscan

Fig. 36.: The notch on the headplate of cat. no. 59 for a decorative silver wire, captured by Keyence VH 5000

Fig. 37.: Hammered-out foot with chased decoration, cat no. 14 (photo: The Institute of Archaeology of the Czech Academy of Sciences, Brno, v. v. i.)

Fig. 38.: The notch on the headplate of cat. no. 59 for a decorative silver wire, captured by Keyence VH 5000

Fig. 39.: Tinning on the headplate of cat. no. 78, captured by Keyence VHX 5000