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From the Fabricae of Augustus and the Workshops of Charlemagne: A compositional study of corroded copper-alloy artifacts using hand-held portable XRF

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From the Fabricae of Augustus and the Workshops of Charlemagne: A compositional study of corroded copper-alloy artifacts using hand-held portable XRF

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Is archaeology a science or an art?

"Neither - it's a vendetta"

- Mortimer Wheeler[1]

1 Quoted in Hopkirk. P., *Foreign Devils on the Silk Road, The Search for the Lost Treasures of Central Asia* (1984), 170.

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Chapter 1

Introduction

This thesis focuses on the copper-alloys used to make some of the more frequently found artefacts recovered from The Netherlands. A number of additional objects recovered from the Baltic States of Estonia and Latvia and also the United Kingdom are included as well for comparative reasons. I hope that this article based thesis will be of value to archaeologists interested in Roman and early medieval copper-alloy craft production, but also be of relevance to archaeological scientists interested in the development of portable X-ray fluorescence spectrometry (also known as pXRF or hand-held, HHpXRF). This is because its intention is also to address some important issues regarding the study of corroded copper-alloy artefacts with an interdisciplinary, typological and compositional approach. The following chapters present six peer reviewed articles and a book chapter discussing the composition of a large number of brooches and other personal artefacts dating from the late Iron-Age, until the end of the early middle ages. This was made possible through the application of an interesting new scientific approach using HHpXRF. The remainder of this introduction sets out the background for the research, the selection of the method, materials and equipment, the projects aims and its relevance. It then introduces the remaining chapters and gives a short account of the contribution of the co-authors.

The analysis of copper-alloys is one of the longest ongoing research projects within archaeological science. Traditionally this research, which has become known as provenance studies, has tried to link objects with distinct metal sources, from specific geographical areas. This is based on an assumption that some characteristics of a finished object (e.g. trace elements or isotope ratios) are diagnostic enough to track the raw materials back to their original geographic source (Pollard 2018, 16). According to Bray *et al.* (2015, 202), however, this approach can be demonstrated as being 'fatally flawed'. This is because this line of study tends not to take into consideration past recycling practices whereby metals from different sources could be mixed together, leading to a misinterpretation of the results; a consideration that has been overlooked in many previous studies (Pollard, 2018, 38). Traditional provenance studies can still produce meaningful results however. Objects that can be shown to have had simple life trajectories (Pollard 2018, 45), made from fresh raw materials with little or no recycling, can still produce useful results. But from the Bronze Age onwards, increased hoarding practices have been linked to widespread metal recycling, suggesting that the recognition of recycling practices in their own right could be a fruitful area of research (Radivojević *et al*. 2018). Rather than traditional provenance studies therefore, detecting change in the 'life history' of copper-alloy objects is an alternative approach, studied through the chronological and geographical nature of 'metal flows' (see Bradley 1988; Needham 1998; Pollard 2009). It is a more socially embedded approach as it explores composition through the intentional actions of crafts people, in the deliberate addition of alloying ingredients. Copper can be deliberately alloyed with tin to make bronze, or with zinc to make brass, with or without the further addition of lead. Furthermore bronze and brass can also be melted together to make an alloy called gunmetal, which then contains copper, tin and zinc, again with or without lead. Whilst gunmetal can be a deliberate alloy choice in its own right, it is frequently associated with the recycling of scrap metal, where old bronze and brass items are melted down to form new objects. All of these choices alter both the working characteristics of an

object during production and its final colour (see Bayley and Butcher 2004, 14-16). Tin and zinc were mined in quite distant geographic regions (from each other) in Roman and medieval times and were probably transported widely in the form of bronze and brass ingots, before being turned into objects (see Penhallurick 1986; Boni and Large 2003). If the 'metal flow' for a region, at a particular time, shows a preference for tin or zinc dominant alloys then something could be inferred about the direction in which the raw material is travelling. The relationship between object typology and alloy can also be explored in terms of consistency (or otherwise) in choice, including the identification of chronological or geographical change and objects whose alloys deviate from the local norm. This is a meaningful approach because it explores the more socio-technological context of production in terms of human interactions with the craft (Bray *et al*. 2015, 208).

The scale of crafting and production activities for any particular period (typically explored through the typological study of ancient artefacts), are our best indicator of the complexity of a past society, especially in identifying economic change (Wickham 2005, 700). The study of ancient artefacts from the Roman and Medieval periods, primarily those of metal, also plays a crucial role in archaeology in matters of identity construction and the study of ancient mobility and migration (e.g. Lucy 2005; Kershaw 2009; Knol 2011; Ivleva 2016). The distribution of artefacts has been used as a proxy for human mobility for a long time and primarily metal costume accessories are seen as valuable indicators in this study. This is not so true of bulk goods like pottery however, that were transported in large quantities by traders and were distributed widely by economic networks, but not necessarily connected to the movement of people. Costume accessories on the other hand were made in smaller numbers and were less likely to have been shipped as bulk goods. Whilst objects must have frequently travelled on the clothes of their owners, perhaps indicating mobility or migration (e.g. Ivleva 2016), there are further complexities that must be taken into consideration when addressing identity construction. Costume accessories could well have been included in exchange events such as marriage rituals and other life cycle events. Retiring soldiers, pilgrims or other travellers, when returning to their homelands, might have brought souvenirs back with them, perhaps as "returning gifts" for friends and family, which when worn could change a persons status without them assuming the identity of the people from which the objects originated. Therefore the role of a costume accessory in creating an identity, as envisaged by the producer, could be quite different from the wearer. Furthermore objects can become venerated over time, perhaps becoming heirlooms; curated by people several generations removed from the original owners (see Caple 2010), whose meaning when worn may associate more with memory than the present day. That said, the distribution maps of find locations of personal costume accessories can still be a valuable indicator for the travel distances covered by mobile individuals and objects, and can therefore be a proxy for the extent of human contact at a given time.

From a historical perspective, interest in the transformation of the Roman world in the west, into the nation states of the modern era, has been ongoing for nearly a century (Dopsch 1937; Pirenne 1939; Duby 1974; Hodges 1982; Wickham 2009). The processes that led to the post Roman or medieval 'recovery' cannot be fully understood without a better understanding of craft production and its role in the economy of the time. The structural characteristics of the Carolingian empire, the first post Roman Empire in the west have recieved much attention in recent years (McCormick 2001, Devroey 2003, Wickham 2005, Story 2005, Devroey 2006, McKitterick 2008, Hodges 2012 and many others). The debate on the nature of the economy of this period (which extends into the Ottonian and Viking Age, ending therefore in the 12th century)

is more than a century old now and various aspects have been discussed and considered more or less important according to various authors, such as agrarian production, trade, craft production and elite demand. The social organisation of production and more specifically the amount of control by the elite, of the output of the lower classes, be they peasants or craftsmen, took centre stage in the debate. The position of craftsmen, at times considered to be 'middle class' and crucial to the development of the economy, is subject to debate as well (see Calmer 2001; Verhulst 2002, 29-84; Hansen *et al*. 2015). An insufficient answered question is: what contribution did craft production make (compared to agricultural production and trade) to the economy as a whole? There is no straightforward answer to this question and this thesis cannot answer it either. Various aspects of the total field of craft production will have to be analysed and both historians and archaeologists have yet to fully tackle the problem. Archaeologists have commonly used the remains of production sites (mainly pottery) as well as finished products to analyse craft production. Traditional research used macroscopic analyses of material remains and their distribution through various regions. Modern research includes the use of scientific methods such as XRF to bring this research one step further. The socially embedded approach presented in this thesis, makes a contribution towards tackling one aspect of the problem by providing a better understanding of the choices made in copper-alloy craft production.

The objects

Copper-alloy artefacts played a very important role in identity construction and brooches (also known as fibulae) in particular are a very visible type of personal-dress accessory. They were used by ancient communities for many centuries, especially during the Roman and early medieval periods where their forms and types change significantly over time and geographic region (see Almgren 1923; Frick 1992; Weetch 2014; Ivleva 2016). For the Rhine basin (covering The Netherlands, parts of Belgium and Northwestern Germany), over 20,000 brooches have been recorded (Heeren and van der Feijst 2017, 8). This has led in turn to the formulation of many hundreds of typological classes, sorted into chronological groups. Although a late Iron Age example was included for comparison (Nauheim type, Heeren and van der Feijst 2017, 42), the departure point for the brooches in this thesis is the early Roman period, dating to the last half of the first century BC (Spoonbow, Bow on spring-tube, Aucissa series, Heeren and van der Feijst 2017, 49, 60, 94 respectively). The latest bow brooches included from The Netherlands are from the late 2nd century AD (Germanic Rollenkappe, One-piece Knee, Van Buchem 23, Heeren and van der Feijst 2017, 115, 121, 127 respectively). Then a selection of middle to late Roman period disc brooches from Estonia and Northern Latvia are presented, dating between the 2nd to 5th centuries. These disc brooches are subsequently reorganised into a new typology building on previous scholars work (e.g. Vassar 1943, 70-71; *Шмидехельм* 1955, 146-199; Laul 2001, 108-114). For those early brooches found in The Netherlands, the main question is whether regional, or civilian production could be identified versus production at military centres. This is because there are some close parallels between some brooch types and military related objects, suggesting that some were made in military workshops (Haalebos 1986, 43; Müller 2002, 29). The choice of alloy is important to this question, as brass is thought to have been produced on an industrial scale by the Romans through the invention of a new technique called cementation, and initially reserved for use by the state in the production of coins and military gear (Bayley and Butcher, 2004, 13; Dungworth, 1997, 903). Any seperation between the use of brass or bronze along typological lines

would add to this debate. A 'Roman' alloy if it exists could be compared to alloys more confined to local or 'tribal' brooch typologies. The questions asked of the later Roman disc brooches found in Estonia and Northern Latvia are a little different. Apart from questioning the organisation of production, variation in regional culture is looked for through comparing compositional, stylistic and typological differences with their geographical find locations. Then the results are compared with the published evidence from outside this region, and the influences brought about by contact with the southern Baltic areas and the much more distant Roman Provinces are subsequently explored.

The next set of brooches included in this thesis are early medieval in date and the study returns once again to The Netherlands with an analysis of Carolingian/Ottonian period disc brooches, many of which are thought to bear Christian motifs, which rapidly gained popularity in the region overtaking earlier Merovingian forms (e.g. Roxburgh *et al* 2014, 23). These disc brooches were at their most popular between the late 8th to 10th centuries but gradually declined in use during the 11th to 12th centuries. The variety of forms and types grew enormously during these centuries, indicating that they played an important role in creating a variety of new identity constructions. The earliest of this type of brooch is known as the *Heiligenfibeln*, or Saints brooch, which was popular during the 9th century but may also have had a late 8th century origin (Bos 2006a, 767). These are included in this study as well as the more common *Kreuzemailfibeln* or enamelled cross type, which date to the 9th and 10th centuries (Bos 2006a, 730). The organisation of production is again looked at for these brooches, based on morphological and typological consistency as well as alloy choice. Then from this departure point, the exchange system in which they circulated is explored, with a particular emphasis on the Christian nature of their motifs. The brooch theme continues with a geographic, compositional and typological comparison of disc and equal-arm brooches (also known as Ansate brooches, see Bos 2006; Thörle 2001) from the island of Walcheren in Zeeland, with the other regions of The Netherlands. The disc brooches studied here date between the 9th and 11th centuries and a comparison is made between those found at Domburg and Middelburg (Walcheren) and those found at Westenschouwen on the neighbouring island of Schouwen-Duiveland, and then the rest of The Netherlands. Again suggestions are put forward regarding the organisation of production of the brooches found on Walcheren against its historical past. This in turn leads to discussions surrounding cultural identity within an interconnected North Sea world. A study of early medieval equal-arm brooches also takes place. This brooch type and its many subgroups are typically found in Western Europe, including Belgium, Britain, Northern France and The Netherlands (Bos 2006, 455; and Weetch in press). There are two relevant typologies for equal-arm brooches. The first is by Thörle (2001) who classifies the brooches from the Frankish areas and the second is by Bos (2006) who classifies the brooches from the Frisian areas. Thörle dates the brooches from Walcheren between the 7th to 10th centuries and associates them to the Western Frankish areas of Neustria, Burgund and Aquitania. Bos, for the Frisian coastal areas, divided the classification into early and late forms based on the early ones being the more robust of the two. He subsequently dated the early ones to the 6th and 7th centuries and the later ones to the 8th to 11th centuries. He also considered the later ones to be most numerous during the 9th century (Bos 2006, 458). A combined typological and compositional comparison was undertaken to further compare the Walcheren brooches against these two geographically different classifications. This tests the hypothesis put forward by Bos (2006, 455) that the more northerly Fresian brooches are regionally different to those from

Northern France, Belgium and Walcheren. Following this the organisation of production is discussed, in particular ideas surrounding local versus regional manufacture. The equal-arm brooches also form part of a discussion on the identity of the peoples living on Walcheren at that time.

Moving away from brooches, the next artefacts to be included are a group of zoomorphic mounts tentatively dated between the 9th and 11th centuries (see Capelle 1976, 28; Webley in press). These mounts are found in large numbers on Walcheren, and similar ones are also distributed along the southern coastal areas of the North Sea, but in much fewer numbers. The origin of these mounts, their original function and their relationship with expressions of identity, are discussed in detail through a combined typological and compositional study. The organisaton of their production is also discussed and comparisons are made to the other types of finds on the island. A number of Stirrup-strap mounts were also found on Walcheren and these are included in the thesis. This type of mount is considered to have an equestrian function and examples of certain subgroups appear both in England and The Netherlands (see Williams 1997, 105). A typological and compositional analysis enabled discussion to take place regarding local versus non-local origins. The choice of alloy could also be compared with the other find types contained in the study. Lastly, ring and dress pins are also investigated, but with a more detailed comparison to an assemblage from England (see Capelle 1976, 17; Rogers et al 2009). The pins are seperated in the first instance into two functional types. Those with shaped decorative heads and those with wire rings threaded through their heads. The wire ring type may have been attached to a chain, perhaps working in a pair with another one at the other end of the chain. The ring, which is sometimes an adjustable slip-ring type, could also have been used to attach to a belt or other personal garb. Dress pins on the other hand do not attach in the same way. They were possibly used in closing or holding together items of personal clothing (again see Capelle 1976, 17 and for comparison Ross 1991; Rogers et al. 2009). The Walcheren examples are thought to date from the 7th to 11th centuries. Pins are quite a common find around the North Sea coastal areas, and the way production was organised for those found on Walcheren is explored once again from a typological and compositional perspective. The analysis is taken further with a comparison between a contemporary group of pins from England. A discussion takes place regarding mercantile contact between the two coasts as well as local or centralised production in an interconnected North Sea world.

The methodological approach

There have been many scientific objections to the use of HHpXRF in Archaeology, especially over its reliability and validity. A major objection is that highly accurate quantitative data is not capable of being obtained on corroded copper-alloy surfaces (Nicholas and Manti 2014, 8). Furthermore it has been suggested that it is an unacceptable side of science, that it is in fact flawed, as archaeologists are too ready to accept the invalid or unreliable data coming from these machines (Speakman and Shackley 2013, 1435). Although this debate is a few years old now, there is still scepticism of analytical performance - typically at conference settings and less formal meetings. A relevant departure point for summarising this debate starts with the very important question posed by Stephen Shackley (2010), regarding the level of reliability and validity present

in the fast growing use of HHpXRF. This question was triggered by his observation that its increased use in archaeology had created a divided community, locked in a heated debate that was fuelling animosity between the two sides. Shackley proposed that the problem centred around the potential misuse of this quickly appearing technology, by a community that was not prepared for it intellectually, primarily through a lack of appropriate scientific training. More specifically he suggested that it was not appropriate for archaeologists to just simply purchase a HHpXRF machine and go out shooting anything they wanted (and apply the results) without having the benefit of years of compositional analysis behind them, or an equivalent training. Therefore a basic protocol was needed (discussed in more detail in Davies et al. 1998; Shackley 2011), especially in establishing reliability and validity for analysing archaeological artefacts.

Firstly he warned that validity cannot be provided without demonstrating that the analyses are undertaken with a demonstrable understanding of the instruments settings and parameters; the results of which could subsequently be compared against readily available callibration standards. Secondly that the magnitude of error introduced by varying artefact surface morphology and size must be known and within acceptable limits. Thirdly that the reliability and stability of an HHpXRF's internal system needs to be better defined, requiring testing outside of a vendors own service parameters. Lastly that the nature of the analyses, be they qualitative or quantitative needs to be understood, particularly in the light of qualitative analyses generally being rejected, mainly due to the risk of missassignment caused by inter-observer error. Quantitative analysis is needed (for sourcing studies at least) based on emperically callibrated datasets that can provide elemental weights expressed as a % value. Shackley ends with a call to establish research protocols for this newly emerging technology and warns of the dangers of the wholesale acceptance of HHpXRF; that a solution is needed that combines the different approaches of the physical scientist and archaeologist, against a potential background of 'scientific ignorance' or indeed 'anti-scientific' sentiment.

The artefacts used by Shackley to elucidate the argument outlined above (for studies involving correct source assignment) were not made of copper-alloy but of obsidian, a naturaly occuring glass like material used by ancient peoples in the production of various tools. That said, the issues outlined earlier are valid for archaeological applications in general, and especially those made of copper-alloy. In addressing Shackleys concerns, two HHpXRF machines from different manufacturers, were tested for use in Aegean obsidian sourcing studies by Ellery Frahm *et al*. (2013). Their conclusions were that the accuracy and precision of both machines were suitable for this area of study even though both used 'off the shelf ' factory settings. Frahm quickly followed up by publishing a more detailed discussion regarding of the validity of this 'off the shelf' approach, using the sourcing of near eastern obsidian fragments as its case study (Frahm 2013).

The first issue addressed by Frahm was one of low accuracy and precision. Accuracy can be described as how close a measurement is to the 'true' value of a particular quantity. This would be important in measuring the 'true' value for the metal ingredients in a copper-alloy brooch for example. Precision, on the other hand is the ability of the machine to repeat its measurements in a precise way under identical conditions. This becomes important when you want to see discernable clusters in the compositional measurements. Frahm's argument followed that for HHpXRF machines, which are less powerful in term of wattage than laboratory based devices (a sacrifice needed in order to make them portable), any applied analytical technique, regardless of equipment type will be subject to a base level of variation (e.g. statistical fluctuations) that limit its precision.

Limitations to accuracy (such as a flawed callibration), on the other hand become a concern when attempting to compare measurements to previously published data. The second issue was that of callibration and correction. The x-ray counts (the count or intensity of the radiation of a specifc wavelength, detected by the XRF device) are turned into elemental concentration data. A correction or callibration model is needed in order to correct for a number of complex phenomena to do with the way for example X-ray emissions, absorbtion and secondary fluorescence are handled by the machine (see Shackley 2011 for more). This model is used to turn the x-ray counts into numerical concentration data that can be used by the operator. But it is unclear when and how this step of the process is done, particularly if it is done within the instrument before outputting the data, or later during database processing. This raises issues about confidence in the internal consistency of the data. The third issue was fundamental to XRF itself. The size of measurement error can be related to the size and shape of the artefacts being measured. Thin artefacts and those that do not fully cover the instruments detector window are harder to analyse as they may not experience the full energy of the electron beam. Variations in the surface morphology of an artefact can also introduce error. The ideal solution is for the samples being measured, to be polished flat, be big enough to cover the detector window and to be thick enough to be able to fully absorb the X-ray emissions. This ideal, especially in the case of copper-alloy artefacts would of course require destructive samplng of selected specimens. Frahm's experiment with two analysers from different suppliers was conducted to address these issues. The experiment was deliberately intended to test the capability of HHpXRF in 'off the shelf' conditions. That is, to accept the issues mentioned above on a range of complex artefacts and to determine if the analysers are sufficently precise enough to produce valid measurements for assigning obsidian flakes to different sources. I. E. to sort them into distinct groups. This turned out to be the case, that HHpXRF was precise enough to apply valid source assignments even though optimum conditions and 'best practice' were not followed. In conclusion Frahm suggested that the use of HHpXRF was neither intrinsicly valid nor invalid, that it is the application, the choice of question, that makes it valid or not.

The observation by Frahm that the aplication of HHpXRF could still produce valuable results, despite its sub-optimal 'off the shelf' approach, may have sat well with one side of the "divided community" but it quickly prompted a published reply by Robert Speakman and again Shackley (2013). They argued that the form of science put forward by Frahm was unacceptable, as he still ignores the real issues behind validity and reliability, by suggesting that 'internal consistency' (e.g. relying on a machine's internal callibration or factory settings) was enough to answer archaeological questions. Speakman and Shackley further argued that this was "playing at science," that HHpXRF use needs to conform to internationally published standards in order for it to be valid. They subsequently described Frahm's approach as 'silo science,' meaning that data produced by researchers working in this way was 'self-contained,' produced in a bubble, whereby outside independent validation could not take place. What they did agree upon however was that most archaeological users lacked relevant experience and tended to take a 'trust me because my results are internally valid' approach, that the users principle understanding of HHpXRF was that it was a 'black box,' that could analyse samples and subsequently generate useful looking numbers. This, according to Speakman and Shackley was poor science and suggest that these portable machines were originally designed to be used as 'black boxes,' to be used by inexperienced operators, but intended for the mining and metal-recycling industries, not archaeological research.

In this respect they were never intended as true research instruments and if they are to be used in sub-optimal conditions as proposed by Frahm, then they questioned whether publishing could be considered at all. Furthermore they called on all peer reviewers of manuscripts containing HHpXRF research to seriously scrutinise them for invalid and unreliable data.

Frahm once more responded to Speakman and Shackley's concerns in a follow up paper (2013a), asking the question are we dealing with geochemistry or archaeology? Frahm argued that the goal was to determine wether a HHpXRF analyser could sort obsidian flakes in relation to their sources. That it was not to achieve geochemical accuracy and that Speakman and Shackley were wrong to associate correlation, reproduceability and validity to this aim. He went on to explain that reproduceability does not equal accuracy and results do not equal raw data, in seperating geochemical versus archaeological avenues of investigation. Validity is also suggested as being confused with accuracy, that attempting to match 'true' values based on standards, is a measure of accuracy, not validity. Validity should be defined as the suitability of a machine's ability to measure values in relation to the context of the question being asked of it. More specifically he suggests that the archaeological approach is primarily concerned with sorting artefacts in relation to typology, also to associate them to geographic origins, before attempting to associate any patterning with past human habits or decision making. It is not concerned with the gathering of reasonably accurate geochemical data that can be directly comparable to other studies and collected into one large database. Furthermore Frahm suggested that past studies have been largely limited to the laboratory, which is problematic in itself in terms of limiting the direction of questioning, mainly due to the internal organisation of people, resources and materials. Also laboratory techniques are often limited to analysing small percentages of an overall assemblage from which interpretations must be drawn. Conversely he suggests that the growing use of HHpXRF will in fact increase reproduceability, as more independant researchers become involved. It will also allow a much higher percentage of an assemblage to be measured, which in turn will allow for better interpretation. In conclusion Frahm calls for a break away from the limitations of laboratory based paradigms and suggests that in order for HHpXRF to be successful in archaeology, users need to work within an appropriate methodology. This conclusion however is at odds with Speakman and Shackleys call to work within the 'traditional' laboratory XRF based paradigm.

The debate that I have briefly summarised is very important when considering the application of HHpXRF on corroded copper-alloys. Firstly there appears to be a sociological, Kuhnian issue at play in terms of a crisis over the emergence of a new scientific paradigm (see Kuhn 1970, 66-76), especially with its lack of acceptance within some areas of the archaeological community. The two groups could be described as those who deem themselves as having "appropriate" scientific training, who typically assume the high ground in the debate, versus those "untrained" archaeological users with lack of scientific parity. But critically there are some genuine technical issues that need to be addressed as well.

The main issue is that of corrosion depth on corroded copper-alloy surfaces (also refered to as the patina). HHpXRF is a surface measuring device whereby the analytical information only comes from the first 20μm (Feretti 2014, 1754). This shallow depth of measurement is typically well within a corroded surface layer which severely affects accuracy if the aim is to measure the absolute composition of the alloy (ibid 2014, 1756). Aside from corrosion, the surface morphology of the object, as well as the varying distance between the object and the x-ray source,

are also issues said to prevent HHpXRF from producing highly accurate quantitative data (Nicholas and Manti, 2014, 8). This quantitative approach can only be achieved in fact by the destructive removal of the patina and the altered outer surface from which the patina grew; a practice that is resisted by museums and artefact owners, thus limiting the number of samples available for study. It is also based on the assumption that gaining a 'true' measurement of the objects composition is central to solving historically based archaeological questions.

The alternative as proposed by Feretti (2014, 1757) is the non-destructive route, where the artefacts are not harmed. Although measuring the corroded layer means that the results are much more variable, more measurements can be taken both in terms of a single object and also much larger numbers of objects within museum or depot collections. This approach involves working with clusters of measurements rather than individual ones. This has the benefit of being able to identify trends (or choices) in alloy use, and subsequently to identify outliers from these trends. This qualitative, or semi-quantitative approach is also in line with the conclusions put forward by Nicholas and Manti (2014, 9). They suggested that whilst HHpXRF is not capable of producing fully quantitiative results on corroded surfaces, the apparatus is still able to produce qualitative data that enables basic alloy classification and therefore provides a similar sorting mechanism to that proposed by Frahm earlier.

These technical issues imply that HHpXRF is a suitable analytical tool to answer questions regarding the basic choices craftsmen made in terms of copper-alloy production (e.g. brass or bronze), when studying large artefact assemblages. This conclusion clearly supports the argument put forward by Frahm, but in doing so opposes Speakman and Shackley's suggestion that quantitative analysis is the only acceptable avenue of scientific enquiry (2013, 1435). Thus, the use of HHpXRF in the study of corroded copper-alloy artefact has to align itself with Frahm's argument and reject that put forward by Speakman and Shackley. But this is not a sufficient place to leave it. Speakman and Shackley's concern about archaeologists 'playing at science' is very valid. There is little to stop an enthusiastic archaeologist, in posession of an HHpXRF device, measuring a corroded copper-alloy object and subsequently interpreting the measurements, incorrectly, in a quantitative manner. It cannot be assumed that archaeologists automatically have awareness of, or a working understanding of the issues mentioned above. Furthermore there are no easily accessible protocols or guidelines as yet which enable them to formulate their questions accordingly. So in this respect Speakman and Shackley's call on the reviewers of peer reviewed journals to be especially vigilant, is a valid one. This discussion is continued further in chapter 2 where a reconaissance oriented protocol is proposed as a way of positioning the application of HHpXRF (employed in a qualititative or semi quanititative manner), alongside, but not replacing, more rigourous laboratory methods.

The dataset

The methodology required that both typological and compositional data be analysed together. This meant that a database had to be created with a relatively large number of variables. Microsoft Excel was decided upon to build the database with, due to its ease of use and familiarity by all those involved in the project. A particular requirement of the database was that data could be entered very quickly in the field. This is because the time required to gather compositional data by

HHpXRF was around 60 seconds per object, meaning that large numbers of measurements, typically several hundred in a day, could be made onsite at a storage facility or museum. This fast throughput of objects created two problems. Firstly there needed to be enough objects coming out of storage to keep up with the demand, otherwise the HHpXRF device could be standing idle for long periods of time. This was not so problematic when direct access to the storage areas was available, but was potentially an issue if the process at a museum or storage facility meant that an individual staff member was responsible for moving objects in and out of storage. This problem would mainly be due to a lack of awareness of the speed of throughput of the device and hence the numbers of items that were required to be moved during a visit. The problem was reduced to some extent by communicating the large-scale nature of the activity in advance. The second problem was that of collecting typological and morphological data as the objects became available for the HHpXRF. The identification, measurement and photographing of each object (for further analysis post-visit) takes several minutes longer than needed for the HHpXRF analysis, quickly leading to a backlog in the data gathering activity. The methodology needs the presence of typological and morphological data for linking to the compositional data in order for it to work. The compositional data is relatively consistant because it is downloaded from the device either in the field or at a later date, then put through a normalisation procedure. The typological and morphological data also needs to be as consistent as possible to gain the best results. The best way to achieve this was to create a basic dataset in the field as the objects were becoming available, then to fill in the missing details after the datagathering event had taken place. This was more reliable and consistant than taking already existing data in the posession of the museums or storage depots. It was more reliable in the event of the existing data not becoming available in a timely way, or subsequently not being useful enough to assign to the compositional data. To gather this information in the field was more consistant than taking and merging a number of different external datasets, whose information would have been gathered by a wider number of individuals, leading to more variation in description and typological assignment. The quality of the data, as it was being created, could also be checked whilst in close proximity to the objects and if neccessary the artefacts could be reassessed much more easily than from a distance and some time afterwards.

The database subsequently required a merging of the following typological, morphological and compositional information. Firstly and quite key was the need for a unique identification number for each artefact (Finds ID). Furthermore this identification number had to have already been formulated by the museum or depot and be their standard way of locating and identifying the object. This is critical if the results of the project are to be reproducible or validated by other researchers in the future. Following on from this an easily identifiable name was needed for the different collections from which the objects were accessed (Collection). This could typically be the name of a museum, or other owner such as an archaeology company or metal detectorist. Then a consistantly identifiable name for each object (Object type) was required. This frequently required a choice as many artefacts are named differently in different publications, or translate differently between languages. The important factor was to be consistent in the use of a name once decided. The next requirement was for a longer description including sub group names and other distinctive features (Description). Again consistency of terminology was important for the later analysis. Two more columns were also included to aid geographic and chronological analysis (Culture name and Broad Period). The culture names could typically be Roman, Merovingian, or Carolingian/Ottonian, but with some local variation such as Migration or Germanic. Subsequently

a column for assigning a broad date for an object was included, with due consideration of the dates proposed by relevant publications. A column was also added to list the name of the publication from which the typology was assigned, including the typological group or subgroup number where possible. Then some columns including morphological details were required, including measurements of length, width, thickness and diameter (recorded in mm). Because of the corroded, distorted and fragmentary nature of individual artefacts, these measurements could only be taken as a guide for inter-group comparisons. Measurements were taken using a caliper device with plastic rather than metal jaws, which was to reduce or eliminate damage to the artefact surfaces when in use. Each time a measurement is taken by the HHpXRF device a unique analysis number is automatically generated. This number (XRF no.) is critical to the success of the database. This is because the typological and morphological data is gathered seperately to the internal generation of the compositional data. As each object was measured by the device, the unique XRF number needed to be logged against the unique Find ID number so that the composition data, once outputted and transfered into a spreadsheet, could be matched to the correct typological and morphological data. The correct matching of these two numbers was key to preventing missassignment of composition to object. The next column is also important in preventing misassignment as it records the location on the object that the measurement was taken (XRF Loc.). To maintain as consistant an approach as possible, artefacts of the same or similar type were presented to the device in the same way. But this was not always possible due to missing parts of an object leading a measurement being taken from a different location. This was noted in the database. More than one location could also be required, such as measuring the front or rear of a brooch, or a corroded, patinated area contrasted with clean patina free area. When these types of situation were encountered a note was required in this column to assist in later analysis. Finally the bulk and trace elements recorded by the device could be added (each element having its own column). These are presented in numerical format and expressed as a percentage of the sum of the individual elements. The important columns contain the data for the bulk elements found in copper-alloys, these were Copper (Cu), Tin (Sn), Lead (Pb) and Zinc (Zn), followed by Gold (Au), Silver (Ag) and Iron (Fe) as contaminants or traces of surface treatment caught up in the corrosion layer. The only trace element that was found to be relevant was Mercury (Hg) as its presence associates with gold plating in a process known as fire gilding.

Aim

To contribute to our understanding of Roman and early medieval craft organisation, through the choices made in the production of copper-alloy personal items. More specifically the aim is to investigate variability in the control of copper-alloy composition, in particular the variation between bronze, brass or gunmetal, and to identify regional or chronological differences between groups of artefacts. Subsequently the intention is to gain new insights into the way production was organised, including the supply of raw materials, and to identify differing cultural associations through the choice of alloy.

Research Goals and Questions

The research goal is, by necessity limited, because basic knowledge about the production processes and organisation of craft production is still in its infancy, although in recent years an increasing amount of research is filling up this knowledge gap. The research focuses on the analysis of copper alloy objects, mainly personal belongings such as brooches, which were produced on a massive scale. The primary research goal is to analyse various aspects of the production process of these objects by analysing their chemical composition and the variable use of different base materials. The degree of variability (or standardisation) of the ratios of the metals used in production will help elucidate the technical and raw material choices available. From there, the social organisation of production and the various (exchange) mechanisms that brought about the observed distribution of objects can be elaborated upon. The main focus therefore is on production practice, then exchange and identity. The expected variability in alloy composition will be analysed in geographical, temporal and organisational terms.

Subsequently the following research questions have been formulated:

a) Is it possible to construct an interpretative framework for the use of HHpXRF on copper-alloy, particularly regarding the issues concerning its use on corroded artefacts?
b) What compositional variation is there in large numbers of similar copper-alloy objects?
c) Is there evidence for deliberate control of copper-alloy composition (perhaps between different types of objects)?
d) Is there evidence for chronological change in alloy use from the early Roman period to the beginning of the Middle Ages (1st century BC - 12th century AD)?
e) Can regional differences in composition be seen (perhaps eluding to the availability or otherwise of raw materials)?
f) What are the potential supply lines for the sources of raw materials?
g) To what extent can compositional variation, across geographical and temporal distributions, allow new insights into the social organisation of production, or the identity of those wearing the finished objects?

Relevance

It has been demonstrated above that changes in craft production can be used as a proxy for changes in economy and society. This engages with the debate surrounding the emergence of the western economy after the end of antiquity and how Europe came into being.

Chapter outline

There are 9 chapters in this thesis including the introduction and conclusion. The structure of the thesis is article based, and presents a collection of 6 peer reviewed articles and 1 editorially reviewed book chapter, all of which are either printed or in press. After the introduction, Chapter 2 presents an article on methodology, then the following chapters 3 to 7 present the results of a series of case studies that not only engage with the debate over HHpXRF, but also employ appropriate lines of typological questioning. After chapter 2 the chapters are set out as far as possible in chronological order. Chapters 3 and 4 present research on early and late Roman brooches respectively. They also draw their measurements from brooches found in two distinctly seperate geographic regions (The Netherlands and Estonia/Latvia) and from two HHpXRF machines, from two different manufacturers (Niton and Brucker). Chapter 5 returns to the Netherlands and also deals with brooches but from the early medieval period. Chapters 6 to 8 then concentrate in more detail on one particular assemblage again from the early medieval period. The artefacts found in and around Domburg, The Netherlands. The artefact types include disc fibulae, equal arm fibulae, dress pins, ring pins, stirrup-strap mounts, and zoomorphic mounts (discussed in more detail in chapter 6). Lastly Chapter 8 draws a comparison between the dress pins found at Domburg and those found in England. HHpXRF compares the alloy compositions of typologically similar pins from these two seperate regions.

Chapter 2 presents an article entitled, A Non-destructive survey of early Roman copper-alloy brooches using portable X-ray Fluorescence Spectrometry. It is authored by Marcus A. Roxburgh, Stijn Heeren, Hans D.J. Huisman and Bertil J.H. Van Os and was published in *Archaeometry*, 2 July 2018, doi.org/10.1111/arcm.12414. Archaeometry is a scientific peer reviewed journal published on behalf of the Research Laboratory for Archaeology and the History of Art, University of Oxford. This paper argues that portable X-ray fluorescence spectrometry (pXRF) is a suitable elemental measurement technique to study the production of copper-alloy artefacts. However, rather than try to imitate the accuracy and precision of laboratory techniques, it is more beneficial to deploy it in a survey role, one that attempts to model chronological and geographical changes within large quantities of artefacts. To achieve this, the effects of corrosion and the issues surrounding surface measurement were investigated to determine their affect on this type of research. Analyses on early Roman period brooches gathered in the Nijmegen region of the Netherlands were subsequently compared with published data.

Chapter 3 - Early Roman copper-alloy brooch production: a compositional analysis of 400 brooches from *Germaina Inferior.* Authored by Marcus. Roxburgh, Stijn. Heeren, Hans Huisman and Bertil Van Os. It is published in the *Journal of Roman Archaeology*, Volume 29, 2016, pp 411-421. The *Journal of Roman Archaeology* is a peer reviewed journal published by Cambridge University press and focuses the Roman world between c. 700 B.C. to 700 A.D. In this paper we present a compositional study of a large number of copper-alloy brooches, undertaken in 2014 using Handheld X-ray Fluorescence Spectrometry (HHpXRF). The brooches, which come from the area of Nijmegen, date from the Late Iron Age until the 2nd c. A.D. Our aim is to explore the ways in which artefact production was organized both in the context of Roman centres and in the countryside. The link between alloys and workshop organization is discussed before the methodology and results are presented. The results are then discussed, leading to the formation of several hypotheses regarding the organization of workshops that produced metal artefacts.

Chapter 4 - Disc Brooches of the Roman Iron-Age, from the *tarand* cemeteries of Estonia and North Latvia. Authored by Maarja Olli and Marcus Roxburgh. It is published in *Lietuvos Archeologija*, 2018, T. 44, p. 39-70, which is a scientific peer reviewed journal, publishing in the Baltic region. Disc brooches from the Roman Iron Age are very diverse in style and execution throughout Europe. Their diversity in the *tarand* cemetery areas of modern day Estonia and North Latvia is also very high, with many unique traits and some multidirectional influences being observable. Therefore, regionality in the *tarand* cemetery areas was studied through these diverse brooches in order to see whether some motifs, typological groups, or alloys were more preferred in some areas than in others. A typological and compositional approach (using HHpXRF) was adopted for this. Based on the distribution of certain groups of disc brooches, their surface treatment, and the direction of the influences, two distinct areas could be seen: Northeast Estonia and Southeast Estonia–North Latvia. The study shows how people in the *tarand* cemetery areas adopted foreign techniques and stylistic features in accordance with local preferences and used them in their local culture.

Chapter 5 - The Cross & the Crucible: The production of Carolingian disc brooches as objects of religious exchange? Authored by Marcus A. Roxburgh, Hans D.J. Huisman and Bertil van Os and published in *Medieval & Modern Matters*, vol.5 (2016) 117-132. This is a peer reviewed Journal by Brepols focusing on the archaeology and material culture in the Low Countries from the middle ages to the modern period. In this article, aspects of the production and exchange of Carolingian/Ottonian disc brooches are examined through an analysis of 281 brooches selected from collections across The Netherlands. The composition of the brooches was measured with a HandHeld-XRF device and the results showed a sharp deviation from the alloys seen in those from earlier periods. The results across all geographic areas consisted of a mixture of copper, zinc and lead, but no tin. If recycling practices were present in the making of these brooches, then you might expect an element of tin to enter the mixture, as bronze items entered the alloy-recycling stream. But this appears not to be the case. The results suggest that production was more likely organised on a regional or even super regional scale. An analysis of production at royal estates, emporia and the great abbeys found the latter to be the most likely source of these objects. Furthermore, the Christian nature of these brooches, if produced within monastic centres, may have imbued them with religious meaning, allow for a fresh interpretation of their methods of exchange.

Chapter 6 - Where Worlds Collide: A typological and compositional analysis of the copper-alloy mounts from Viking Age Walcheren. Authored by Marcus A. Roxburgh, Nelleke L. IJssennagger, Hans D.J. Huisman and Bertil J.H. van Os. It was published in *The Medieval Low Countries*, vol.5 (2018), pp.1-33. This is a peer reviewed journal by Brepols focusing on the Low Countries from the beginning of the 5th to the second half of the 16th centuries. In this article we present a combined compositional and typological analysis for a group of 90 Viking-Age mounts, found in Walcheren, The Netherlands. This new analysis is supported by the use of Handheld X-Ray Fluorescence Spectrometry (HHpXRF). The new data sheds light not only on the character of the technology available at the time, but also allows us to formulate a new hypothesis of their purpose and cultural associations within a Viking-Age, North Sea world. Similar mounts have been found in other coastal areas of the southern North Sea, but not in great numbers, suggesting that production was more likely to have been local. Their compositional and typological characteristics matched those of certain forms of Viking-age equestrian gear, but the relatively

small size of these mounts allowed for the possibility that these items were more likely used on personal equipment. Although a question over the exact dating remains, the styles suggest that close ties existed between the Frisian, Viking and Anglo-Scandinavian worlds between the 9 th and 11 th centuries. This expression of identity should be considered in a context of continued intensive relations between Frisian, Viking and Anglo-Saxon.

Chapter 7 - A workshop at the edge of the world? A compositional analysis of copper-alloy finds from Early Medieval Walcheren. Authored by Marcus A. Roxburgh, Nelleke L. IJssennagger, Pim van Tendeloo, Hans D.J. Huisman, and Bertil J.H van Os. This is a book chapter (in press), published in P. Deckers and L. Ten Harkel (eds), *A Central Place on the World's Edge: Studies on the early medieval history and archaeology of the Island of Walcheren, the Netherlands*, Brepols. Over many years a large and diverse number of early medieval copper alloy artefacts have been recovered from the former island of Walcheren (Zeeland, the Netherlands). In this chapter we present the results of a combined typological and compositional study of six groups of these artefacts dating between the 7th and 12th centuries, encapsulating a period in time better known as the (long) Viking-Age. The valuable new qualitative data collected by the non-destructive HHpXRF technique sheds light not only on the character of ancient technology and the organisation of craft production, but also allows a reconsideration of the role of these personal objects in expressing social identity within an interconnected North Sea world.

Chapter 8 - A Comparative Compositional Study of 7th- to 11th century Copper-Alloy Pins from Sedgeford, England and Domburg, the Netherlands. Authored by Marcus A. Roxburgh and Bertil J.H. van Os and published in *Medieval Archaeology*, Vol 62, Issue 2, 2018. Early medieval pins are found in large quantities on both sides of the North Sea and the English Channel, and as a result are one of the few artefact types that can facilitate the exploration of cross-cultural contacts in terms of style, material and manufacture. This paper presents the results of the analyses of two contemporary groups of copper-alloy pins dating from the 7th to the 11th centuries using X-Ray Fluorescence Spectrometry. One group of pins considered here was recovered from an excavated Anglo-Saxon settlement at Sedgeford (Norfolk), while the other derives from a coastal settlement at Domburg (Zeeland, the Netherlands). We argue here, on the basis of our results, that while pin production may have been focused around major mercantile, royal or ecclesiastical centres, it was also localised in terms of materials and production methods, suggesting potentially different trajectories in each region for the development and control of specialist production.

Chapter 9 - In conclusion this chapter presents a synthesis of the articles. The discussion evaluates the methodology for the use of HHpXRF on corroded copper-alloys. It also addresses the evidence for compositional variation in large numbers of typologically similar objects. Regional and chronological differences are discussed where identified, followed by the evidence for deliberate compositonal control. Following this the availability and source of the raw materials are considered. Lastly the social organisation of production, exchange and notions of identity associated with these personal objects are discussed against the projects overall aims.

A discussion then follows regarding limits of the methodology. Its weaknesses are explored against the scientific debate concerning the use of HHpXRF on corroded copper-alloys, especially focusing on the validity of the qualititative versus quantitative approach and also the potential for misinterpretation by less experienced operators. Finally, the future development of HHpXRF is addressed, in its application on corroded copper-alloy objects.

The role of the co-authors

Prof. dr. Hans D. J. Huisman has a background in soil science and geochemistry. He worked for several years in the geochemical laboratory of the geological survey of the Netherlands, before joining the Cultural Heritage Agency of the Netherlands (RCE) as a senior researcher (soil science and degradation of archaeological remains) in 2003. He is also a professor of geoarchaeology and archaeometry (by special appointment), at the Groningen Institute of Archaeology (GIA), University of Groningen. From 2009 to 2015 he held an ancillary position as lecturer at the Faculty of Archaeology, University of Leiden. His main interests are micromorphology and also chemical research on ancient artefacts, including the changes brought about by the corrosion of copper-alloy artefacts when buried in the soil. He was involved in the development of the methodology, in particular the decision to apply the qualitative/semi-quantitative approach to the study of large groups of artefacts, and in understanding the chemical processes taking place within the formation of the copper-alloy patinas of the destructively tested Nijmegen brooches.

Dr. Bertil. J. H. van Os has a background in geology and geochemistry. He works as a senior researcher of inorganic materials at the Cultural Heritage Agency of the Netherlands. His research is focused on wetlands, archaeological artefacts, built environments and the degradation of cultural heritage in general. He has had over 25 years experience of many scientific analysis techniques such as those used in spectrometers including XRF. One speciality in particular is the application of HHpXRF on soil and archaeological artefacts. His contribution to the research presented here was primarily in the development of the methodology, especially in the use of the Niton HHpXRF device. More specifically he was responsible for outputting the raw data from the device into a numerical format suitable for use in Microsoft Excel. This also involved a quality control check of the data, for system and other errors, as it was being outputted. He was also reponsible for the initial data normalisation.

Dr. Stijn Heeren was a lecturer and post-doctorial researcher at the department of archaeology, the Vrije Universiteit Amsterdam, before taking up the position of coordinator of the PAN programme (Portable Antiquities of the Netherlands). His main research interests are rural communities, their settlements, cemeteries and material culture, from the Late Iron Age into the Early Middle Ages. This especially includes the Late Roman period (3rd to 5th centuries) in the Low Countries and metal artefacts in particular. His role in the project was to provide additional specialist typological knowledge (for chapters 2 and 3) on the Roman period brooches and to assist in the formulation of the interpretation and subsequent hypotheses.

Dr. Nelleke L. IJssennagger was the curator of the archaeological and medieval collections at the Fries Museum in Leeuwarden, whilst working on her PhD at the University of Groningen (Dept. of Medieval History). Her thesis explored the position of Frisia in, and interconnections with, the Viking Age North Sea world, through both material and written sources. This included metal-detected finds. Her role in the collaboration was to assist in the typological analysis and the formulation of the subsequent hypotheses for the artefacts found at Domburg (chapters 6 and 7).

Maarja Olli is a PhD researcher at the department of archaeology, University of Tartu where she is mainly interested in understanding regional identities in the *tarand* grave distribution areas during the Roman Iron Age. Her role in the article in chapter 4 was that of lead author, focusing on the typological analysis and subsequent interpretation of the combined typological/compositional results.

Pim van Tendeloo was a Research Masters student at the department of archaeology, the Vrije Universiteit Amsterdam. His research project under the supervision of Prof. dr. Henk Kars and Prof. dr. Hans D. J. Huisman (see above) was on the copper-alloy artefacts found at Domburg. This also included HHpXRF analysis. The dataset that was produced was subsequently donated to the bigger project of the first author. As well as kindly donating the dataset he also contributed in the interpretation of the results for chapter 7.

As well as the specific roles mentioned above, all of the authors also volunteered their time at the depots and museums assisting in the gathering of the typological and compositional data.

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Chapter 2

A Non-destructive survey of early Roman copper-alloy brooches using portable X-ray Fluorescence Spectrometry

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INTRODUCTION

This paper argues that portable X-ray fluorescence spectrometry (pXRF) is a suitable elemental measurement technique with which to study the production of copper-alloy artefacts. Rather than attempt to match the accuracy and precision of laboratory-based techniques, we deploy pXRF in a survey, or screening mode, arguing that it is more suitable to model the social, chronological and geographical nature of 'metal flows' through the non-destructive study of large groups of artefacts (Needham 1998; Pollard et al. 2015). The primary goal of the present research is to investigate to what extent the analyses of the corrosion layer by pXRF can be used for classifying copper-alloy artefacts. The ability to classify objects by their alloy composition is critical if pXRF is to be a valid technique for this approach.

Our approach is to explore the relationship between the form and bulk alloy composition, both of which are intentional actions determined by human choice: the choice of alloy composition can be guided by such factors as raw material availability, workshop organization, and trade or exchange. Many large collections of copper-alloy artefacts have become available for study since the 1970s when the cost and availability of metal detectors resulted in widespread use by both amateur and professional users. Many thousands of these items, which would otherwise have been lost to modern farming practices or building projects, provide ideal data sets for compositional study. Although much of the material has been recovered without a detailed archaeological context - in contrast to those found in carefully planned site excavations - it does provide an opportunity to study trends in availability and choice of alloys in a typological, geographical and chronological context.

By using a large Roman period pXRF data set, measured from collections in the Nijmegen region of the Netherlands, we explore the effectiveness of the technique by comparing the traditionally held problems associated with pXRF against the requirements needed for more socially orientated research models. Other studies have demonstrated the usefulness of the technique for late Roman and early Medieval copper-alloy objects (Roxburgh and Van Os 2018; Roxburgh et al. 2018).

The traditional challenges facing pXRF

Recent years have seen a significant increase in the use of pXRF devices in archaeological research (Shackley 2010, 17), especially those that are compact enough to be held in the hand. These instruments are typically user friendly and allow for a high throughput of non-destructive analysis. Much criticism has been put forward, however, concerning their reliability when used by operators with inadequate analytical training (e.g. Shackley 2010, 17; Speakman and Shackley

2013). The point, shoot and read nature of these devices means they can be operated with the minimum of training and supervision. This does not mean, however, that interpretation of the results should be undertaken at that same operator level. Archaeological pXRF projects should include researchers who are experienced in both the interpretation of compositional data and the basics of XRF analysis (Shackley 2010, 18) to produce valid and reliable results.

Because of the continuing development and miniaturization of the XRF technique, many portable machines on the market today now have superior detector resolution than laboratory equipment in use a decade ago (Frahm and Doonan 2013, 1080; Speakman and Shackley 2013, 1436). Although higher precision and lower detection limits may be obtained with more standard analytical laboratory techniques (e.g., Lab-XRF, neutron activation analysis (NAA), atomic absorption spectrometry (AAS), scanning electron microscopy (SEM) or inductively coupled plasma (ICP) techniques, which are also improving), the need for artefact damage—by drilling or the removal of corroded surface layers—may be problematic for many objects. The non-destructive nature of the technique therefore makes access to and analyses of artefacts possible which would be inaccessible for damaging techniques (see below).

However, while it has been shown that it is possible to obtain reliable compositional data on corroded, ancient copper-alloy surfaces using XRF (Lutz and Pernika 1996), it is still a surface-measuring technique. Therefore, it becomes necessary to consider any compositional variation present on the surface of artefacts. Variation can be caused by sample inhomogeneity, the effects of corrosion, including surface irregularity and variations in thickness. These parameters affect the outcome of all analytical techniques, but in most cases pXRF optimization of sample measurement conditions due to its nature and restrictions placed on it by artefact owners (e.g. forbidding destructive sample preparation) is minimal or lacking.

Despite these less favourable conditions, a number of archaeological applications of pXRF have since been published that include, for instance, insights into the production organization behind the bronze weapons found with the Terracotta Army in Xi'an, China (Martinón-Torres et al. 2012) as well as later Roman and early Medieval studies by the present authors (Roxburgh and Van Os 2018; Roxburgh et al. 2016b, 2017, 2018). A study of both early and late Roman brooches at Richborough, Kent, by Bayley and Butcher (2004) is particularly useful in its comparison of quantitative and qualitative techniques (XRF versus AAS), showing especially that the assignment of alloy names is comparable, but only when measuring large data sets (Bayley 1992, 301; Bayley and Butcher 2004, 22). Lately, the approach has also been applied in an analysis of the social organization behind the production of late Roman brooches in northern Gaul (van Thienen and Lycke 2017).

The use of pXRF devices in archaeometric research is dependent, therefore, on an appropriate methodological approach. This includes adequate sample preparation and a calibration process relying on internationally recognized standards (Kaiser and Shugar 2012). The usefulness of pXRF devices depends on whether the achievable level of measurement accuracy and precision is enough to address a particular archaeological problem.

In the case of metallic artefacts, the major advantage of pXRF devices is that they can be employed in non-destructive analysis. This is especially true for copper-based artefacts where preservation of the patina, or corrosion layer, is often considered to be of great importance by conservators. Since pXRF allows for safe, non-destructive analyses, much larger numbers of artefacts can be released by museum curators. An additional advantage is that analyses are quick

and require short preparation times, which allows for faster analyses of large collections, with the same machine and settings. However, more than for other artefacts, the elemental composition of the corrosion layer from alloys will almost certainly differ from the uncorroded core. This would hinder the use of pXRF analyses in a pure 'provenance'role. But the potential for the technique to group artefacts according to variations in their alloy composition and thus engage with a different set of questions—those relating to human interaction, their deliberate choice of alloying elements, recycling practices, questions that reflect social and economic change over broad chronological and geographical frameworks— is certainly large.

Artefact production and compositional variation

The composition of copper-alloy artefacts is influenced by intentional acts by the craftsmen as they manipulated the alloy in a liquid and a solid state. Studying variation in alloy composition is an avenue of research aimed at a better understanding of the social organization of craft production in past societies. For this, we need to determine and group the compositional variation in the alloys of a considerable number of objects of a uniform typology. Comparing alloy composition with form allows us to try to infer, for example, whether or not objects were produced in large production centres and subsequently distributed. Or, conversely, whether they were more likely produced in widely dispersed local workshops. Other, related, inferences could include whether the raw materials came from several sources or from centralized supply centres (e.g. Ling et al. 2014) or if scarcity of the raw materials induced recycling practices (and if that were the case, to what extent different alloys were sorted before being remelted?).

Even when the raw material sources are unknown, the degree of centralization of raw material procurement can be inferred from the compositional variation in the artefacts. Recent pXRF studies on the copper-alloy weaponry found with the terracotta warriors, Martinón-Torres et al. (2012) attempted to shed a light on production organization and craft specialization employed by ancient craftsmen. The degree of compositional uniformity found in large groups of objects such as these is likely to suggest something further about the organization of labour, transmission of technical knowledge and cross-craft interaction. High degrees of uniformity over a wide geographical area could imply that raw materials were sourced and supplied in a centralized fashion, or that artefacts were mass-produced in a central workshop. In contrast, significant compositional variation may indicate separate production modes, and differences in raw material sourcing including variation due to recycling. Thus, the study of artefact composition can provide useful information when investigating the organization of production, providing the right questions are asked.

Analytical challenges

A reliable level of accuracy and precision has previously been demonstrated using XRF on the corrosion layer on copper alloys (Lutz and Pernika 1996). However, the degradation of copper alloys typically results in the formation of a corrosion layer that may be depleted in copper (decuprification) and, therefore, enriched by the alloying metals, when compared with the intact metal core. Different soil types may also influence the rate at which an object corrodes and, therefore, the type of corrosion, its intensity and the direction in which the changes take place

interfere with the determination of an original alloy composition for an artefact. To complicate this issue further, surface concentrations may also vary considerably given the heterogeneous distribution of lead globules within a copper alloy (Smit 2012). In addition, deposition of iron hydroxides or sulphides onto metal objects often occurs in the soil. The effect of such an iron-rich layer is that secondary copper radiation is absorbed, but that higher energy secondary tin X-rays are relatively enhanced.

The reflection depth of X-rays in metals is dependent on the mass attenuation of the material and the incident X-ray energy. In metals, the critical reflection depth, i.e., the depth of analyses is restricted for most elements below 0.1 mm (Gigante et al. 2005). As a result, in the case of metals, XRF devices provide the composition of an object's surface and thus will be influenced by compositional changes caused by corrosion effects (see also Gigante et al. 2005; Orfanou and Rehren 2014).

In the present study, we assessed the challenge presented by these surface variations by comparing XRF analyses on corroded and subsequently cleaned surfaces of a group of Roman brooch fragments. We then test whether the corrosion-induced changes in alloy ratios affect the potential for using the data for studying the human choices involved in production.

MATERIALS AND METHODS

Materials

Non-destructive measurements were taken from 187 identifiable bow brooches from the private collection of Harry Sanders, which was made available for scientific study at the Bureau Archeologie & Monumenten at Nijmegen (Table S1). The objects, which dated between 150BC and 200AD were all recovered during archaeological fieldwork in and around the city of Nijmegen and from metal detection in ploughed fields in neighbouring municipalities. Nijmegen is located on the south bank of the River Waal (a branch of the Rhine) and was the site of a major Roman military and civil centre, situated on a hill at the apex of the Rhine and Meuse delta. The soils around Nijmegen and those to the south are generally sandy, well drained and relatively acidic (podzol types). North of the river, however, the region is dominated by clayey lime-buffered soils with elevated groundwater tables. There were 14 additional bow brooch fragments (reserved for destructive mechanical cleaning) that were recovered from the villages of Elst and Oosterhout, both on the northern side of the river.

The following common typological names have been used to identify the brooch types in this survey. The earliest measured is the pre-Roman Nauheim series (150 to 70BC), included as a comparison for the following early Roman types. For the 187 complete brooches, we have the Aucissa, Eye and Almgren 15 series (20BC– 80AD, 5–100AD and 30–180AD respectively), then the corrosion test includes 14 additional brooch fragments, including fragments from the Almgren 20 series (20BC–100AD) and also van Buchem 24 and Böhme 19 variants (both second century AD). See Heeren and van der Feijst (2017), types 8, 30, 20, 45, 17, 47– 48 and 51 respectively for recent typological analyses and links to earlier publications. A common manufacturing characteristic for brooches of this period was that many types were wrought (hammered) out of a single piece of copper alloy, including the spring (Bayley and Butcher 2004, 32). This meant these

particular brooches were made in a extremely low or unleaded alloy, because of the working limitations of lead in alloys (Bayley and Butcher 2004, 15). Other brooch types were composed of multipiece assemblies, with the spring being made separately from the body of the brooch. This meant that higher proportions of lead could be added to the main body because it was made separately from the spring. Of the brooch types used in this study, the Aucissa and Böhme 19 variants are multipiece assemblies. The rest are one-piece variants.

The organization behind brooch production is still attracting archaeological debate. One theory being explored is that brooch production was linked to military workshops, primarily due to their similarity in form to a number of military items (Roxburgh et al. 2016a, 413). The Aucissa type, for example, is considered by some to be the soldiers brooch, which if the case allows the question to be posed as to whether all brooches at this time had a close relation to the army or whether some types were more local in nature, perhaps linked to a particular regional group, which may be the case for the Almgren 15 series (Heeren and van der Feijst 2014, 99). The debate surrounding the introduction of brass into Roman production is of some importance to this question. It is thought that brass was first produced on an industrial scale during the first century BC (Bayley1998, 8–9). Furthermore it is also thought that during this early period the Roman state reserved it for the production of military gear and coins, but at some point towards the end of the first century AD its use rapidly declines (Bayley and Butcher 1995, 118; Dungworth 1997, 903). To engage this debate with pXRF, large numbers of individual brooches from well-defined typologies are required in order to assess how homogeneous they are over a wide area. This cannot as yet be done through other methods requiring the destructive cleaning or sampling of large numbers of items. If pXRF can do this non-destructively, then a comparison can be made between pre-conquest and Roman period production (between brass and bronze use in particular), then further an exploration of alloy types found at later military production sites can be compared with local tribal settlements.

For the Netherlands (the province of Germania Inferior in Roman times) this ability to explore alloy choice and the level of homogeneity present in large numbers of brooch types enables useful comparisons to be drawn with research in other regions, such as that undertaken by Bayley and Butcher (2004) at Richborough in Britain.

Methods

pXRF

A Niton XL3t GOLDD Handheld XRF analyser was used for this study. It was factory calibrated with standards for metals and alloys and equipped with a large area silicon drift detector with optimized geometry. The electronic metals mode was selected and used throughout the data-gathering phase. This takes an off-the-shelf approach rather than rely on the development of custom calibrations. The advantage of this mode is that the same metals of interest (i.e., those found in Roman and Medieval alloys) are used in modern electronic equipment (Cu, Sn, Ag, Zn, Au), or are marked as potential hazardous materials (Pb, Hg, As, Se). In order to test whether this mode, which may not have been originally designed for use on copper alloys, was suitable for this application, we tested its performance on the Cultural Heritage Alloy Reference Material Set (CHARM) set of reference metals (see below).

The analyser was mounted on a portable test bench (hence, we use pXRF not hhXRF; see Frahm and Doonan, 2013, 1426, for further labelling discussion), with a lead cover to provide a consistent operating environment whilst protecting the user from radiation. The test bench made it possible to place the objects over the 8 mm spot size easily. In most cases the objects fully covered the opening, but some were slightly smaller. However, slightly varying the angle of the object to the opening, including the amount of coverage across the opening, was found to be insignificant in terms of the method proposed here. By checking the machine read-out during analyses, it was found that the machine-reported analytical error, for the elements of interest, was <0.2% with reading times >35 s, so this reading time was deemed sufficient for the present study (see below for the performance of the analyses with this reading time on the CHARM set of reference materials). Two spectrum readings per 35 s intervals were taken, the first for the main range of elements at 50 kV (Cu-K to Ba-K, and Au-L to Pb-L) and the second for the low range at 10 kV (Al-K to Cu-K). After the analyses, the spectra were checked individually for inconsistencies and unexpected overlaps. Based on these checks, the analytical values for arsenic were discarded because of a peak overlap of lead.

One measurement was taken for each item, on the front, central bow section of the brooch, or on the front, head or foot sections when fragments were used. An external normalization of the completed data set in a spreadsheet program (Microsoft Excel™) was then undertaken, which corrected for the contribution of the light elements that would be present in the patina due to contamination from soil residues (such as sand, clay and iron hydroxides). The elemental concentrations of the alloying elements were normalized on a light elements (Si-Fe)-free basis. In the present paper, only the main alloying elements (Cu, Sn, Zn, Pb) are considered. The factory calibration of the device was checked against the reference samples of the copper CHARM set (Heginbotham et al. 2015). The results (Table 1 and Fig. 1) show that standard deviations remain within a few per cent. Plotting the results in a ternary diagram, such as the one uses for all analyses results (see below), shows no deviation for all but one of the samples. Only sample 32xLB10 deviates in its lead content, possibly due to the inhomogeneity that is common for leaded copper alloys.

Corrosion study

The study was conducted in a similar manner to that of Fernandes et al. (2013) by comparing the compositions of the corrosion layer and uncorroded core of the artefacts. Contrary to some of the Fernandes et al. objects, we fully removed the corrosion layer for all tested artefacts. The pXRF analyses were conducted on both corroded and cleaned surfaces and typically 0.5–1.0 mm in depth were removed to reach the uncorroded core (Fig. 2, inset), using the same type of Niton machine as described above, including settings and calibration.

Visualization of compositional data

The study of copper alloys in Roman Britain by Bayley and Butcher (1995, 2004) demonstrated the effectiveness of using triangular (ternary) diagrams for visualizing the concentrations of Sn, Zn and Pb measured using AAS (Fig. 2). The study identified multiple distinct compositional groups of Roman brooches that matched well with typo-chronological groupings. The use of

ternary diagrams implies that concentrations of the selected alloying elements (Sn, Zn, Pb) are normalized to 100% so that copper content is not taken into account. This has a disadvantage that objects that are almost pure copper without care will still be classified as an alloy (e.g., a bronze or brass) on the basis of very low concentrations of alloying elements. It is important, therefore, that an assessment of the data is made before producing these diagrams—checking and removing items produced in copper, lead or tin, for example. The measurements should also be used as reference when interpreting the nature of any groups present, such as determining if certain elements were deliberately added or not. It must also be kept in mind that the alloy classification in these diagrams does not match the common alloy definitions based on absolute concentrations. A major benefit, however, is that large numbers of compositional analyses can be visualized in one diagram, so that trends in alloy choice can be identified for differing groups of artefacts. Bayley and Butcher (1995, 2004) have set a benchmark by showing how compositional variation—in their case determined by AAS analyses—as depicted in triangular diagrams is especially suitable for Roman fibulae, and how distinct groups are easily distinguished by eye.

Pollard et al. (2015) applied a different approach for interpreting a large database of copper-alloy artefacts: they classified copper alloy artefacts based on absolute concentrations, using a threshold of 1% to identify deliberately added alloying elements to the metal melt. The present approach is different, partly out of necessity: a 1% threshold cannot be maintained in corrosion-affected measurement data. More important, however, is that a 'hard' a priori classification may not do justice to the actual grouping that, for example, become apparent in ternary graphs such as those published by Bayley and Butcher (1995, 2004). Visually assessing the degree of separation between groups, or recognizing mixing lines between end members is a necessity for studying trends in alloy choice that is only possible by using such graphs. Bayley and Butcher (2004, 24) divided their ternary diagrams into alloy classes (Fig. 1, inset). These classes (e.g., brass, bronze and gunmetal) are of course associated with terminology employed in modern metallurgy. A hard classification between leaded and unleaded alloys is also not maintainable in corroded objects so a qualitative judgement based on the construction limitations mentioned above is preferred (i.e., one typological group may systematically show a higher lead measurement than another). In the present diagrams, we indicate a simplified version of this classification (with brass (>4% Zn), bronze (≥3% Sn) as background without imposing a rigid classification. Note that these diagrams do not include copper contents and are therefore not suitable for determining alloy properties.

It is also important to understand that ancient names and their corresponding alloy ratios are not well understood (Bayley and Butcher 2004, 14). Attempts to impose rigid modern classifications would be unlikely to reflect historical boundaries, intentionally created or otherwise, by ancient craftsmen. Plotting large numbers of measurements in ternary diagrams and observing their distributions allows for a better understanding of historical boundaries and, therefore, technical choices. In the present study, we therefore only lightly touch on this classification, and put more confidence in the study of alloy distributions in ternary diagrams.

Pb	Measured values				Reference values		Differences	
	Mean	St. Dev.	RSD(%)	CI (95%)	Mean	CI (95%)	Delta	Delta %
31X 7835.8	2.88	0.031	1.09	0.022	3.2	0.03	0.32	9.9
31X 7835.9	1.15	0.022	1.95	0.012	1	0.017	-0.15	-14.6
31X TB5	0.58	0.014	2.41	0.007	0.6	0.007	0.02	3.2
32X LB10	9.57	0.042	0.43	0.022	11.7	0.07	2.13	18.2
32X LB14	14.92	0.076	0.51	0.044	14.6	0.06	-0.32	-2.2
32XLB17	9.77	0.019	0.20	0.01	9.8	0.1	0.03	0.3
32X SN5	0.32	0.010	3.18	0.005	0.3	0.004	-0.02	-6.4
32X SN6	1.73	0.020	1.18	0.011	1.6	0.015	-0.13	-7.9
32X SN7	2.64	0.028	1.08	0.015	2.6	0.03	-0.04	-1.6
32X GM4	4.91	0.034	0.68	0.018	4.7	0.04	-0.21	-4.5
33X GM20	0.12	0.008	6.57	0.004	0.1	0.002	-0.02	-15.8
33X GM21	6.69	0.032	0.47	0.017	7	0.05	0.31	4.4
Zn								
	Mean	St. Dev.	RSD(%)	CI (95%)	Mean	CI (95%)	Delta (Ref. -	Delta %
31X 7835.8	25.66	0.047	0.18	0.039	24.8	0.06	-0.86	-3.5
31X 7835.9	14.53	0.018	0.13	0.01	14.3	0.06	-0.23	-1.6
31X TB5	41.27	0.050	0.12	0.026	40.6	0.15	-0.67	-1.6
32X LB10	0.56	0.005	0.84	0.003	0.6	0.009	0.04	6.8
32X LB14	0.04	0.005	14.06	0.004	0	0.024	-0.04	-
32XLB17	0.64	0.007	1.10	0.004	0.6	-	-0.04	-6.0
32X SN5	0.49	0.011	2.35	0.006	0.5	0.005	0.01	2.7
32X SN6	1.19	0.013	1.09	0.007	1.2	0.02	0.01	0.9
32X SN7	1.95	0.010	0.51	0.005	2	0.02	0.05	2.5
32X GM4	7.21	0.023	0.31	0.012	7.1	0.04	-0.11	-1.6
33X GM20	3.91	0.016	0.40	0.008	3.9	0.04	-0.01	-0.1
33X GM21	5.28	0.013	0.25	0.007	5.1	0.04	-0.18	-3.5
Sn								
	Mean	St. Dev.	RSD(%)	CI (95%)	Mean	CI (95%)	Delta (Ref. -	Delta %
31X 7835.8	0.48	0.0036012	0.74	0.003	0.5	0.007	0.02	3.0
31X 7835.9	1.53	0.0125432	0.82	0.007	1.5	0.02	-0.03	-2.2
31X TB5	0.11	0.0026662	2.42	0.001	0.1	0.003	-0.01	-10.2
32X LB10	8.14	0.0153391	0.19	0.008	8.2	0.09	0.06	0.8
32X LB14	5.30	0.0200469	0.38	0.011	5.4	0.034	0.10	1.9
32XLB17	5.92	0.0142643	0.24	0.008	6	0.04	0.08	1.3
32X SN5	16.94	0.048693	0.29	0.026	16.1	0.09	-0.84	-5.2
32X SN6	7.55	0.0182118	0.24	0.01	7.3	0.03	-0.25	-3.5
32X SN7	12.84	0.0212551	0.17	0.011	12.6	0.09	-0.24	-1.9
32X GM4	2.55	0.0071798	0.28	0.004	2.6	0.05	0.05	1.9
33X GM20	4.25	0.0093724	0.22	0.005	4.1	0.02	-0.15	-3.7
33X GM21	4.48	0.0189098	0.42	0.01	4.6	0.03	0.12	2.5

Table 1 Results of the measurements from the Cultural Heritage Alloy Reference Material Set (CHARM) reference set for lead (Pb), zinc (Zn) and tin (Sn) compared with the reference values and 95% confidence interval (CI) range

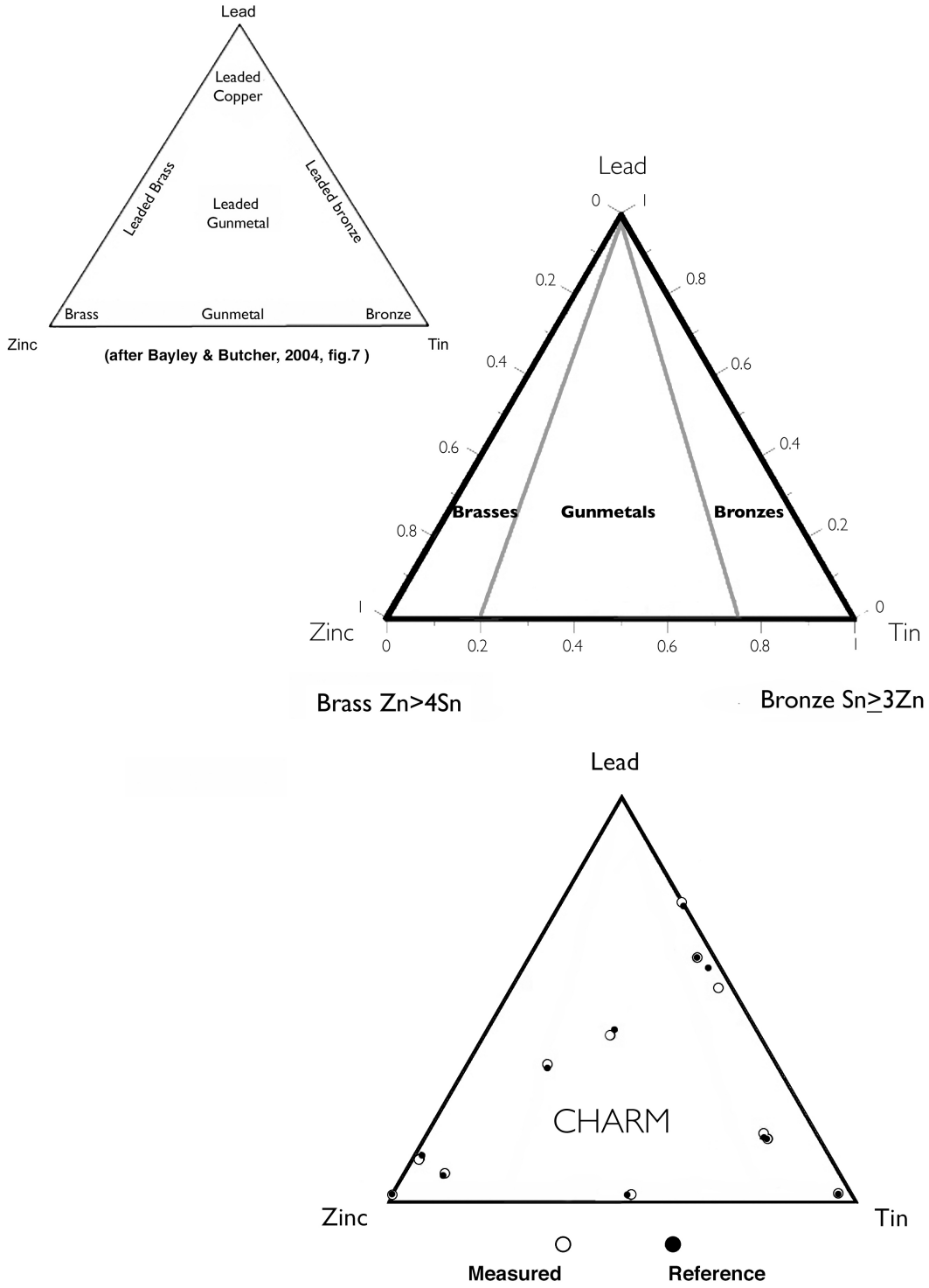


Figure 1 Ternary graphs (after Bayley and Butcher 2004, fig. 7): (upper and middle graphs) simplified classifications; and (lower graph) measured and reference values from the Cultural Heritage Alloy Reference Material Set (CHARM) reference alloy set. Note the deviation of one sample (32X LB10). This sample has a systematic lower measured lead content.

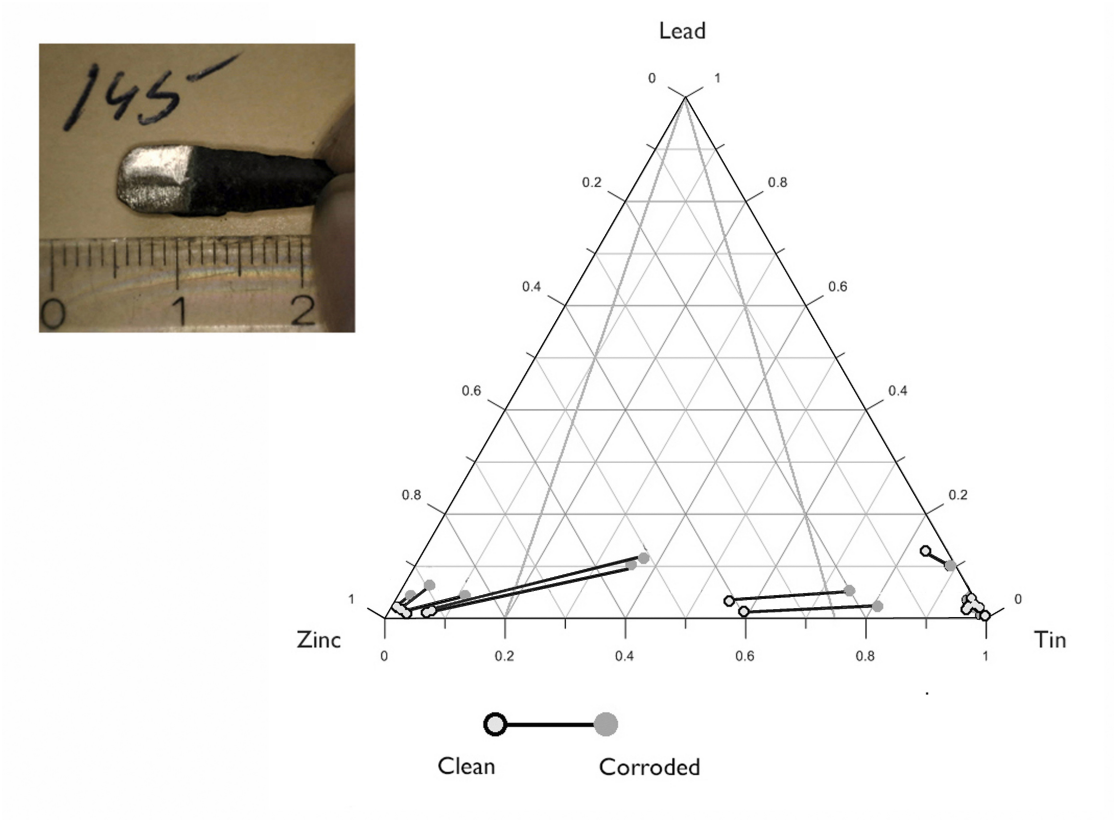


Figure 2 Comparison of measurements made on the corrosion layers and cleaned metal. Black lines connect measurements to the same object.

RESULTS

Corrosion effects on pXRF analyses

A comparison of the corroded and uncorroded measurements on the Nijmegen brooch fragments is shown in Table 2 (for additional data, see Table S1). In general, we can see an average depletion in copper contents of 35% for the seven brooches alloyed with tin. For the two brooches having relatively high tin and zinc contents, the average depletion in copper was 18.5%, but only a small depletion of 0.7% zinc was observed. The remaining five brooches were alloyed with zinc and exhibited a zinc depletion of 9%.

The results show that decuprification and dezincification represented the main corrosion processes at work. Depletion in copper content was observed to be the most relevant change in bronzes and the leaching of zinc from brass objects was also common.

When plotted in a ternary diagram, the effects of corrosion and heterogeneity can be compared with the alloy groups (Fig. 2). Since a triangular diagram is based on a copper-free recalculation (so Sn + Pb + Zn = 100%), small variations of alloying elements in copper-rich alloys are magnified. The comparison shows that two measurements that initially are classified as bronze after cleaning become gunmetal. A further two measurements that initially fall into the gunmetal classification with around 50% zinc after cleaning cross into the brass classification, with a new value of 95% zinc—although the composition has not changed. There is also a leaded bronze measurement that also sees a slight increase in lead and an associated decrease in tin. This may be due to the inhomogeneous distribution of lead in copper alloys. For the remaining nine items, the corrosion effects are limited in the sense that they still fall within the same broad compositional group. For our study, it is important to realize that the corrosion effects have not affected the overall grouping; the zinc-dominated alloys ('brass'), the tin-dominated alloys ('bronze') and the intermediate ones ('gunmetal') are still recognizable as distinct clusters, even though the 'brass' group shows more inter-artefact variation, especially those samples with a high copper (i.e., low alloying elements) content.

Grouping the early Roman brooches

The Nauheim brooches appear to have only been made with tin, whereas the (later) Aucissa brooches are made with zinc (Fig. 3) (for the data set for the Nijmegen brooches, see also Table S1). This observation is in line with the brass alloys from Roman period brooches and military equipment found in Masada, Israel, as well as in Britain and other locations in Western Europe (Bishop and Coulston 1993; Ponting and Segal 1998; Bayley and Butcher 2004) The group of measurements for the Eye brooch series show that they are also zinc based, similar to the Aucissa brooches. In contrast, however, the measurements for the Almgren 15 wire brooch series reveal two clusters: one tin based, the other showing a mixing line from zinc- to a lead- and tin-based copper alloy. Comparing this with the Eye brooch and the Almgren 15 measurements from Britain (for the British results, see Fig. 3) shows a similar division in zinc- and tin-based series reveal two clusters: one tin based, the other showing a mixing line from zinc- to a lead- and tin-based copper alloy. Comparing this with the Eye brooch and the Almgren 15 measurements from Britain (for the British results, see Fig. 3) shows a similar division in zinc- and tin-based alloys, but with a different distribution for the outliers—probably due to the corrosion processes.
If these distributions are compared with the displacement values seen in Figure 2, the outliers on the Nijmegen results would be more in line with the British results, after decuprification, dezincification or secondary copper X-ray absorption processes have been considered. Although outliers exist in all cases, it is possible to distinguish the core alloy properties when observed in large numbers. Also knowing that the one-piece brooches contain by necessity little or no lead (see the second section), the large proportion of measurements are below the 20% lead line in the ternary graphs.

Group	Find ID	Cu	Sn	Pb	Zn	Ag	Fe
Measurement before cleaning							
Tin-dominant							
	EM-142	35.26	49.81	5.67	0.57	0.17	7.52
	EM-95	43.77	27.06	0.12	0.20	0.13	25.77
	EM-16	55.22	36.50	1.33	0.51	0.11	5.63
	EM-18b	41.89	44.75	1.79	0.45	0.30	9.23
	EM-140	21.15	59.54	0.30	0.17	0.09	17.32
	EM-552	78.57	20.10	0.45	0.18	0.07	0.31
	EM-597	71.87	25.44	0.56	0.56	0.09	1.02
Gun metal-like							
	EM-902	69.25	17.80	1.26	4.81	0.15	6.02
	EM-655	63.59	24.88	0.72	5.20	0.13	4.69
Zinc-dominated							
	EM-007	85.95	0.27	0.55	11.87	0.03	1.10
	EM-492	85.02	0.53	0.80	11.16	0.07	1.85
	EM-540	81.75	1.28	0.50	9.62	0.07	5.55
	OH-145	79.65	5.86	1.81	8.07	0.08	3.68
	EM-018a	78.81	5.78	1.69	8.74	0.12	4.12
Measurement after cleaning							
Tin-dominant							
	EM-142	83.36	13.44	2.07	0.66	0.07	0.20
	EM-95	85.43	13.65	0.05	0.07	0.10	0.42
	EM-16	85.90	12.98	0.29	0.31	0.05	0.27
	EM-18b	87.66	10.91	0.40	0.13	0.12	0.39
	EM-140	81.37	17.77	0.05	0.09	0.05	0.48
	EM-552	86.04	13.36	0.25	0.08	0.05	0.11
	EM-597	83.78	14.84	0.23	0.45	0.08	0.32
Gun metal-like							
	EM-902	85.04	7.55	0.42	5.65	0.10	0.92
	EM-655	84.82	8.50	0.17	5.79	0.07	0.44
Zinc-dominated							
	EM-007	80.74	0.17	0.35	17.99	0.04	0.64
	EM-492	79.29	0.29	0.36	19.54	0.02	0.43
	EM-540	80.77	0.57	0.11	17.92	0.03	0.39
	OH-145	77.99	1.34	0.19	20.15	0.05	0.19
	EM-018a	79.01	1.35	0.27	18.97	0.04	0.23
Absolute differences							
Tin-dominant							
	EM-142	48.10	-36.36	-3.60	0.09	-0.10	-7.32
	EM-95	41.66	-13.41	-0.07	-0.13	-0.03	-25.35
	EM-16	30.68	-23.52	-1.04	-0.20	-0.06	-5.35
	EM-18b	45.78	-33.84	-1.40	-0.33	-0.18	-8.84
	EM-140	60.22	-41.77	-0.25	-0.08	-0.03	-16.84
	EM-552	7.47	-6.74	-0.20	-0.10	-0.03	-0.20
	EM-597	11.91	-10.61	-0.33	-0.11	-0.01	-0.70
Gun metal-like							
	EM-902	15.79	-10.26	-0.84	0.84	-0.05	-5.10
	EM-655	21.23	-16.39	-0.56	0.59	-0.06	-4.25
Zinc-dominated							
	EM-007	-5.21	-0.10	-0.20	6.11	0.01	-0.46
	EM-492	-5.74	-0.25	-0.44	8.38	-0.05	-1.42
	EM-540	-0.99	-0.71	-0.39	8.30	-0.05	-5.15
	OH-145	-1.66	-4.53	-1.63	12.08	-0.03	-3.49
	EM-018a	0.20	-4.44	-1.42	10.22	-0.08	-3.89

Table 2 Comparison of corroded versus cleaned measurements

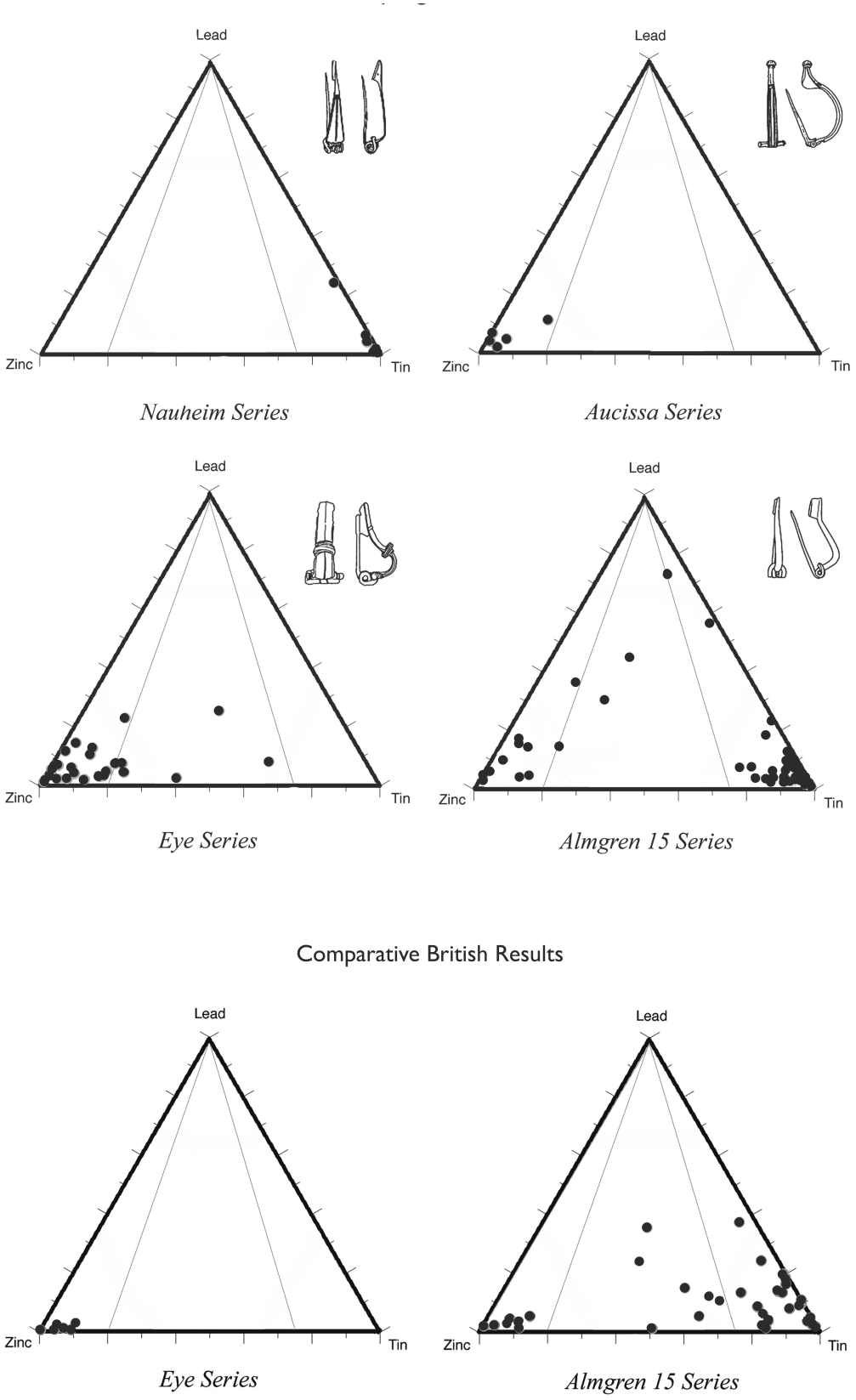


Figure 3 Nijmegen portable X-ray fluorescence spectrometry (pXRF) results versus Bayley and Butcher's atomic absorption spectrometry (AAS) results (after Bayley and Butcher 1995,figs 3 and 4.1)

DISCUSSION

The tests on the CHARM reference set showed good levels of accuracy and precision under more ideal analytical circumstances. On corroded brooches, however, lack of sample preparation and non-ideal measurement conditions (e.g., not removing the corrosion layer, or preparing a flat surface and variations in angle of brooch to sensor), do not prevent a broader classification of alloys into zinc- or tin-rich traditions. Within the limitations of this measurement method (e.g., no removal of the corrosion layer) we can still address relevant archaeological questions such as those mentioned above.

The offsets between corroded and uncorroded compositions demonstrated that the corrosion effects do not preclude the recognition of separate alloy groups. A measurement taken from a corroded item subsequently classified, for example, as zinc based will not have come from a tin-based alloy.

The results for the Nijmegen study can therefore be compared with the trends found by Bayley and Butcher (1995, 2004). Although we measured the corrosion layer, it is clear that pXRF measurements on corroded brooches can be classified broadly into archaeologically relevant groups.Therefore, subsequent interpretations can be formed alongside those presented in more ideal circumstances. Furthermore, because the rapid and non-destructive technique allows for more items to be measured than with any other method (enabling the better definition of the core distribution for brooch types), it gives a better chronological resolution, allowing a closer view of the transition between types such as those objects changing from bronze to brass, or those staying in bronze during the early Roman period.

CONCLUSIONS

Systematic compositional differences for the major elements (tin, lead, zinc) are observed between the corroded surfaces and the uncorroded metal cores. However, the magnitude of these changes only becomes relevant when considering the specific research question. For questions needing simple alloy classification, achieved through identifying the compositions of large sets of artefacts, it has been shown that compositional ratios remain within a satisfactory tolerance. The results for Nijmegen showed a difference between pre-Roman and early Roman brooches, the former being produced in a tin-rich tradition and the latter in a zinc tradition. Furthermore, where two alloy traditions were present within a brooch series, it was noticed that the same was true of the same series measured in Britain.

It has been demonstrated, therefore, that data provided by an appropriate application of pXRF—perhaps best described as a survey or reconnaissance role—are reliable enough to detect the deliberate control of composition between typological, copper-alloy groups and that the data are comparable with earlier research.

Understanding more about how corrosion affects the results of non-destructive measurements is an important step forward in adopting an appropriate application of pXRF to archaeological copper alloy. Once an association between typology and alloy is identified using this approach, the next step would be to explore the results in more detail using much fewer, carefully selected examples under more rigorous laboratory conditions.

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SUPPORTING INFORMATION

Table S1. Nijmegen worksheet and corrosion experiment worksheet

Nijmegen worksheet - part 1 typological data

Collection / Location	Find ID	Description	Period	XRF No.
HS Linden	9 w	Bow - Nauheim type	Pre-Roman	98097
HS Linden	9 aw	Bow - Nauheim type	Pre-Roman	98110
HS Linden	9 m	Bow - Nauheim type	Pre-Roman	98113
HS Linden	9 ay	Bow - Nauheim type	Pre-Roman	98116
HS Eimeren	2 413	Bow - Nauheim type	Pre-Roman	5511
HS Eimeren	2 62	Bow - Nauheim type	Pre-Roman	5514
HS Linden	9 179	Bow - Nauheim type	Pre-Roman	5582
HS Elst	EM-061	Bow - Almgren 15	Roman	102850
HS Elst	EM-062	Bow - Almgren 15	Roman	102851
HS Elst	EM-004	Bow - Almgren 15	Roman	102855
HS Elst	EM-068	Bow - Almgren 15	Roman	102856
HS Elst	EM-017	Bow - Almgren 15	Roman	102857
HS Elst	EM-082	Bow - Almgren 15	Roman	102860
HS Elst	EM-058	Bow - Almgren 15	Roman	102861
HS Elst	EM-086	Bow - Almgren 15	Roman	102862
HS Elst	EM-063	Bow - Almgren 15	Roman	102863
HS Elst	EM-085	Bow - Almgren 15	Roman	102864
HS Elst	EM-066	Bow - Almgren 15	Roman	102866
HS Elst	EM-065	Bow - Almgren 15	Roman	102867
HS Elst	EM-0868	Bow - Almgren 15	Roman	102870
HS Elst	EM-059	Bow - Almgren 15	Roman	102875
HS Elst	EM-098	Bow - Almgren 15	Roman	102876
HS Elst	EM-084	Bow - Almgren 15	Roman	102877
HS Elst	EM-099	Bow - Almgren 15	Roman	102881
HS Elst	EM-069	Bow - Almgren 15	Roman	102886
HS Elst	EM-071	Bow - Almgren 15	Roman	102890
HS Elst	EM-080	Bow - Almgren 15	Roman	102892
HS Elst	EM-091	Bow - Almgren 15	Roman	102894
HS Elst	EM-088	Bow - Almgren 15	Roman	102895
HS Elst	EM-064	Bow - Almgren 15	Roman	102897
HS Elst	EM-119	Bow - Almgren 15	Roman	103199
HS Elst	EM-103	Bow - Almgren 15	Roman	103201
HS Elst	EM-108	Bow - Almgren 15	Roman	103205
HS Elst	EM-109	Bow - Almgren 15	Roman	103211
HS Elst	EM-125	Bow - Almgren 15	Roman	103216
HS Elst	EM-111	Bow - Almgren 15	Roman	103219
HS Elst	EM-128	Bow - Almgren 15	Roman	103222

HS Oosterhout	OA-047	Bow - Almgren 15	Roman	103261
HS Oosterhout	OA-114	Bow - Almgren 15	Roman	103267
HS Elst	ELa-10	Bow - Almgren 15	Roman	103294
HS Valburg	VT-10	Bow - Almgren 15	Roman	103295
HS Valburg	VT-01	Bow - Almgren 15	Roman	103303
HS Elst	EAH-050	Bow - Almgren 15	Roman	103322
HS Elst	EM-159	Bow - Almgren 15	Roman	103351
HS Linden	9 309	Bow - Almgren 15	Roman	98005
HS Linden	9 f	Bow - Almgren 15	Roman	98019
HS Linden	9 77	Bow - Almgren 15	Roman	98031
HS Linden	9 100	Bow - Almgren 15	Roman	98036
HS Linden	9 234	Bow - Almgren 15	Roman	98046
HS Linden	9 217	Bow - Almgren 15	Roman	98050
HS Linden	9 138	Bow - Almgren 15	Roman	98056
HS Linden	9 235	Bow - Almgren 15	Roman	98060
HS Linden	9 220	Bow - Almgren 15	Roman	98064
HS Linden	9 181	Bow - Almgren 15	Roman	98067
HS Linden	9 104	Bow - Almgren 15	Roman	98068
HS Linden	9 102	Bow - Almgren 15	Roman	98070
HS Linden	9 ae	Bow - Almgren 15	Roman	98078
HS Linden	9 j	Bow - Almgren 15	Roman	98084
HS Linden	9 g	Bow - Almgren 15	Roman	98090
HS Linden	9 k	Bow - Almgren 15	Roman	98091
HS Linden	9 ai	Bow - Almgren 15	Roman	98105
HS Linden	9 q	Bow - Almgren 15	Roman	98106
HS Linden	9 u	Bow - Almgren 15	Roman	98111
HS Linden	9 bb	Bow - Almgren 15	Roman	98122
HS Raayen	5 u	Bow - Almgren 15	Roman	98142
HS Raayen	5 60	Bow - Almgren 15	Roman	98153
HS Raayen	5 w	Bow - Almgren 15	Roman	98157
HS Raayen	5 m	Bow - Almgren 15	Roman	98169
HS Raayen	5 n	Bow - Almgren 15	Roman	98170
HS Raayen	5 l	Bow - Almgren 15	Roman	98171
HS Raayen	5 k	Bow - Almgren 15	Roman	98172
HS Raayen	5 84	Bow - Almgren 15	Roman	98174
HS Raayen	5 f	Bow - Almgren 15	Roman	98175
HS Raayen	5 b	Bow - Almgren 15	Roman	98181
HS Eimeren	2 308	Bow - Almgren 15	Roman	5367
HS Eimeren	2 a	Bow - Almgren 15	Roman	5394
HS Eimeren	2 c	Bow - Almgren 15	Roman	5401
HS Eimeren	2 n	Bow - Almgren 15	Roman	5404
HS Eimeren	2 l 2013	Bow - Almgren 15	Roman	5415
HS Eimeren	2 f 2013	Bow - Almgren 15	Roman	5420
HS Eimeren	2 3	Bow - Almgren 15	Roman	5463
HS Eimeren	2 g	Bow - Almgren 15	Roman	5472
HS Eimeren	2 d 2012	Bow - Almgren 15	Roman	5474

HS Eimeren	2 e	Bow - Almgren 15	Roman	5476
HS Eimeren	2 500	Bow - Almgren 15	Roman	5493
HS Eimeren	2 728	Bow - Almgren 15	Roman	5518
HS Eimeren	2 732	Bow - Almgren 15	Roman	5520
HS Reeth	11 40	Bow - Almgren 15	Roman	5524
HS Reeth	11 55	Bow - Almgren 15	Roman	5527
HS Reeth	11 123	Bow - Almgren 15	Roman	5528
HS Reeth	11 194	Bow - Almgren 15	Roman	5537
HS Reeth	11 196	Bow - Almgren 15	Roman	5538
HS Reeth	11 177	Bow - Almgren 15	Roman	5546
HS Reeth	11 10	Bow - Almgren 15	Roman	5554
HS Reeth	11 132	Bow - Almgren 15	Roman	5558
HS Linden	9 356	Bow - Almgren 15	Roman	5575
HS Linden	9 194	Bow - Almgren 15	Roman	5576
HS Linden	9 370	Bow - Almgren 15	Roman	5580
HS Linden	9 176	Bow - Almgren 15	Roman	5586
HS Linden	9 406	Bow - Almgren 15	Roman	5587
HS Linden	9 176	Bow - Almgren 15	Roman	5588
HS Linden	9 454	Bow - Almgren 15	Roman	5593
HS Linden	9 297	Bow - Almgren 15	Roman	5598
HS Linden	9 331	Bow - Almgren 15	Roman	5599
HS Linden	9 314	Bow - Almgren 15	Roman	5605
HS Linden	9 387	Bow - Almgren 15	Roman	5607
HS Linden	9 338	Bow - Almgren 15	Roman	5608
HS Linden	9 212	Bow - Almgren 15 related	Roman	98058
HS Linden	9 6	Bow - Almgren 15 related	Roman	98104
HS Linden	9 av	Bow - Almgren 15 related	Roman	98109
HS Eimeren	2 j 2013	Bow - Almgren 15 related	Roman	5407
HS Eimeren	2 s 2013	Bow - Almgren 15 related	Roman	5414
HS Eimeren	2 375	Bow - Almgren 15 related	Roman	5507
HS Eimeren	2 66	Bow - Almgren 15 related	Roman	5519
HS Linden	9 323	Bow - Almgren 15 related	Roman	5609
HS Elst	EM-090	Bow - Almgren 15 related	Roman	102901
HS Elst	EM-070	Bow - Almgren 15 related	Roman	102874
HS Elst	EM-509	Bow - Almgren 15 related	Roman	103350
HS Oosterhout	OA-505	Bow - Almgren 15 related	Roman	103272
HS Linden	9 245	Bow - Almgren 15 related (moulded shoulder)	Roman	98053
HS Linden	9 133	Bow - Almgren 15 related (moulded shoulder)	Roman	98055
HS Linden	9 109	Bow - Almgren 15 related (moulded shoulder)	Roman	98069
HS Raayen	5 j	Bow - Almgren 15 related (moulded shoulder)	Roman	98156
HS Eimeren	2 229	Bow - Almgren 15 related (moulded shoulder)	Roman	5470
HS Eimeren	2 547	Bow - Almgren 15 related (moulded shoulder)	Roman	5496
HS Reeth	11 50	Bow - Almgren 15 related (moulded shoulder)	Roman	5525
HS Reeth	11 57	Bow - Almgren 15 related (moulded shoulder)	Roman	5548
HS Reeth	11 158	Bow - Almgren 15 related (moulded shoulder)	Roman	5560
HS Elst	EM-074	Bow - Almgren 15 related (moulded shoulder)	Roman	102865

HS Oosterhout	OA-079	Bow - Almgren 15 related (moulded shoulder)	Roman	103258
HS Linden	9 347	Bow - Eye series	Roman	98004
HS Linden	9 417	Bow - Eye series	Roman	98006
HS Linden	9 51	Bow - Eye series	Roman	98021
HS Linden	9 d	Bow - Eye series	Roman	98080
HS Linden	9 aj	Bow - Eye series	Roman	98096
HS Linden	9 v	Bow - Eye series	Roman	98098
HS Linden	9 af	Bow - Eye series	Roman	98119
HS Linden	9 ba	Bow - Eye series	Roman	98132
HS Raayen	5 3	Bow - Eye series	Roman	98155
HS Raayen	5 32	Bow - Eye series	Roman	98182
HS Eimeren	2 r	Bow - Eye series	Roman	5382
HS Eimeren	2 g	Bow - Eye series	Roman	5395
HS Eimeren	2 q	Bow - Eye series	Roman	5397
HS Eimeren	2 i 2013	Bow - Eye series	Roman	5421
HS Eimeren	2 e 2013	Bow - Eye series	Roman	5424
HS Eimeren	2 292	Bow - Eye series	Roman	5442
HS Eimeren	2 39	Bow - Eye series	Roman	5443
HS Eimeren	2 46	Bow - Eye series	Roman	5447
HS Eimeren	2 199	Bow - Eye series	Roman	5461
HS Eimeren	2 115	Bow - Eye series	Roman	5471
HS Eimeren	2 f	Bow - Eye series	Roman	5473
HS Eimeren	2 743	Bow - Eye series	Roman	5487
HS Reeth	11 180	Bow - Eye series	Roman	5544
HS Reeth	11 175	Bow - Eye series	Roman	5553
HS Linden	9 295	Bow - Eye series	Roman	5578
HS Linden	9 449	Bow - Eye series	Roman	5602
HS Linden	9 448	Bow - Eye series	Roman	5606
HS Elst	EM-138	Bow - Eye series	Roman	103197
HS Elst	EM-122	Bow - Eye series	Roman	103202
HS Elst	EAH-078	Bow - Eye series	Roman	103360
HS Elst	EG-83	Bow - Eye series	Roman	103343
HS Elst	ELa-08	Bow - Eye series	Roman	103292
HS Arnhem	AS-12	Bow - Eye series	Roman	103280
HS Oosterhout	OA-030	Bow - Eye series	Roman	103260
HS Oosterhout	OA-072	Bow - Eye series	Roman	103259
HS Elst	EM-137	Bow - Eye series	Roman	103221
HS Elst	EM-131	Bow - Eye series	Roman	103207
HS Elst	EG-27	Bow - Eye series, foot, frag	Roman	103341
HS Eimeren	2 740	Bow - Eye series, foot, frag	Roman	5501
HS Eimeren	2 b 2013	Bow - Eye series, foot, frag	Roman	5426
HS Raayen	5 62	Bow - Eye series, foot, frag	Roman	98194
HS Raayen	5 s	Bow - Eye series, foot, frag	Roman	98144
HS Linden	9 190	Bow - Eye series, foot, frag	Roman	98054
HS Linden	9 344	Bow - Aucissa series	Roman	98047
HS Linden	9 ad	Bow - Aucissa series	Roman	98079

HS Linden	9 c 2013	Bow - Aucissa series	Roman	98139
HS Eimeren	2 171	Bow - Aucissa series	Roman	5455
HS Eimeren	2 100	Bow - Aucissa series	Roman	5503
HS Elst	EAH-083	Bow - Aucissa series	Roman	103320
HS Elst	EAH-124	Bow - Aucissa series	Roman	103319
HS Elst	EAH-074	Bow - Aucissa series	Roman	103316
HS Arnhem	AS-16	Bow - Aucissa series	Roman	103282
HS Oosterhout	OA-062	Bow - Aucissa series	Roman	103269
HS Oosterhout	OA-057	Bow - Aucissa series	Roman	103268
HS Eimeren	2 f	Bow - Aucissa series, Alesia	Roman	5396
HS Eimeren	2 h	Bow - Aucissa openwork variant	Roman	5480
HS Elst	EM-533	Bow - Aucissa openwork variant	Roman	103346

Nijmegen worksheet - part 2 bulk elements

XRF No.	Cu	Sn	Pb	Zn	Ag	Fe
98097	76.32	19.47	1.41	0.19	0.09	1.75
98110	77.77	20.78	0.09	0.08	0.07	0.81
98113	56.95	28.05	9.32	0.41	0.26	3.17
98116	72.61	23.65	0.40	0.09	0.09	2.60
5511	62.05	32.82	0.23	0.16	0.17	1.53
5514	75.46	22.01	0.20	0.27	0.08	1.57
5582	77.84	18.76	0.91	0.30	0.12	1.36
102850	65.80	30.96	1.09	0.16	0.13	1.34
102851	58.55	35.21	0.78	0.10	0.10	4.72
102855	57.41	29.33	0.69	0.15	0.08	10.81
102856	71.79	25.27	0.62	0.61	0.11	1.02
102857	65.14	30.24	0.35	0.13	0.21	3.28
102860	68.30	27.02	0.66	0.17	0.25	2.80
102861	66.65	31.20	0.20	0.12	0.11	1.26
102862	63.84	31.33	0.44	0.22	0.17	3.22
102863	76.55	21.79	0.26	0.26	0.11	0.57
102864	46.64	39.98	1.04	0.50	0.16	10.03
102866	58.29	30.87	0.58	0.35	0.12	8.86
102867	76.03	22.30	0.23	0.17	0.12	0.58
102870	59.33	36.98	0.53	0.48	0.09	1.85
102875	74.35	22.49	0.75	0.14	0.16	1.54
102876	62.34	31.93	0.64	0.12	0.29	3.66
102877	62.10	31.88	0.53	0.12	0.11	4.38
102881	77.29	18.82	0.69	1.74	0.11	0.75
102886	57.71	33.07	0.40	0.83	0.13	6.83
102890	78.28	20.07	0.34	0.19	0.08	0.71
102892	66.61	30.67	0.57	0.25	0.11	1.38
102894	69.99	27.23	0.36	0.18	0.24	1.40

102895	55.15	34.04	0.68	0.17	0.12	8.80
102897	74.06	24.51	0.18	0.15	0.08	0.73
103199	76.50	21.07	0.17	0.09	<0,04	1.79
103201	70.95	25.71	0.56	0.08	0.25	1.41
103205	75.53	19.47	0.43	0.21	0.11	3.59
103211	59.59	37.92	0.46	0.13	0.15	1.17
103216	71.16	24.57	0.32	0.18	<0,05	3.27
103219	58.98	30.55	4.39	0.86	0.08	4.10
103222	76.98	16.97	0.22	0.18	0.08	4.55
103261	77.16	17.34	0.96	1.83	0.07	2.12
103267	78.88	1.10	2.67	11.56	0.07	4.90
103294	82.06	16.59	0.21	0.34	<0,05	0.42
103295	50.47	17.62	25.73	0.54	1.33	3.47
103303	76.71	21.35	0.06	<0,08	0.14	0.96
103322	60.81	34.40	0.88	0.17	0.23	2.76
103351	78.39	20.07	0.27	<0,07	0.08	0.37
98005	78.85	19.13	0.66	0.09	0.16	0.55
98019	84.34	14.67	0.14	0.07	0.08	0.46
98031	84.90	14.55	0.13	<0,09	<0,04	0.18
98036	75.38	20.83	0.89	0.21	0.10	2.17
98046	80.75	18.14	0.26	0.30	0.08	0.13
98050	66.30	28.26	0.27	0.27	0.09	3.87
98056	72.59	25.28	0.33	0.10	0.20	1.20
98060	77.37	10.68	1.16	0.18	0.07	10.18
98064	84.41	14.01	0.09	<0,06	0.16	1.04
98067	37.03	49.43	0.73	0.65	0.30	10.16
98068	60.78	32.10	0.74	0.48	0.11	4.87
98070	77.77	16.87	0.07	0.24	0.09	3.99
98078	36.21	41.58	1.59	3.72	0.18	14.95
98084	81.64	16.72	0.37	0.25	0.07	0.66
98090	79.48	18.49	0.34	0.15	0.12	1.07
98091	38.72	28.20	2.68	5.50	0.15	21.04
98105	48.64	37.87	1.51	5.57	0.43	4.63
98106	82.17	17.06	0.23	0.10	0.11	0.15
98111	71.75	23.91	1.61	1.53	0.10	0.62
98122	86.02	12.90	0.40	0.27	<0,03	0.22
98142	72.77	23.51	0.37	0.27	0.32	1.86
98153	74.43	18.72	0.70	0.58	0.27	4.52
98157	87.71	10.87	0.25	0.74	0.06	0.22
98169	87.08	9.76	0.42	1.92	0.10	0.39
98170	82.59	15.95	0.10	0.14	0.07	0.60
98171	61.24	34.24	0.82	0.42	0.20	1.46
98172	77.57	18.42	0.49	0.88	0.14	1.93
98174	67.63	20.40	0.25	0.40	0.16	9.98
98175	68.85	24.45	1.41	0.39	0.24	3.22
98181	77.07	19.63	0.51	0.32	0.36	1.21

5367	42.24	29.36	0.74	4.04	0.14	22.01
5394	41.42	11.05	38.53	3.79	0.11	4.31
5401	74.77	20.67	0.54	1.85	0.09	1.63
5404	72.10	22.09	2.31	0.85	0.22	1.16
5415	64.03	29.51	0.39	0.50	<0,1	4.49
5420	82.05	16.97	0.16	0.12	0.06	0.41
5463	56.42	38.42	0.33	0.18	0.23	3.44
5472	72.70	19.45	1.46	0.53	0.19	3.74
5474	81.35	16.61	0.12	<0,07	0.09	1.39
5476	58.31	33.86	3.33	0.61	0.12	3.03
5493	80.49	2.43	0.80	14.29	0.06	1.54
5518	79.40	18.30	0.55	0.66	0.07	0.58
5520	68.65	27.30	0.09	0.10	0.10	3.06
5524	62.59	14.84	2.16	0.33	<0,10	17.13
5527	65.75	20.88	0.88	0.83	0.12	9.44
5528	66.29	31.04	0.55	0.12	0.14	1.20
5537	58.72	23.27	2.29	5.71	0.14	8.39
5538	67.56	24.39	1.73	2.70	0.12	2.39
5546	64.44	26.39	1.15	3.27	0.08	3.73
5554	75.82	18.32	0.42	0.13	0.10	4.11
5558	51.36	40.23	1.88	1.15	0.12	4.28
5575	66.33	6.43	12.03	8.62	0.11	5.64
5576	72.03	19.79	0.70	0.43	0.15	5.00
5580	71.40	23.15	1.79	0.30	0.08	2.55
5586	82.37	16.36	0.16	0.19	0.17	0.39
5587	78.64	20.11	0.45	0.26	<0,03	0.33
5588	83.76	15.27	0.12	0.14	0.14	0.30
5593	66.41	4.32	5.52	8.64	0.11	12.52
5598	87.09	11.85	0.35	0.10	0.07	0.29
5599	84.57	14.12	0.38	0.38	0.08	0.22
5605	80.88	17.06	0.39	0.68	0.08	0.48
5607	43.29	43.91	0.46	0.22	0.13	10.18
5608	76.09	16.56	3.92	1.09	0.11	1.59
98058	67.31	25.37	2.14	1.21	0.17	2.67
98104	47.83	29.32	8.79	0.47	0.23	11.93
98109	85.61	0.52	1.21	11.11	0.08	1.21
5407	51.86	35.34	4.38	0.62	0.82	5.51
5414	79.54	18.77	0.20	0.28	0.08	0.65
5507	70.00	25.91	0.77	0.66	0.11	1.72
5519	50.73	39.34	1.15	0.50	0.23	6.53
5609	70.02	24.33	1.00	1.83	0.07	2.10
102901	56.47	36.77	0.15	0.17	0.18	5.35
102874	54.75	35.62	0.93	0.21	0.09	6.58
103350	63.12	31.83	0.83	0.60	0.11	2.68
103272	69.22	5.67	3.68	11.93	0.12	7.81
98053	85.88	2.04	1.64	7.77	0.11	2.09

98055	84.82	1.56	0.50	11.22	0.09	1.43
98069	86.43	0.49	1.40	7.06	0.12	3.83
98156	87.22	0.51	1.74	8.11	0.12	2.10
5470	85.36	0.06	0.59	12.63	<0,03	0.96
5496	88.92	0.18	0.55	8.56	<0,05	1.21
5525	68.99	1.52	4.57	6.59	0.09	16.01
5548	78.23	1.32	2.05	11.39	<0,03	6.40
5560	84.82	0.21	0.43	13.87	<0,03	0.54
102865	84.86	0.27	0.62	13.64	<0,03	0.43
103258	87.35	0.09	0.44	10.88	<0,02	1.05
98004	84.57	1.15	1.50	9.32	<0,03	2.71
98006	84.65	2.12	0.59	9.61	0.07	2.31
98021	83.38	0.43	0.35	11.54	<0,02	4.03
98080	88.00	0.20	1.20	8.88	0.07	1.35
98096	86.94	0.16	0.64	10.67	<0,02	1.38
98098	74.84	8.81	0.66	13.23	0.07	1.88
98119	86.18	2.31	0.46	10.51	<0,02	0.31
98132	82.30	1.12	0.62	12.32	0.09	2.90
98155	85.15	1.51	0.28	7.23	0.17	5.39
98182	84.92	1.37	2.35	6.44	0.13	4.38
5382	78.18	0.22	0.66	8.88	<0,03	10.51
5395	83.84	0.07	0.23	13.10	0.07	2.09
5397	84.23	0.08	0.77	12.20	<0,03	2.32
5421	86.18	0.35	0.27	12.29	<0,02	0.74
5424	83.38	1.15	0.36	14.32	0.11	0.34
5442	87.30	0.02	0.08	12.37	<0,02	0.09
5443	84.96	1.27	1.29	9.94	0.07	2.24
5447	81.08	0.43	1.77	9.97	<0,05	5.95
5461	86.26	1.50	0.24	10.35	<0,03	1.30
5471	75.88	10.85	1.38	4.96	0.06	6.31
5473	85.33	0.76	0.68	9.96	0.07	2.55
5487	71.07	4.95	3.16	4.23	0.17	15.70
5544	84.79	0.20	0.87	13.11	<0,03	0.80
5553	87.89	1.79	0.37	5.75	0.08	3.25
5578	82.34	2.62	0.98	9.19	0.12	4.04
5602	77.07	1.81	0.76	7.17	<0,05	10.39
5606	86.00	0.25	0.26	12.72	<0,02	0.58
103197	71.68	6.73	2.16	6.36	0.16	10.94
103202	88.15	0.05	0.25	10.38	0.08	0.70
103360	88.98	0.41	0.27	9.70	0.24	0.25
103343	86.28	1.15	0.88	6.91	<0,09	3.67
103292	88.27	0.18	0.38	10.18	0.07	0.65
103280	78.24	0.57	1.71	9.53	0.08	8.42
103260	90.74	0.04	0.45	7.02	0.07	1.36
103259	59.79	9.91	3.00	13.60	0.16	11.03
103221	86.95	1.02	0.36	10.82	0.06	0.55

103207	83.68	1.29	2.04	8.94	0.10	2.75
103341	83.20	1.17	2.99	8.19	<0,02	3.56
5501	77.53	0.55	0.97	18.82	<0,02	1.91
5426	83.29	1.88	3.87	7.15	0.12	3.04
98194	71.41	1.46	0.56	18.80	0.21	6.89
98144	94.47	0.13	0.64	3.27	0.14	1.11
98054	80.19	2.12	2.24	11.48	<0,03	3.55
98047	89.80	0.50	0.43	7.98	0.20	0.84
98079	46.49	18.45	25.93	3.60	0.08	4.58
98139	84.93	0.58	0.32	11.96	0.10	1.70
5455	89.95	0.05	0.60	8.05	0.23	0.77
5503	85.18	0.13	0.61	12.82	0.06	0.93
103320	83.78	0.18	0.64	13.51	0.12	1.32
103319	88.45	0.10	0.55	9.36	<0,03	1.24
103316	84.36	1.34	1.13	6.07	<0,03	6.63
103282	72.15	1.86	3.68	8.73	0.36	12.15
103269	89.63	0.59	1.17	7.14	0.07	0.98
103268	83.32	4.43	0.19	7.97	0.10	2.81
5396	83.86	1.73	1.37	8.76	0.21	3.42
5480	42.53	36.98	1.11	0.53	0.13	17.81
103346	73.52	2.42	3.41	12.35	0.07	7.34

Nijmegen worksheet - part 3 error

XRF No.	Cu error	Sn error	Pb error	Zn error	Ag error	Fe error
98097	0.13	0.10	0.06	0.03	0.02	0.05
98110	0.12	0.11	0.02	0.03	0.02	0.04
98113	0.18	0.14	0.13	0.03	0.02	0.09
98116	0.12	0.10	0.03	0.02	0.02	0.06
5511	0.16	0.15	0.03	0.03	0.02	0.07
5514	0.11	0.09	0.02	0.03	0.02	0.05
5582	0.13	0.10	0.05	0.03	0.02	0.05
102850	0.20	0.19	0.07	0.04	0.03	0.08
102851	0.21	0.21	0.06	0.04	0.03	0.13
102855	0.20	0.16	0.05	0.04	0.03	0.16
102856	0.19	0.16	0.05	0.05	0.03	0.07
102857	0.16	0.15	0.03	0.03	0.03	0.09
102860	0.20	0.17	0.06	0.04	0.03	0.10
102861	0.20	0.18	0.03	0.04	0.03	0.08
102862	0.16	0.15	0.04	0.03	0.02	0.09
102863	0.17	0.14	0.04	0.04	0.03	0.05
102864	0.31	0.31	0.08	0.07	0.04	0.26
102866	0.17	0.15	0.04	0.04	0.02	0.14
102867	0.16	0.13	0.03	0.04	0.03	0.05
102870	0.20	0.19	0.05	0.05	0.03	0.09
102875	0.16	0.13	0.05	0.03	0.03	0.06
102876	0.22	0.20	0.06	0.04	0.04	0.13
102877	0.20	0.19	0.05	0.04	0.03	0.13
102881	0.21	0.16	0.07	0.08	0.03	0.06
102886	0.22	0.20	0.04	0.06	0.03	0.16
102890	0.14	0.11	0.03	0.03	0.02	0.04
102892	0.24	0.21	0.06	0.05	0.03	0.09
102894	0.22	0.19	0.05	0.05	0.04	0.08
102895	0.22	0.20	0.05	0.04	0.03	0.17
102897	0.16	0.13	0.03	0.03	0.02	0.05
103199	0.13	0.11	0.02	0.03	0.04	0.06
103201	0.17	0.15	0.05	0.03	0.03	0.07
103205	0.14	0.11	0.04	0.03	0.02	0.08
103211	0.20	0.20	0.04	0.04	0.03	0.08
103216	0.16	0.14	0.04	0.04	0.05	0.09
103219	0.19	0.17	0.11	0.05	0.03	0.11
103222	0.13	0.10	0.03	0.03	0.02	0.08
103261	0.19	0.12	0.06	0.07	0.02	0.07
103267	0.22	0.03	0.10	0.13	0.02	0.08
103294	0.16	0.12	0.03	0.04	0.05	0.04
103295	0.18	0.10	0.16	0.03	0.03	0.09
103303	0.18	0.15	0.02	0.08	0.03	0.06

103322	0.21	0.20	0.06	0.04	0.03	0.11
103351	0.15	0.12	0.03	0.07	0.02	0.04
98005	0.12	0.09	0.04	0.03	0.02	0.03
98019	0.11	0.08	0.02	0.03	0.02	0.03
98031	0.12	0.09	0.02	0.09	0.04	0.02
98036	0.13	0.11	0.05	0.03	0.02	0.06
98046	0.11	0.09	0.03	0.03	0.02	0.02
98050	0.15	0.13	0.03	0.03	0.02	0.09
98056	0.17	0.15	0.04	0.04	0.03	0.06
98060	0.23	0.10	0.08	0.05	0.03	0.15
98064	0.11	0.08	0.02	0.06	0.02	0.04
98067	0.22	0.26	0.05	0.05	0.03	0.19
98068	0.19	0.17	0.05	0.04	0.03	0.12
98070	0.13	0.09	0.02	0.03	0.02	0.08
98078	0.21	0.21	0.06	0.09	0.03	0.19
98084	0.11	0.09	0.03	0.03	0.02	0.03
98090	0.13	0.10	0.03	0.03	0.02	0.05
98091	0.23	0.16	0.08	0.11	0.03	0.20
98105	0.22	0.19	0.07	0.10	0.03	0.12
98106	0.11	0.08	0.02	0.03	0.02	0.02
98111	0.16	0.13	0.07	0.05	0.02	0.04
98122	0.10	0.07	0.03	0.03	0.03	0.02
98142	0.11	0.09	0.02	0.02	0.02	0.04
98153	0.10	0.07	0.02	0.02	0.02	0.04
98157	0.08	0.05	0.02	0.02	0.02	0.01
98169	0.08	0.05	0.02	0.03	0.02	0.01
98170	0.08	0.05	0.01	0.02	0.02	0.02
98171	0.11	0.11	0.03	0.02	0.02	0.04
98172	0.10	0.07	0.02	0.03	0.02	0.03
98174	0.11	0.08	0.02	0.02	0.02	0.07
98175	0.10	0.08	0.03	0.02	0.02	0.04
98181	0.10	0.08	0.02	0.02	0.02	0.03
5367	0.28	0.20	0.06	0.12	0.03	0.24
5394	0.18	0.09	0.18	0.07	0.02	0.09
5401	0.17	0.13	0.05	0.06	0.02	0.07
5404	0.37	0.25	0.17	0.09	0.05	0.11
5415	0.36	0.31	0.07	0.08	0.10	0.21
5420	0.11	0.09	0.02	0.03	0.02	0.03
5463	0.20	0.20	0.04	0.04	0.03	0.12
5472	0.65	0.39	0.23	0.14	0.09	0.29
5474	0.14	0.11	0.02	0.07	0.02	0.06
5476	0.24	0.21	0.12	0.05	0.03	0.12
5493	0.20	0.05	0.06	0.14	0.02	0.05
5518	0.16	0.12	0.05	0.05	0.02	0.04
5520	0.15	0.13	0.02	0.03	0.02	0.08
5524	0.38	0.18	0.14	0.07	0.10	0.28

5527	0.34	0.22	0.10	0.09	0.05	0.23
5528	0.15	0.14	0.04	0.03	0.02	0.06
5537	0.29	0.19	0.11	0.14	0.03	0.17
5538	0.30	0.20	0.11	0.11	0.04	0.12
5546	0.23	0.17	0.07	0.09	0.03	0.12
5554	0.19	0.14	0.05	0.04	0.03	0.11
5558	0.19	0.19	0.07	0.05	0.03	0.12
5575	0.21	0.07	0.15	0.11	0.02	0.09
5576	0.14	0.10	0.04	0.03	0.02	0.09
5580	0.15	0.12	0.07	0.03	0.02	0.07
5586	0.13	0.10	0.02	0.03	0.02	0.03
5587	0.13	0.10	0.03	0.03	0.03	0.03
5588	0.13	0.10	0.02	0.03	0.02	0.03
5593	0.31	0.07	0.15	0.15	0.03	0.15
5598	0.11	0.08	0.03	0.03	0.02	0.02
5599	0.11	0.08	0.03	0.03	0.02	0.02
5605	0.12	0.09	0.03	0.04	0.02	0.03
5607	0.21	0.23	0.04	0.04	0.03	0.18
5608	0.17	0.10	0.10	0.05	0.02	0.06
98058	0.18	0.14	0.08	0.05	0.02	0.08
98104	0.19	0.15	0.12	0.04	0.02	0.15
98109	0.13	0.02	0.06	0.09	0.01	0.03
5407	0.21	0.19	0.11	0.05	0.04	0.14
5414	0.16	0.13	0.03	0.04	0.03	0.05
5507	0.14	0.12	0.04	0.04	0.02	0.06
5519	0.23	0.23	0.07	0.05	0.03	0.17
5609	0.15	0.12	0.05	0.05	0.02	0.07
102901	0.20	0.20	0.03	0.04	0.03	0.14
102874	0.19	0.18	0.05	0.04	0.03	0.14
103350	0.17	0.16	0.05	0.04	0.02	0.09
103272	0.31	0.09	0.14	0.18	0.03	0.14
98053	0.17	0.04	0.08	0.10	0.02	0.05
98055	0.14	0.03	0.04	0.10	0.01	0.04
98069	0.16	0.02	0.06	0.08	0.02	0.06
98156	0.11	0.01	0.05	0.05	0.01	0.03
5470	0.17	0.01	0.05	0.12	0.03	0.03
5496	0.13	0.01	0.04	0.09	0.05	0.03
5525	0.33	0.05	0.15	0.14	0.03	0.19
5548	0.19	0.03	0.07	0.11	0.03	0.08
5560	0.18	0.02	0.04	0.13	0.03	0.03
102865	0.18	0.02	0.05	0.13	0.03	0.03
103258	0.13	0.01	0.03	0.09	0.02	0.03
98004	0.16	0.03	0.07	0.09	0.03	0.05
98006	0.13	0.03	0.04	0.08	0.01	0.04
98021	0.12	0.01	0.03	0.08	0.02	0.05
98080	0.11	0.01	0.05	0.07	0.01	0.03

98096	0.11	0.01	0.04	0.08	0.02	0.03
98098	0.15	0.06	0.04	0.10	0.02	0.04
98119	0.12	0.03	0.03	0.08	0.02	0.02
98132	0.17	0.03	0.05	0.11	0.02	0.06
98155	0.07	0.02	0.02	0.04	0.01	0.03
98182	0.13	0.02	0.04	0.04	0.01	0.04
5382	0.18	0.01	0.04	0.09	0.03	0.09
5395	0.14	0.01	0.03	0.10	0.01	0.04
5397	0.16	0.01	0.05	0.10	0.03	0.04
5421	0.12	0.01	0.03	0.09	0.02	0.02
5424	0.11	0.02	0.03	0.09	0.01	0.02
5442	0.10	0.01	0.01	0.08	0.02	0.01
5443	0.13	0.02	0.05	0.08	0.01	0.04
5447	0.18	0.02	0.07	0.10	0.05	0.07
5461	0.13	0.03	0.02	0.09	0.03	0.03
5471	0.23	0.10	0.08	0.11	0.03	0.12
5473	0.18	0.02	0.05	0.11	0.02	0.05
5487	0.17	0.04	0.08	0.07	0.02	0.11
5544	0.15	0.01	0.05	0.11	0.03	0.03
5553	0.13	0.03	0.03	0.07	0.02	0.05
5578	0.14	0.03	0.05	0.08	0.01	0.05
5602	0.21	0.04	0.05	0.10	0.05	0.11
5606	0.11	0.01	0.02	0.09	0.02	0.02
103197	0.22	0.07	0.09	0.11	0.03	0.13
103202	0.11	0.01	0.02	0.08	0.01	0.02
103360	0.10	0.01	0.02	0.07	0.01	0.01
103343	0.29	0.04	0.09	0.14	0.09	0.10
103292	0.11	0.01	0.03	0.08	0.01	0.02
103280	0.16	0.02	0.06	0.09	0.01	0.08
103260	0.11	0.01	0.03	0.07	0.01	0.03
103259	0.21	0.07	0.08	0.12	0.02	0.11
103221	0.11	0.02	0.03	0.09	0.01	0.02
103207	0.16	0.03	0.07	0.09	0.02	0.05
103341	0.14	0.02	0.07	0.07	0.02	0.05
5501	0.14	0.02	0.04	0.10	0.02	0.03
5426	0.16	0.03	0.09	0.08	0.02	0.05
98194	0.13	0.03	0.03	0.09	0.02	0.05
98144	0.07	0.01	0.02	0.03	0.01	0.02
98054	0.16	0.03	0.07	0.10	0.03	0.06
98047	0.11	0.02	0.03	0.07	0.01	0.02
98079	0.19	0.12	0.18	0.07	0.02	0.10
98139	0.12	0.02	0.03	0.09	0.01	0.03
5455	0.13	0.01	0.04	0.08	0.02	0.03
5503	0.13	0.01	0.04	0.09	0.01	0.03
103320	0.12	0.01	0.04	0.09	0.01	0.03
103319	0.13	0.01	0.04	0.08	0.03	0.03

103316	0.14	0.02	0.05	0.07	0.03	0.07
103282	0.18	0.03	0.09	0.09	0.02	0.10
103269	0.11	0.02	0.05	0.07	0.01	0.03
103268	0.14	0.05	0.02	0.09	0.02	0.05
5396	0.13	0.03	0.05	0.08	0.01	0.05
5480	0.24	0.22	0.06	0.05	0.03	0.22
103346	0.19	0.03	0.09	0.11	0.02	0.08

Corrosion Experiment Worksheet part 1 typological data

Collection	**Find ID**	**Description**	**XRF No.**
HS Elst	EM-018b	Bow - Almgren 15 - Corr.	103140
HS Elst	EM-018b	Bow - Almgren 15 - Clean	103142
HS Elst	EM-018a	Bow - Almgren 20 - Corr.	103143
HS Elst	EM-018a	Bow - Almgren 20 - Clean	103144
HS Elst	EM-007	Bow - Almgren 20 - Corr.	103145
HS Elst	EM-007	Bow - Almgren 20 - Clean	103146
HS Elst	EM-016	Bow - knee-brooch Böhme 19, foot - Corr.	103147
HS Elst	EM-016	Bow - knee-brooch Böhme 19, foot - Clean	103148
HS Elst	EM-095	Bow - Corr.	103149
HS Elst	EM-095	Bow - Clean	103150
HS Elst	EM-142	Bow - Corr.	103151
HS Elst	EM-142	Bow - Clean	103152
HS Elst	EM-492	Bow - Almgren 20 - Corr.	103153
HS Elst	EM-492	Bow - Almgren 20 - Clean	103154
HS Elst	EM-140	Bow - Corr.	103155
HS Elst	EM-140	Bow - Clean	103156
HS Elst	EM-540	Bow - Almgren 20 - Corr.	103159
HS Elst	EM-540	Bow - Almgren 20 - Clean	103160
HS Elst	EM-902	Bow - Corr.	103163
HS Elst	EM-902	Bow - Clean	103165
HS Elst	EM-552	Bow - Almgren 15 - Corr.	103166
HS Elst	EM-552	Bow - Almgren 15 - Clean	103167
HS Elst	EM-655	Bow - Van Buchem 24 - Corr	103168
HS Elst	EM-655	Bow - Van Buchem 24 - Clean	103170
HS Elst	EM-597	Bow - Almgren 15 - Corr.	103171
HS Elst	EM-597	Bow - Almgren 15 - Clean	103172
HS Oosterhout	OA-145	Bow - Eye series, foot, frag - Corr	103173
HS Oosterhout	OA-145	Bow - Eye series, foot, frag - Clean	103174

Corrosion Experiment Worksheet part 2 bulk elements

XRF No.	Cu	Sn	Pb	Zn	Ag	Fe
103140	41.89	44.75	1.79	0.45	0.30	9.23
103142	87.66	10.91	0.40	<0,13	0.12	0.39
103143	78.81	5.78	1.69	8.74	0.12	4.12
103144	79.01	1.35	0.27	18.97	<0,04	0.23
103145	85.95	0.27	0.55	11.87	<0,03	1.10
103146	80.74	0.17	0.35	17.99	<0,04	0.64
103147	55.22	36.50	1.33	0.51	0.11	5.63
103148	85.90	12.98	0.29	0.31	<0,05	0.27
103149	43.77	27.06	0.12	0.20	0.13	25.77
103150	85.43	13.65	0.05	<0,07	0.10	0.42
103151	35.26	49.81	5.67	0.57	0.17	7.52
103152	83.36	13.44	2.07	0.66	0.07	0.20
103153	85.02	0.53	0.80	11.16	0.07	1.85
103154	79.29	0.29	0.36	19.54	<0,02	0.43
103155	21.15	59.54	0.30	0.17	0.09	17.32
103156	81.37	17.77	0.05	<0,09	<0,05	0.48
103159	81.75	1.28	0.50	9.62	0.07	5.55
103160	80.77	0.57	0.11	17.92	<0,03	0.39
103163	69.25	17.80	1.26	4.81	0.15	6.02
103165	87.27	6.61	0.36	4.77	<0,10	0.61
103166	78.57	20.10	0.45	0.18	0.07	0.31
103167	86.04	13.36	0.25	0.08	<0,05	0.11
103168	63.59	24.88	0.72	5.20	0.13	4.69
103170	85.75	7.61	0.17	6.06	<0,04	0.29
103171	71.87	25.44	0.56	0.56	0.09	1.02
103172	83.78	14.84	0.23	0.45	0.08	0.32
103173	79.65	5.86	1.81	8.07	0.08	3.68
103174	77.99	1.34	0.19	20.15	<0,05	0.19

Corrosion Experiment Worksheet part 3 error

XRF No.	Cu error	Sn error	Pb error	Zn error	Ag error	Fe error
103140	0.27	0.29	0.09	0.05	0.04	0.23
103142	0.30	0.17	0.08	0.13	0.04	0.06
103143	0.23	0.08	0.10	0.14	0.03	0.09
103144	0.25	0.04	0.04	0.18	0.04	0.02
103145	0.16	0.02	0.05	0.11	0.03	0.04
103146	0.24	0.02	0.05	0.17	0.04	0.04
103147	0.24	0.23	0.08	0.05	0.03	0.16
103148	0.18	0.12	0.04	0.05	0.05	0.03
103149	0.28	0.20	0.03	0.05	0.04	0.27
103150	0.14	0.11	0.02	0.07	0.02	0.04
103151	0.22	0.26	0.12	0.04	0.03	0.18
103152	0.17	0.11	0.10	0.05	0.02	0.03
103153	0.13	0.02	0.04	0.09	0.01	0.04
103154	0.16	0.01	0.03	0.12	0.02	0.02
103155	0.26	0.37	0.04	0.04	0.04	0.31
103156	0.19	0.15	0.02	0.09	0.05	0.05
103159	0.33	0.05	0.07	0.17	0.03	0.12
103160	0.19	0.02	0.02	0.14	0.03	0.02
103163	0.22	0.13	0.07	0.10	0.03	0.12
103165	0.50	0.17	0.10	0.20	0.10	0.08
103166	0.14	0.12	0.04	0.04	0.02	0.03
103167	0.15	0.11	0.04	0.04	0.05	0.02
103168	0.21	0.16	0.06	0.11	0.03	0.12
103170	0.16	0.07	0.03	0.09	0.04	0.03
103171	0.23	0.19	0.06	0.06	0.03	0.08
103172	0.25	0.17	0.05	0.07	0.04	0.05

Chapter 3

Early Roman copper-alloy brooch production: a compositional analysis of 400 brooches from *Germaina Inferior.*

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We present here a compositional study of a large number of copper-alloy brooches, undertaken in 2014 using Handheld X-ray Fluorescence Spectrometry (HHpXRF). The brooches, which come from the area of Nijmegen, date from the Late Iron Age until the 2nd c. A.D. Our aim is to explore the ways in which artefact production was organized both in the context of Roman centres and in the countryside. The link between alloys and workshop organization will be elucidated before the methodology and results are presented. The results will then be discussed, leading to the formation of several hypotheses regarding the organization of workshops that produced metal artefacts.

Scientific interest in the composition of ancient artefacts has existed for well over two centuries. Roman brooches in particular have been in the forefront of this research both because of their ease of categorization and because they are found in large numbers on archaeological sites. Much work has been done on how they were made and on the technical choices available to the craftsmen. In particular, the choice of alloying agents (tin, lead, zinc) added to copper demonstrated a complex relationship between composition and typology, especially in the debate over Roman or local production (Dungworth 1997, 902). The technological restraints imposed on these artefacts by different alloy ratios have been studied in some detail (Smythe 1938; Unglick 1991; Bayley and Butcher 1995, 2004; Craddock 1988), especially in terms of casting in liquid form, into a mould, or being wrought through beating with a hammer.

Thanks to the development of X-Ray laboratory-based research since the 1950s, a clearer understanding of the alloying process has been achieved. Until the last decade, however, most of this research has taken place in scientific institutions rather than in museums or places of storage. Not only were there significant cost implications arising from the choice of method or apparatus employed, there was also a hidden cost of safely transporting items to and from their owners and the laboratory. To compound the issue, nearly all methods involved a certain level of damage to the artefact, either by drilling into its centre to remove a sample for testing, or by removing the patina (outer corrosion layer) to gain a clean surface — a requirement plainly at odds with the conservation practices of most museums and other owners, which resulted in a limited availability of objects to study.

X-Ray fluorescence, as a technique for identifying an item's composition, has been available for a number of decades but, thanks to advances driven initially by the mining and scrap metal industries, the equipment has been miniaturised to a point where it can easily be transported and thereby set up on remote sites, such as on archaeological excavations or in museums and storage depots. Yet it is also necessary to understand the limitations: the X-rays only penetrate a fraction of a millimeter below the surface, which could be especially problematical where surface enrichment has taken place, such as in the gilding or silvering of coins (e.g. Hall 1961; Cowell and Niece 1991; Pollard and Heron 1996). To bypass this limitation, appropriate research questions and qualitative or semi-quantitative approaches should be employed (See Shugar and Mass 2012; Gigante, Ricciardi and Ridülfi 2005 for further reading on HHpXRF approaches). The general

advantage of HHpXRF over laboratory apparatus is that it is relatively cheap, quick to use, easily portable, and can be applied in a non-destructive way. Research on brooches found in The Netherlands has until now mainly centred on typological issues and the description of brooches from individual sites (van Buchem 1941; Haalebos 1986; van der Roest 1988). Little is known generally about brooch production in what was the Roman province of Germania Inferior because excavated workshops are very rare. The little research done has been conducted on small numbers of brooches, not least because of the destructive nature of the methods. Fortunately, the recent advances in technology have allowed new approaches to be considered.

When large numbers of objects of a uniform typology are present in the archaeological record, a research opportunity presents itself. One avenue addresses the question: What kind of organization was required to produce and distribute large numbers of these items, to an agreed standard, across a large geographic area? For example, were objects produced in a single, regional or even supra-regional production centre and subsequently distributed along familiar trade routes, or were they made in many dispersed local workshops that copied and distributed new designs as required, to satisfy local demand? An associated question is whether raw materials involved in production were sourced from widely dispersed locations, or from single supply centres (e.g., the long-established mining areas of Cornwall or the Belgian Ardennes).

Even in cases when the source of the raw materials is not known, the complexity of their procurement and subsequent production standards can be implied. In a study of compositional variation across a wide geographic area, a high degree of uniformity is likely to imply that the objects and raw materials were supplied and produced in a centralised fashion. By contrast, significant compositional variation is likely to indicate separate production events, perhaps at many different workshops governed by differing quality standards that in turn were influenced by variations in the sourcing of the raw material. This avenue of research becomes even more useful once it is applied to chronological variation, changes in morphology, and the creation of typologies, especially in relation to the known dating of sites and materials. For example, the typological classification of Roman brooches is well advanced in many countries (Just a few of the main works are: Almgren 1923; Böhme 1972; Riha 1979; Feugère 1985). Less well developed before the recent technological advances has been the study of composition. With good typological dating, variations over time, perhaps combined with changes in production quantity, can be taken as indications of wider economic changes.

For investigating the organization of artefact production the study of composition can provide useful information, but only if large amounts of compositional analyses are available and when the precision of the measurements is sufficient to distinguish between compositional groups. The development of HHpXRF applied especially on large collections resulting from metal-detecting has provided this opportunity. Previous research had already suggested that Roman brooches offered a prime opportunity to study objects in this way due to the uniformity seen in their typologies (See Istenič and Šmit 2007; Drnić 2013).

However, information on the production of brooches in the form of the discovery of workshops or parts from them (e.g. casting moulds) is rare. Only two workshops have been excavated and recognised as such, along with a small number of sites that have turned up recognisable casting moulds (Riha 1979, 37; Böhme 1972, 48)

There are some existing theories on the organisation of brooch production because there are close parallels between some brooch types and items of military gear, in particular sword

suspension hooks and armour fittings, as well as other military-related objects such as seal-boxes. The resemblance in form and decoration of such objects suggests that many brooches were produced in military workshops; this is further suggested by the fact that several of these types have been found in military camps. The Aucissa type is seen as the soldiers' brooch during the Early Imperial period (c.20 B.C.–A.D.70), since it is present in large numbers in camps during the expansion under Augustus:at the military site of Haltern, 81% of the brooches recovered (n=361) were of the Aucissa type (Haalebos 1986, 43; Müller 2002, 29). This high amount might be accounted for by the fact that the camp was abandoned in A.D.9 and the type was quite new at that point. At sites with a longer habitation history, for instance the camp at Nijmegen–Kops Plateau, the proportion of Aucissas amounts to 33% (n=567). In contrast, the Aucissas from the contemporaneous civilian town of Nijmegen–Oppidum Batavorum amounts to only 15% of the brooch assemblages, suggesting therefore that the type is connected to the military (Heeren and van der Feijst 2014). Half-finished examples of Aucissa brooches have also been found in several military camps, again suggesting military-related production (See Riha 1979, 37, Abb. 17; Haalebos 1986, 74, fig. 28, no. 1).

The question can be posed as to whether the close relationship between the army and brooch production is valid only for a select group of brooch types. Certain types are widely distributed and therefore associated with the army, while locally distributed types are associated with a specific provincial region or tribe. In Germania Inferior the presence of various types of 'wire brooches' (Draadfibulae or "Nauheim-derivative") is a regional phenomenon.Wire brooches have also been found in small numbers in other provinces (Mackreth 2011, pl.12 for Britain), but percentages as high as 40-60% are common on any given site in Germania Inferior (Heeren and van der Feijst 2014, 99). Thus the question of the provenance of these types (and others such as the Eye brooch, which is contemporary with the Aucissa brooch) remains open. They have been called Soldatenfibeln before (Riha 1979, 59, "Soldatenfibeln") but now large numbers from rural sites are available, so that other options must also be explored (E.g., production in local or 'tribal' workshops. Alloy classification and alloy uniformity can provide further arguments.

In this debate the Roman production of brass artefacts is also of some importance. Apparently brass was first introduced on an industrial scale by the Romans during the 1st c. B.C. (Craddock 1978, 8-9; Istenič 2005, 187-188), and then only through the development of a technique now known as the cementation process (Bayley and Butcher 2004, 13). It has been assumed that the Roman state reserved it for the production of items such as coins and military equipment, at least for a time (Dungworth 1997, 903), but towards the end of the 1st c. A.D. brass appears to have been withdrawn from circulation (Bayley and Butcher 1995, 118), as may be suggested by the increasing use of bronze in brooch production.

In order to study the organisation of Roman brooch production from examples found in various locations across The Netherlands, the following were necessary. First, the metal composition of pre-conquest Iron Age brooches had to be established in order to provide a comparison for Roman-era production. Sufficient brooches of a well-defined typology, such as the Nauheim series, would have to be included. Second, it had to be established whether the alloys used for Roman military types, such as the Aucissa series, were considerably different from the Late Iron Age alloys; and it needed to be shown that the Roman alloys are homogeneous over large areas. If this were to prove the case, they can be considered to be real 'Roman' brooch alloys. Third, sufficient brooches of many different types needed to be measured, so that 'real

Roman' alloys, once established, could be compared to alloys confined to more local or tribal typologies. It would then be possible to say something about the level of compositional control found in different brooch types. By comparing the Dutch results to those from other regions, ideas about the organization of both production and the distribution of finished items could be proposed.

METHODOLOGY

The present study was conducted on 406 brooches recovered from several locations across The Netherlands. The largest group of measurements was taken from bow brooches in the private collection of Harry Sanders and at the Bureau Archeologie & Monumenten, Nijmegen; these brooches were all recovered during archaeological fieldwork in that city or in metal-detecting on ploughed fields in neighbouring municipalities. The remainder were from the northern provinces of Friesland and Groningen (The Zijlstra and Regtop collections, housed at the Northern Archaeological Depot, Nuis.), from the city of Maastricht (From the municipality collections at the Centre Céramique, Maastricht, in the province of Zuid Limburg), and from the province of Zeeland (From collections housed at the Zeeuws Museum and the Cultural Heritage Agency for Zeeland (SCEZ). The brooch types were chosen from a broader selection of material according to the following criteria: they needed to be easily recognisable, they had to be datable, and there had to be enough of them to be significant. A minimum number of 6 brooches was decided upon, and this led to generating the results for each of the types listed below (Future data gathering could add more typologies (e.g. enamelled military and animal brooches), but only when access to further collections with sufficient numbers of brooches becomes possible.).

A Niton XL3t GOLDD XRF analyser was used for the study. It was factory calibrated with standards for metals and alloys; it also had a silicon drift detector with optimised geometry. The electronic metals mode was selected and used throughout the data-gathering phase; the advantage of this mode is that the same metals contained in Roman alloys (copper, tin, silver, zinc, gold) are found in modern electronic equipment, including potentially hazardous metals that need to be identified in the recycling of scrap (lead, mercury, arsenic, selenium). The analyser was mounted on a lead-covered portable test bench so as to provide a consistent operating environment and to protect the user from radiation. After various measuring times were tested, the signal was found to be stable after a reading time of 30 seconds. Following the analyses, the spectra were checked for inconsistencies and an external normalization of the data-set was undertaken. The calibration of the device was further checked for applicability to copper-alloy research against the CHARM - heritage bronze reference set (see Heginbotham et al. 2015, and ternary diagram a in fig. 1). The data was then reproduced as an Excel database to aid further study.

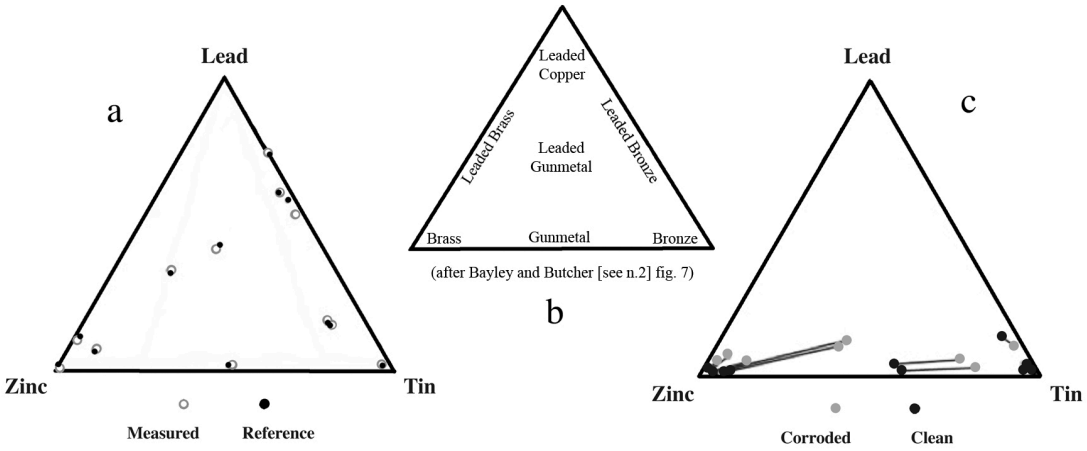


Fig. 1. Ternary diagrams: a) Charm calibration; b) Classifications; c) Corrosion effects.

Corroded metal is one of the most problematic materials to investigate with HHpXRF because the outer corrosion has an altered composition relative to its original (uncorroded) state. The bias introduced due to corrosion was evaluated by studies on a selection of corroded Roman bow-brooch fragments; this revealed that a depletion in copper and zinc takes place, altering measurements recorded on the outer surface of an item (See Fernandes, van Os and Huisman, 2013 for methodology. In our analysis both the patina and altered outer surface were removed to a depth of 1 mm to access a clean inner core for measuring.). Ternary diagram c in fig. 1 shows the difference in graph locations for corroded and non-corroded results. This suggested that decuprification and dezincification are the most probable corrosion processes at work. Depletion in copper content was seen to be the most active change, with the leeching of zinc from brass objects also seen to be common. Yet the effects of corrosion on the alloying elements tin, lead and zinc, when plotted as a ratio in ternary diagrams, did not prevent the measurements from falling into broad compositional groups. Identifying these groups was considered to be of some help in terms of further understanding Roman metal production. This is useful for brooches in particular because they are found in great numbers and variation.

RESULTS

The study of copper alloys in Roman Britain by J. Bayley and S. Butcher (1995 and 2004), already demonstrated the effectiveness of ternary diagrams for visualising their ratios of tin, zinc and lead. Their study identified multiple distinct compositional groups of Roman brooches that matched well the typological data. Because we were interested only in the deliberate addition of alloying metals, copper was not taken into account, as it is present (by definition) in all copper alloys. This type of classification is thus less sensitive to variations in surface copper content resulting from corrosion effects. For our study this was the classification scheme adopted (fig. 1 diagram b). The alloy compositions are presented in the following ternary diagrams (fig. 2) in chronological order, along with the number of each type measured. We start with a common Iron Age variant, the Nauheim brooch, to identify pre-Roman alloy production. The diagrams chart the introduction of brass in the 1st c. B.C. as seen in the Aucissa series, and its subsequent phasing out by the end of the 1st c. A.D., seen in the van Buchem 23 types.

DISCUSSION

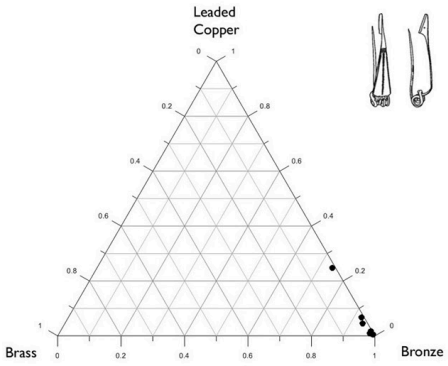
The pre-Roman production of Nauheim brooches is in a bronze alloy, demonstrating the widespread lack of brass at this time, but by the time the Spoonbow types appear (late 1st c. B.C.) the data suggest a switch away from bronze to production in brass, an alloy that became widely available during this period. Because we have examples of this type made of both brass and bronze, one explanation could be that the brass examples are later than those cast in bronze.

In the Aucissa series, appearing around 20 B.C., brass appears to be the preferred alloy. Although some Aucissas may have been used in non-military contexts, the Aucissa type is the most frequently used brooch in military camps, and production is known from military centres.

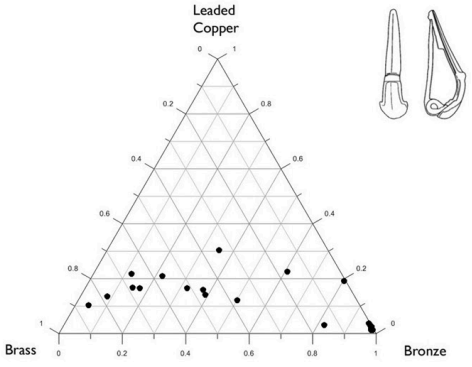
Roman military production fits neatly with the 'industrialisation' of brass production by the Romans in the 1st c. B.C. Note that the alloy measurements for Aucissa brooches are available for other areas too: Bayley and Butcher published laboratory results for Aucissa brooches from Britain (2004, 152, fig.118.), and there are also measurements from Israel (Ponting and Segal 1998). All lie firmly in the brass corner of their ternary diagrams, suggesting that all Aucissas were made in brass, at least in the early period. Two models then arise for the military workshops where the Aucissa brooches were made: either the artisans in these workshops were fully able to control their choice of alloy, or half-products were cast in a central workshop and then widely distributed. Since half-finished products were found in different locations (Riha 1979, 37, Abb. 17; Haalebos 1986, 74, fig. 28, no. 1.), the possibility that finished products were distributed in this way is less likely — or at least not valid for all Aucissa brooches.

The results for the Aucissa series identified two bronze outliers, easily detected in the ternary diagram. These measurements may result from hitting a patch of surface decoration such as tinning, or a solder repair — either could produce a result in the bronze area of the diagram — but there is also the possibility of copying taking place by local workshops, in a non-standard alloy, an option which can now be explored.

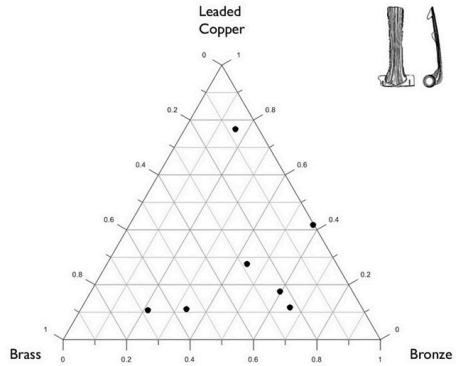
Other important brooch types, such as Eye brooches, Knickfibeln, Almgren 19 and 20, the early wire brooches, the Almgren 22a+b series, and Van Buchem 13Ce, the rounded brooch with 4 knobs, are also produced in brass. One curious brass type is related to the early wire series; this can easily be mistaken for one of the more common Almgren 15 types, but closer inspection reveals a moulded shoulder just behind the spring, and the shape of the bow itself also appears cast rather than drawn. The alloy puts this brooch at odds with other morphologically-similar Almgren 15 types. That the Almgren 22a+b series is composed of brass is also an important result, as this type is not very numerous at military sites but present in elevated numbers at rural sites. This probably suggests that brass was also employed in the countryside by traditional workshops, though to a far lesser extent than bronze and gunmetal (the other option, that the Roman army controlled all brass and produced separate types for the native population, is far less likely). This makes it likely that the choice of brass or bronze was related to choices in the production process.



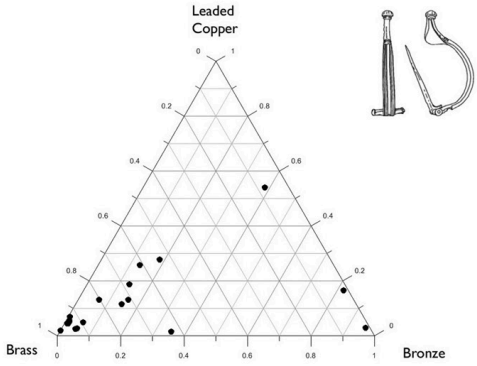
Nauheim 150 - 70 B.C. n. 7



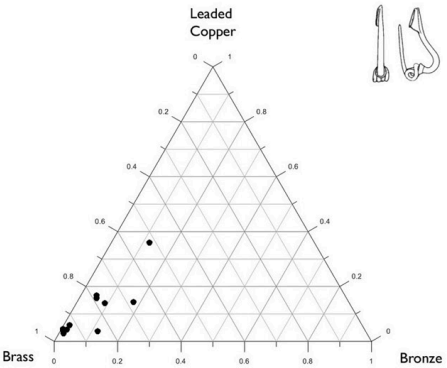
Spoonbow 30 B.C. - A.D. 40 n. 20



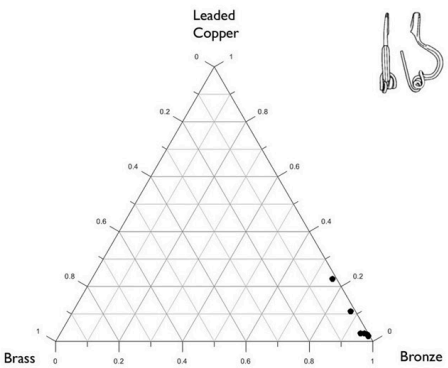
Bow on Spring-tube (Gallic) 20 B.C. - A.D. 40 n. 8



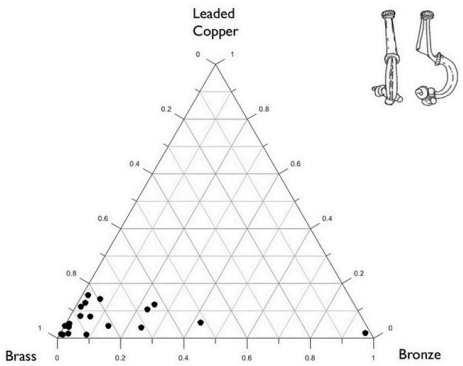
Aucissa Series 20 B.C. - A.D. 80 n. 19



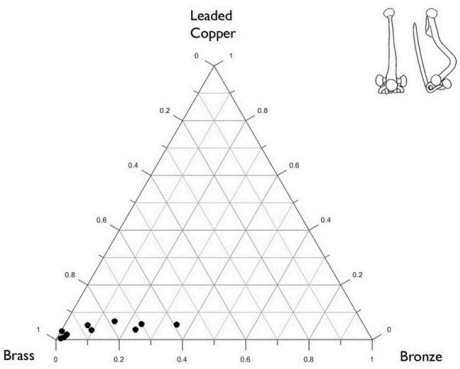
Almgren15 Related 15 B.C. - A.D. 70 n. 11



Almgren15 Related 15 B.C. - A.D. 70 n. 6

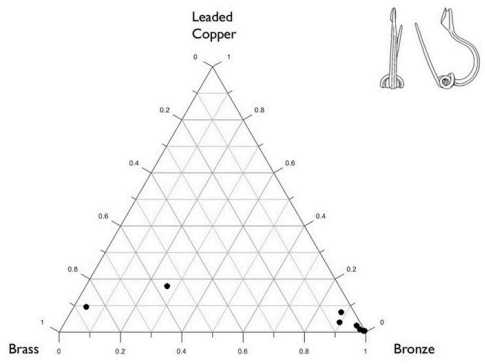


Almgren 22 series A.D. 1-50 n. 19

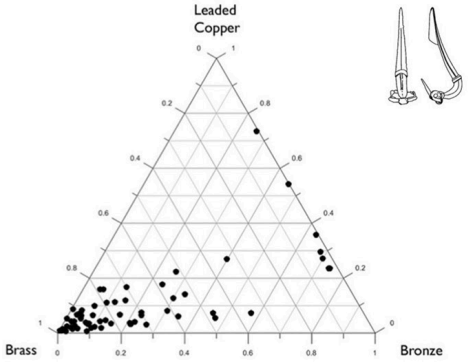


Van Buchem13Ce A.D. 1-50 n. 9

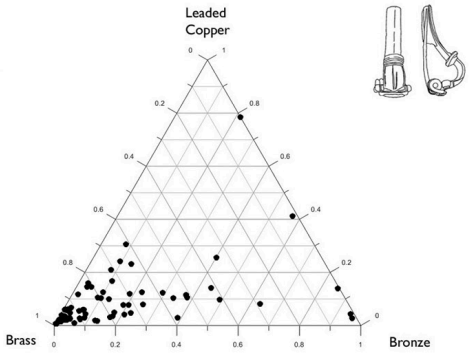
Fig. 2. Compositional results organized chronologically and by type.



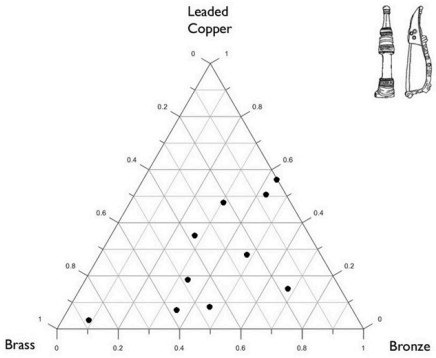
Almgren15 Related A.D. 1-50 n. 8



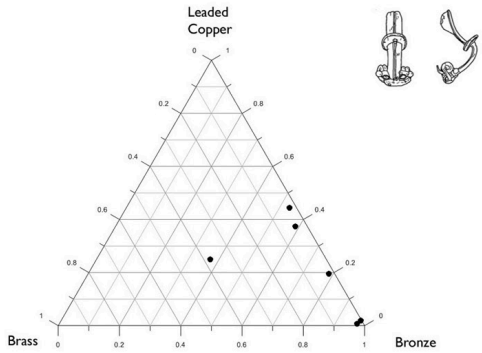
Almgren19 + 20 Series A.D. 1-100 n. 65



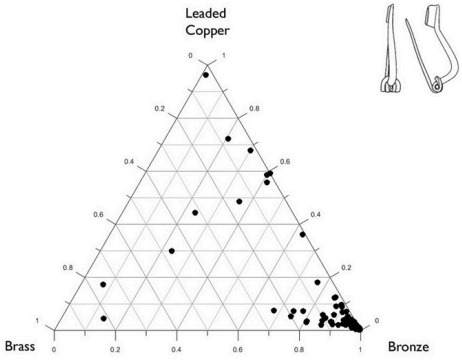
Eye Series A.D. 5-70 n.67



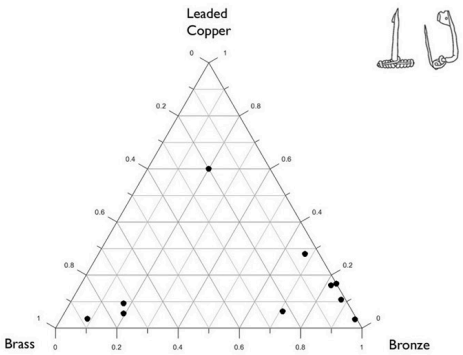
Hod Hill Series A.D. 20-90 n. 9



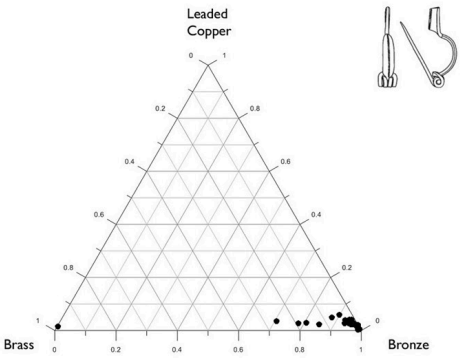
Germanic Rollenkappe A.D. 40-150 n. 6



Almgren15 Series A.D. 40-150 n. 115



One-piece Knee (Germanic) A.D. 70-150 n. 10



Van Buchem23 A.D. 90-180 n. 27

Fig. 2 (continued). Compositional results organised chronologically and by type.

Not all brooch styles, however, converted to brass in the 1st c. B.C.; some Almgren 15 wire types datable between c. 15 B.C. and A.D. 70 remained in bronze. Furthermore, the archetypal Almgren 15 wire brooch, a common find on Roman sites from the mid-1st c. into the 2nd c. A.D., is also in bronze. A further observation is that these wire brooches are drawn and hammered into shape, rather than cast. Bronze could therefore have been chosen for its practical properties in relation to the manufacturing technique, rather than for other reasons.

Two important groups do not conform to either brass or bronze. The Gallic Bow-on spring series, dating to around the same time as the Aucissa series, appears to avoid either option, having leaded gunmetal as a preferred alloy. One plausible explanation is that this series had a tinned surface probably on a brass core, with the result that the surface measurements would include a varying amount of residual tin, pulling the measurements into the gunmetal areas of the ternary diagram. This result also appears in the Hod Hill brooch series, which is quite diverse (it includes many from the British Isles). The results of Bayley and Butcher's study are comparable (2004, 153, fig.120) in that both studies show a scattered spread of alloy compositions in leaded gunmetal; importantly, however, a large concentration of brass and a secondary concentration of leaded bronze, present in the British results, are missing in the Dutch results. Towards the end of the 1st c. A.D., we detect a shift away from brass back to bronze, as shown by the alloy measurements of the Van Buchem 23 and 24 series.
The timing of this change conforms to the notion that brass is withdrawn from circulation around this date (Bayley and Butcher, 1995, 118).

VARIOUS HYPOTHESES

a) Craftsmen control the choice of alloy

Many brooches have a very uniform composition: whether brass or bronze, in many of the types all or most of the readings are of a single alloy category. This probably means that the type of alloy was well controlled by the craftsmen. The other option; that half-products were cast centrally and then distributed, is much less likely (See the discussion of the Aucissa type above.).

b) The choice of alloy relates to the mode of production

Since Nauheim-brooches of the prehistoric period were in almost pure bronze and Aucissa brooches (which are strongly associated with the Roman military, though from their presence in civilian contexts are not entirely reserved to the military) were in an almost pure brass, one explanation could be that traditional workshops retained the use of bronze, and that all brass brooches are produced by the military. The other option is that the choice of material is connected to the production method: alloys for casting require other properties than alloys for smithing (drawing and hammering). It was observed above that a simple wire brooch (Almgren 15) was predominantly in bronze, whereas a wire-related brooch with a broad collar, which requires casting, was in brass. This still leaves open both options: either the casting process determined the choice for brass, or (possible) production in a military camp explains the choice of brass. The same line of argument can be pursued for eye brooches: the massive form needs to be cast, and

this might be the reason that it is executed in brass; but it is also possible that it is simply a 'military' type, made by the military and later taken home by veterans returning to live in the countryside (explaining why it is also found relatively often in the countryside). An important clue lies in the fact that the brooch type Van Buchem 13 Ce is hardly ever present in military contexts but is fairly common (though not numerous) on rural settlements. The results given above prove that this type is executed in brass. Morphologically, this type with an upper chord and 4 massive knobs had to be cast. We can suggest therefore that the production process was determined to some extent by the choice of alloy. Therefore brass may not have been strictly limited to military supply.

c) Military-based and traditional metalworking existed alongside one another

It is conceivable that all brooches were produced by army workshops; the process of smithing for certain types could have been executed next to the casting for other types. According to a first hypothetical model, rural production will simply have ceased after large quantities of brooches became available in the civilian settlements surrounding army camps. A second hypothetical model is that the military workshops created brooches only for the needs of the military personnel in camps and their families nearby, while rural smiths produced brooches for the local people. The longevity of the selection of bronze alloys for wire brooches based on the Nauheim archetype is an argument for the second model. The first model would imply a highly commercial exchange sector aimed at providing goods for a large market, with profit as the chief motivator. These 'modernist' positions however, have been heavily criticised in the past (Finley 2014; Badian 1968; Hobson 2014), and the first model is less likely as the explanation for the observations made above.

SUMMARY AND CONCLUSIONS

The metal composition of pre-conquest Iron Age brooches was first established in order to provide a comparison for Roman-period production. It was shown that alloys used for Roman military types, such as the Aucissa series, were considerably different from Late Iron Age alloys. As a result of comparison with other studies undertaken elsewhere in the Roman empire, such alloys can be considered homogeneous over large areas. This permits an argument to be put forward that this composition can be considered to be a real 'Roman' alloy. Sufficient numbers of brooches of sufficient different types were measured so that differences in alloy ratios could be compared. This in turn made it possible to discuss the level of compositional control for the different types of brooch. The results drawn from across the Netherlands could then be compared to published results from other regions, allowing ideas about the organisation of production and the distribution of finished items to be formed. The observation of differences in the alloys of distinct typological groups allows new arguments to be brought to the discussion of the provenance and cultural tradition of certain brooch types found in The Netherlands. Although no direct provenance can be given for any brooch, the identification of a standard alloy for the Aucissa brooch, considered the archetypical military brooch, as well as for other typological groups with alloys that deviate from it, is a useful step forward.

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Chapter 4

Disc Brooches of the Roman Iron-Age from the tarand cemeteries of Estonia and North Latvia.

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INTRODUCTION

This study focuses on the disc brooches found in the *tarand* cemetery area of Estonia and North Latvia. Such cemeteries were a common burial practice in the Roman Iron Age (50-450AD for Estonia, 1-400AD for Latvia), and are found across a wide area covering Southwest Finland and Ingria (Ingermanland), as well as the area included in our study (Fig. 1). So far, no specific study has been dedicated to these disc brooches as they have mainly been included in the broader research of the material culture from seperate countries or regions (Tallgren 1922; Moora 1938; Vassar 1943; Шмидехельм 1955; Laul 2001). Furthermore, only a few have been discussed in papers dealing with brooches from the Baltic area (Vaska 2013; Khomiakova 2015). Also very little discussion has occurred in respect to the different subgroups within the broader disc brooch category and no compositional analysis has been conducted up to now to study their production
(For the purposes of this study, the term, 'disc brooches' includes not only round examples, but also rectangular and cruciform ones, as is customary in the research tradition. See Bos 2006, 709).
The aim of this paper was to conduct a detailed study of these disc brooches, with a focus on regional differences within our study area. This was to see whether some motifs, typological groups, or alloys were preferred in some regions more than in others. If such distinctions are observed, then it may possible to say something about variations in regional culture. In addition, cultural contacts with regions outside the *tarand* cemetery area are also considered in order to identify local and non-local influences in the disc brooch styles and in brooch production. The various motifs used to decorate many disc brooches will also be discussed together with their possible meanings.
This article combines a study of the stylistic and typological features of these brooches and their production. But first it re-examines and compares the existing typology and chronology to those outside regions thought to be the most influential for the forms found in the study area: West Lithuania and the northern Roman provinces (Moora 1938, 100–105). In addition, it groups and compares the stylistic features to motifs used in these outside regions. Handheld X-Ray florescence spectrometry (HHXRF) was also employed using a qualitative, non-destructive approach, to study the composition of the alloy from which they were made. This was undertaken in order to see whether it was possible to identify any standardised alloy choices for the sub-groups and to better understand the nature of any surface treatments.
The article goes on to present some new insights into the resulting variation in typological groups. It then identifies any regional preferences and looks at the influences behind any grouping in relation to the rest of Europe, which would appear to be worlds apart from such a distant, northerly research area. Lastly it also discusses the organisation behind their production.

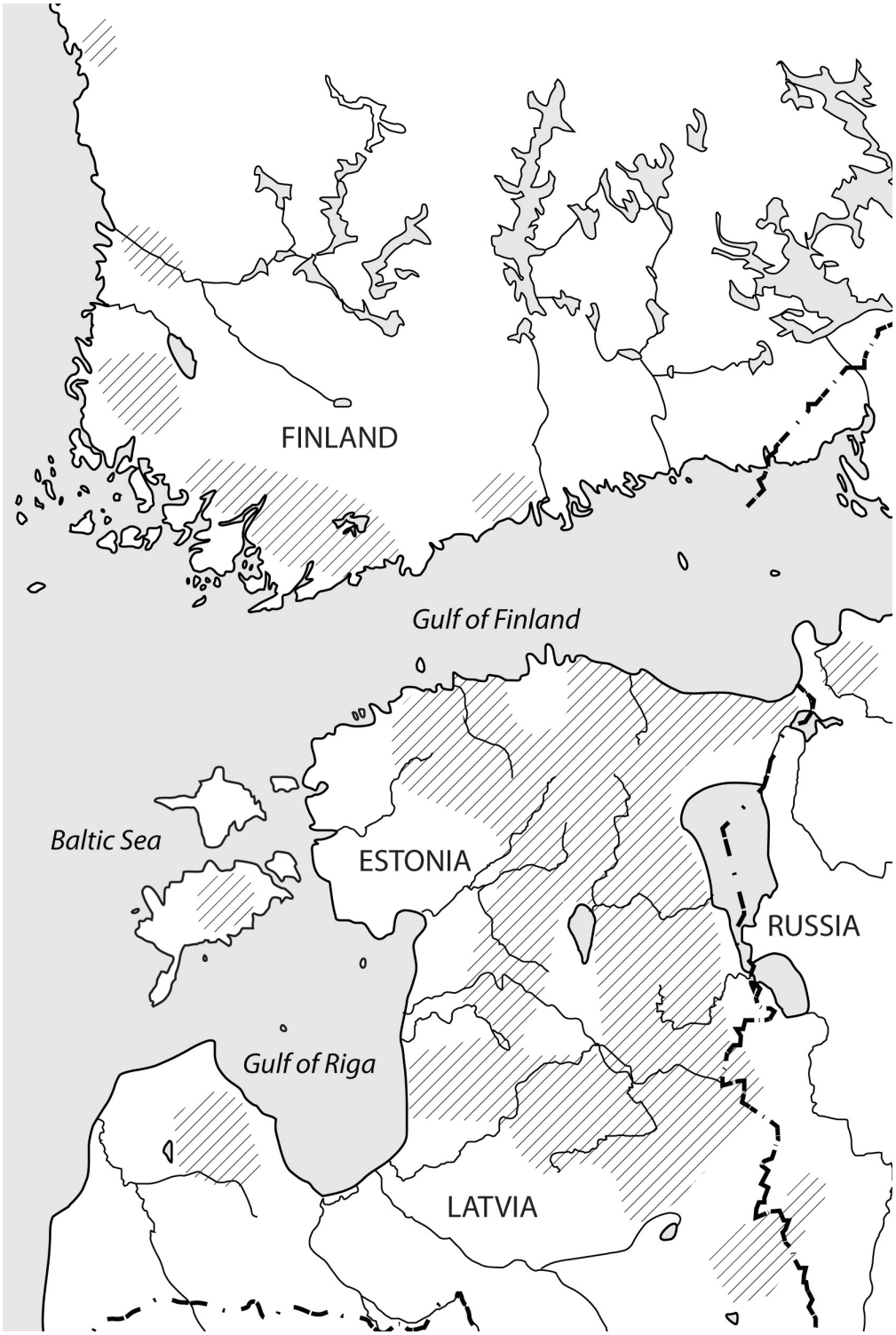


Fig. 1. The distribution area of *tarand* cemeteries in the Roman Iron Age. *Drawing by M. Olli* after Lang 2018, p.175, Fig. 5.10.

HISTORY OF THE TYPOLOGICAL RESEARCH

The disc brooches from the *tarand* cemetery area have been studied in combination with other Roman Iron Age brooches since the early 20th century. Initially, the evolutionary aspects were the main focus, which resulted in the hypothesis that they evolved naturally from a simple form into more complex ones over time. This focus subsequently led to the creation of a broad chronology (Tallgren 1922, 100–102). In addition, the connections between those from the *tarand* cemetery area and those from the northern Roman provinces and Lithuania were first outlined (Moora 1938, 100–105). To this day, the results of these studies form a well-known argument, recognised by many researchers (Banytė-Rowell and Bitner-Wróblewska 2005; Vaska 2013; Banytė-Rowell et al. 2016). The disc brooches from various Estonian regions, together with many other finds from the period, have been studied by different scholars: Marta Schmiedehelm (Шмидехельм 1955, 146, 199) created a chronology for those in Northeast Estonia, dating them mainly to the 3rd–4th centuries. Artur Vassar (1943, 70–71) concentrated on the Central Estonian examples, Harri Moora (1938, 100–105) on the North Latvian ones. Then later, Silvia Laul (2001, 108–114) focused on those from Southeast Estonia and contributed to their typology and chronology. Because two disc brooches were found in Finland's *tarand* cemetery area but not in a *tarand* cemetery itself, their actual find spots are unfortunately unknown (Kivikoski 1973, 31–32), they were not included in this study. Also no disc brooches have as yet been found in the Ingrian *tarand* cemeteries (Юшкова 2011) so they also could not be included.

These earlier works mainly emphasise the typological and chronological issues of the time. Disc brooches as well as many other types of brooches and artefacts have also been connected to smaller ethnic groups from different regions (Jaanits et al. 1982, 244–246), a viewpoint that has recently been disputed in the light of new research approaches (Lang 2018, 224).

Baiba Vaska (2013, 88–110) studied openwork ornamentation on Latvian finds and subsequently discussed the disc brooches found in *tarand* cemeteries. She regrouped them and proposed some new chronological aspects; in addition, she discussed the meaning and origin of the motifs. The meaning behind the diverse motifs on disc brooches has also been discussed by various Estonian and Latvian researchers. These researchers connected them mainly with solar symbolism (Zemītis 2004, 206–207; Vasks 2006; Jonuks 2009, 227–230; Olli 2013, 113).

Disc brooches have been widely studied across the Baltic area. Around 30 disc brooches from Lithuania that date to the C_{1b}–C_3 period (220–350AD) have been studied by Mykolas Michelbertas (1986, 122–124) and Rasa Banytė-Rowell (2001; 2009; Banytė-Rowell et al. 2016). Olga Khomiakova (2015) examined the various disc brooches from the Dollkeim-Kovrovo culture area (Sambian Peninsula), revising their dating mainly to the B_2, B_2/C_1 and C_{1b} periods (ca 1–225AD). Although the two areas are neighbours, their disc brooch styles differ chronologically and typologically (Banytė-Rowell 2001).

Enamelled disc brooches have also been studied in combination with other enamelled items from Eastern Europe (Корзухина 1978).

HISTORY OF ROMAN ALLOY RESEARCH

Ancient artefacts and their composition have been the subject of scientific interest for well over two centuries now. Roman brooches in particular have been one of the most popular artefact groups, attracting such attention mainly because they are found in large numbers and are relatively easy to categorise. A great deal of work has already been done in understanding the production methods and technical decisions of the artisans. For copper-alloy brooches, the composition choices (with tin, with zinc, or both, with or without lead) allow the complex relationship between typology and composition to be studied and their origin to be debated (Dungworth 1997, 902; see also Smythe 1938; Craddock 1988, 1990; Unglick 1991).

One technique available for the study of an item's composition is X-Ray fluorescence spectrometry (XRF), which has been around for decades. The device was initially a bulky, immobile, laboratory apparatus, which, thanks to advances in miniaturisation, became increasingly portable; some models can now even be easily carried to museums or excavation sites (see Gigante et al. 2005; Shugar and Mass 2012). Another benefit of these portable, handheld (HHXRF) devices is that they are non-destructive in their approach. Other methods have traditionally required an object to be damaged through drilling or scraping in order to obtain a sample for measuring. In the case of a copper-alloy brooch, for example, the patina would typically be scraped off in order to reach a clean subsurface. Such damaging procedures are plainly contrary to modern conservation practices and result in the greatly-reduced availability of various collections. HHXRF avoids this problem because it can be deployed as a surface measuring technique, but in this role it is important to recognise its limitations. The X-rays only penetrate a fraction of a millimetre below the surface of a copper-alloy object. This means that the measurements are nearly always taken on a surface that has been altered by the corrosion processes. Previous research has shown that this process involves the leeching of copper (decuprification) and, to a lesser degree, zinc (dezincification), both of which contribute to the formation of the outer patina (Robbiola et al. 1998, 2108; Chiavari et al. 2007). It is, therefore, important to ask the right research questions, which, in this case, involves measuring large numbers of typologically similar items in order to distinguish between the basic compositional groups (see Bayley and Butcher 2004; Martinón-Torres et al. 2014; van Thienen and Lyche 2017).

The alloy properties of disc brooches from Northwest Europe were studied in detail by Justine Bayley and Sarnia Butcher (2004, 176) using the same XRF principles as were employed for this paper. Their results suggested that whilst there was a standardisation of design and surface decoration, which is suggestive of well organised, large-scale production, the alloy choice varied greatly (see Fig. 2:b). This high variation was found to substantially differ with the results for many other brooch types published in the same and more recent studies (see Bayley, Butcher 1995; 2004; Roxburgh et al. 2017). Bayley and Butcher's (2004, 145) measurements on nearly 3,500 brooches suggested that individual brooch types were usually made of a specific alloy, typically a bronze, brass, or gunmetal, which is a mixture of the two (see Fig. 2:c and d for examples). Great variation in the alloy choice was also suggested as evidence for manufacturing items from whatever scrap metal was available at a particular moment (Dungworth 1997, 903). A highly varied distribution was likewise shown by a number of other brooch types, including head-stud brooches (Bayley and Butcher 2004, 165), some of which were enamelled, and sheath-footed brooches (Bayley and Butcher 2004, 183), which had been decorated using tinning or mercury

gilding techniques. Stijn Heeren and Laurens van der Feijst (2017,155) suggested that enamelled disc brooches are found across all the western Roman provinces and whilst evidence for their production centres is still missing, they proposed that there was some regional variation. Little has been proposed about the production location of openwork disc brooches, other than that there may be a military connection as many of the motifs appear on army equipment (Heeren and van der Feijst 2017, 162). There is, however, a disc brooch subtype (type 60) with a two-piece spring construction and applied decoration that Heeren and van der Feijst (2017, 165) suggest was likely produced in the Germanic areas north of the Rhine.

The compositional analysis of Estonian Roman Iron Age artefacts is not new (see Черных et al. 1969), but a combined approach that includes both typological and compositional analyses has only recently emerged (Roxburgh et al, 2018). A compositional analysis of some Roman Iron Age artefacts has also been conducted in Lithuania (e.g. Volkaitė-Kulikauskienė and Jankauskas 1992) but it has seldom been combined with a typological analysis (Simniškytė 2002).

Enamelling– using the Champlevé *technique* – was a common decorative technique at this time and was applied to many disc brooches. It has also been suggested that tin was sometimes applied to the areas around the enamel fields (Bayley and Butcher 2004, 46). The earliest reference to tinning used as a decorative technique was given by Pliny in his *Natural History*. It was considered to have been widespread through the Roman world (Meeks 1986, 134) and was also used in the eastern Baltic (Volkaitė-Kulikauskienė and Jankauskas 1992; Bitner-Wróblewska and Stawiarska 2009). Tinning at this time would have involved either dipping the object in a bath of molten tin or rubbing the hot object with a tin or pewter rod (Bayley and Butcher 2004, 43). A close relationship between lead and enamel has also been suggested when considering these decorative techniques (see Bateson and Hedges 1975). Not only is lead present in enamel, it was also used as a wetting agent to form a stronger bond between the enamel and the metal.

HHXRF METHODOLOGY

As mentioned earlier, a handheld X-Ray florescence spectrometer (HHXRF) was chosen for collecting the compositional data. This surface measurement device had the advantage of being easy to transport to the archives containing the bulk of the Roman disc brooches. Whilst these devices can be operated in a 'point and shoot' manner, they frequently come with a portable test bench, which, although reminiscent of the earlier, bulkier portable machines, allows for a more stable working environment (for further reading see Potts and West 2008; Shackley 2011; Smit 2012). A *Bruker Tracer IIIsd* machine was used in this study and, as per the manufacturer's standard operating guide, was fitted with a yellow filter (position 1), which is recommended for a dry atmosphere and the high mass elements found in copper-alloys, and was set at 40kev-10um. Trial testing was then conducted and the signal was found to be stable at 60 second intervals. These settings remained unchanged during the full data-gathering phase. The output for each measurement was saved as a PDZ file from which a spectrograph could be viewed. These graphs were then individually checked for inconsistencies using the manufacturer's own *S1PXRF* software. Two manufacturer-supplied copper-alloy calibrations were used (Cu1 and, for high lead levels, Cu3) to convert the spectra data into quantitative chemical weights (expressed as a %). The

elements subsequently measured using these calibrations were Mn, Fe, Co, Ni, Cu, Zn, As, Pb, Bi, Zr, Nb, Ag, Sn, and Sb.

One measurement per brooch was taken, typically on the front face but if impractical, along a relatively flat edge. Once the weights were available, an external normalisation of the dataset took place using *Microsoft Excel*™. This had the effect of correcting the dataset for soil contamination and other residues from light elements. Then the main elements that make up copper-alloys, namely copper (Cu), zinc (Zn), tin (Sn), and lead (Pb), were then normalised on an iron (Fe) and light element free basis.

This research method was developed in line with a scheme published by Bayley and Butcher (2004, 24) who used ternary diagrams to visually display the three component metals: tin (Sn), zinc (zn), and lead (Pb) in their results. This visualisation method is particularly useful as it allows clusters of results to be compared to one another (see Fig. 2:a).

To aid repeatability, the Bruker machine's calibration was checked by comparing its results to those of a *Niton XL3t GOLDD* XRF analyser (with the kind assistance of the Cultural Heritage Agency of the Netherlands) using a shared set of copper-alloy samples. The results of this analysis are presented in Table 1 and while a small variation between their measurements can be seen, it is insufficient to impede the approach employed in this paper.

As mentioned earlier, the approach required non-destructive measurements to be taken on uncleaned surfaces, an approach that is consistent with previously published research (Tate 1986; Lutz and Pernicka 1995; Bayley and Butcher 2004; Roxburgh et al. 2016) and that is effective in the basic identification of trends in bulk alloy types (Tate 1986, 23). Once this stage is achieved, however, the results are analysed interpretively rather than through the use of destructive testing. And so, the reconnaissance role of HHXRF is complete at that point.

For the HHXRF study, 69 brooches were selected from the full dataset on the basis of their availability as many items were not easily accessible. This represents 64% of the known brooches and can therefore be considered a representative sample of the full dataset.

Sample	Cu (av.)	Sn (av.)	Zn (av.)	Pb (av.)
Niton Analyser				
Bronze	79.0	15.0	0.0	5.5
Brass	84.0	0.0	12.0	4.5
Gunmetal (+Sn)	80.5	10.0	4.5	5.5
Gunmetal (+Zn)	79.5	6.0	8.0	6.5
Bruker Analyser				
Bronze	76.0	16.5	0.0	7.5
Brass	82.5	0.5	12.0	5.5
Gunmetal (+Sn)	79.0	10.0	12.0	6.5
Gunmetal (+Zn)	79.5	5.5	8.0	7.0

Table 1. Niton versus Bruker, a comparison.

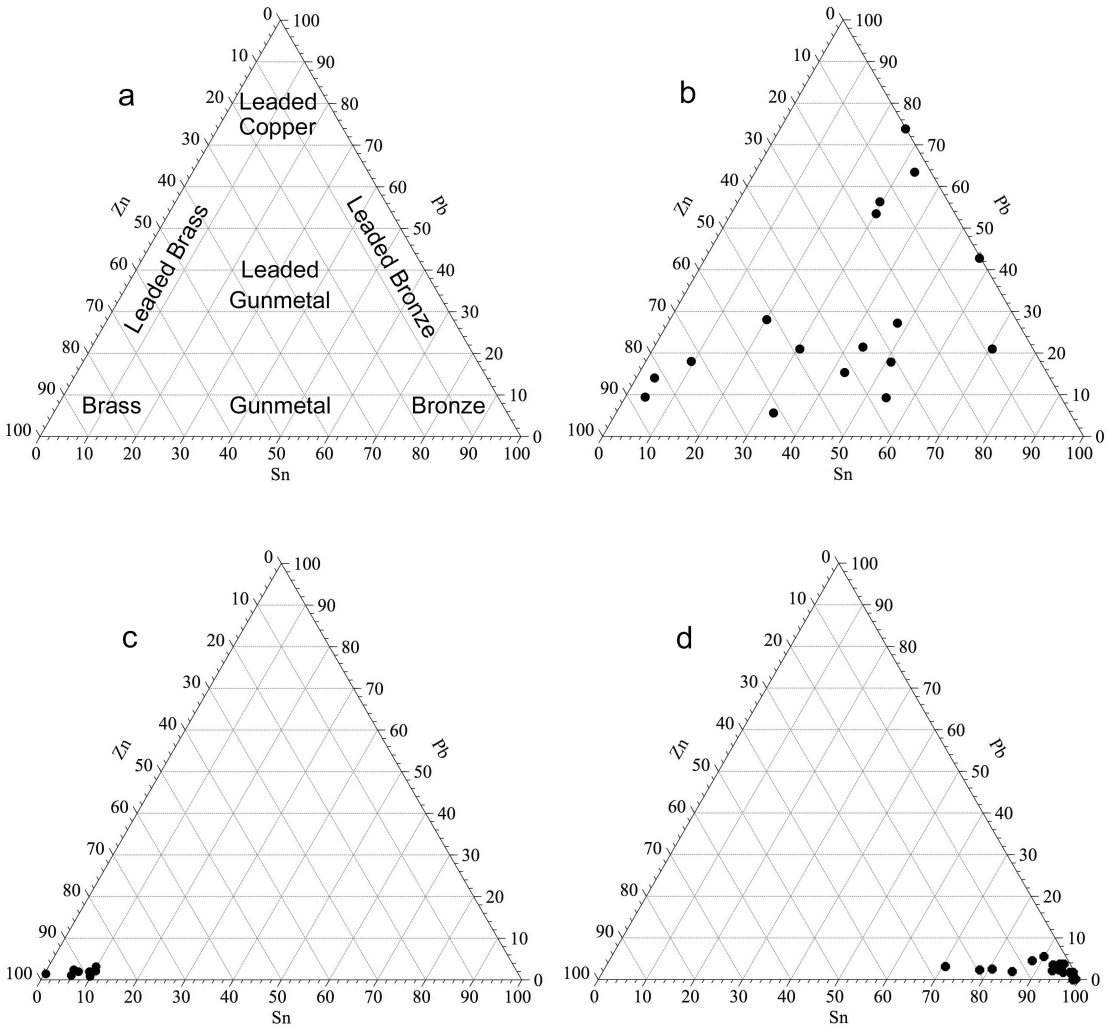


Fig. 2. Ternary diagrams displaying: a – the classification scheme (after Bayley, Butcher 2004, p.24, Fig. 7); b – 'continental disc brooches' of Northwest Europe (after Bayley, Butcher 2004, p.176, Fig. 151); c – eye-series brooches (after Bayley, Butcher 1995, p.115, Fig. 4:1); d – wire type 46 brooches (after Roxburgh *et al*. 2017, p.252, Fig. 5.3.16). *Drawing by M. A. Roxburgh.*

MATERIAL

At least 110 disc brooches have been found in this paper's research area (Moora 1938, 100; Vassar 1943, 71; Laul 2001, 108) and 108 were included in the typological study (see the Appendix). They are housed in the Tallinn University Archaeological Research Collection, the University of Tartu Archaeological Collection, the Estonian History Museum, the National History Museum of Latvia, and in various Estonian county museums. Any brooches, which could not be physically located and for which no picture or drawing was available, were excluded (One was found at Essu,

Haljala, Virumaa and was supposed to have been cruciform (Moora 1938, 115); the other is from an unknown find spot and should have had a spoked central motif (Laul 2001, 109).
The majority of the disc brooches were recovered from stone-lined burial areas, known as 'typical' and 'single' *tarand* cemeteries, which are the main cemetery type for the Roman Iron Age (Lang 2007, 192; 2018 174–178). These cemeteries are monumental, aboveground, communal places where fragmented, cremated, and un-cremated bones were scattered together with burnt and unburnt grave goods, mostly ornaments, tools, and pottery (Lang 2007, 203, 206; Kivirüüt and Olli 2016; Olli and Kivirüüt 2017). Intact burials are rare and the commingled nature of the cemeteries makes the creation of a relative or absolute chronology for local items difficult (Lang 2007, 206; Vaska 2013, 97).

TYPOLOGY AND CHRONOLOGY

The typology used in this paper is a combination of previous classifications (Laul 2001, 108–114; Banytė-Rowell 2009; Vaska 2013) and new observations. Although the brooches do not form a series (Vaska 2013, 97), they have been grouped on the basis of similar features, namely decoration, size, pin attachment, and production technology. A subgroup was created if there were at least two similar specimens.

Four types of pin constructions were used for disc brooches. For some of the brooches, no construction has survived but for the most the type could be determined (see the Appendix). The majority of the disc brooches in the study area had an eye-and-hook construction (Fig. 3:a), which is not very common in the Baltic region, but does appear on some Sambian Peninsula disc brooches dating to the first centuries (Banytė-Rowell 2009, 21; Khomiakova 2015, 18) as well as on enamelled disc brooches in the Kiev culture area (Обломский 2007, 302–303, 314, рис. 150.7, 151.3, 162.1) but not, for example, in the northern Roman provinces. It was also used in the Lower Rhine area, but at a much later date, i.e. during the 8th century (Heeren and van der Feijst 2017, 265). The eye-and-hook construction appears to have been a local version of a hinged pin, which consists of two cast lugs, each with a hole that holds one end of the axial bar on which the pin rotates (Fig. 3:b). Eight disc brooches from the study area have hinged pins. In the Roman world, this type of mechanism is widely used for early, 1st century plate brooches as well as enamelled plate brooches from the second half of the 2st –late 3rd century (Heeren and van der Feijst 2017, 110, 113, 155).

One brooch has a tube construction that hides the hinge (tubular variant) where the axial bar, around which the pin was wound, was located in a tube. Another enamelled brooch has a spring mounted on a single lug, a construction used for 3rd century enamelled plate brooches from the northern Roman frontier as well as other types of brooches (Heeren, van der Feijst 2017, 137, 139, 155, 158). Tubular variants were also used for some cross ribbed brooches (sometimes also referred to as ladder brooches, three-crossbar brooches or *Dreisprossenfibeln*), also found in the

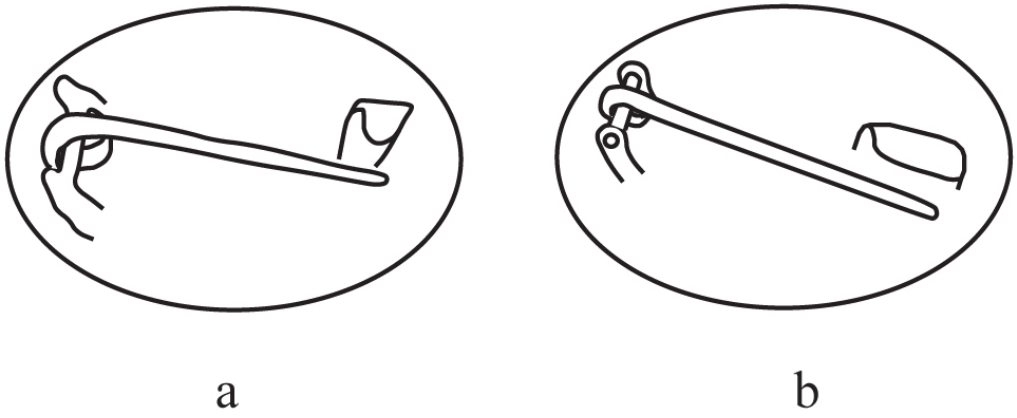


Fig. 3. Pin attachment constructions: a – eye-and-hook pin construction, b – two cast lugs each having a hole that holds an axial bar to which the pin is attached. *Drawing by M. Olli.*

tarand cemetery area (Laul 2001, 105) and were widely used elsewhere for various types of Roman brooches (see Heeren and van der Feijst 2017, 106, 108).

It is possible to distinguish nine main disc brooch groups as well as many subgroups (Fig. 4, 5; Appendix). While the dates for some groups were possible to revise, some problems existed with dating most of the locally-made brooches, especially on the basis of relative chronology (no phasing having been undertaken for items from *tarand* cemeteries). To create such a chronology, the accompanying items need to be restudied and their dating compared to that of other similar items in *Barbaricum*, but this research is outside the limits of this paper.

The brooches of the first group (16 items) are decorated with a beaded rim and a central knob. The subgroups are distinguished by the design around the central knob. The first subgroup (1.1) has circles around the knob and no openwork, the second (1.2) an openwork cross in the middle, and the third (1.3) either an openwork swastika or spokes in the middle. All of them have an eye-and-hook pin construction. They are fairly evenly distributed across Southeast Estonia and North Latvia and one has been found in Northeast Estonia. This group has not been previously distinguished, having instead been included with the spoked type by Laul (2001, 108–109) but because the brooches are too similar to each other, a new subgroup was distinguished. They are dated to the 4^{th}–5^{th} centuries (Laul 2001,114).

The brooches of the second group (27 items) are small in size (17–25 mm in diameter, one being 36 mm) and have a raised centre, a rim that is usually beaded, and a primary motif that is mainly an openwork rhombus. Four subgroups can be distinguished: the first (2.1) has simple openwork cross motif in the middle, the second (2.2) an openwork rhombus, the third (2.3) an openwork rhombus combined with a cross, and the fourth (2.4) an openwork sieve decoration. This group includes one other brooch, which is closed and lacks a beaded rim and central motif, but is small in size. The brooches of the first subgroup (2.1) lack small knobs on the rim, which could make them typologically earlier. All of the brooches of this group have an eye-and-hook pin construction, except for one in subgroup 2.3 which has a tubular variant. It could be a copy of the

eye-and-hook group, especially as it was found at a location outside the typical distribution area. This group has been previously distinguished by both Laul (2001, 108–109) and Vaska (2013, 100). These brooches are thought to have been developed locally in Southeast Estonia, which is also the main area where they are found (Laul 2001, 110). These brooches are dated to the 4th–5th centuries (Laul 2001, 114). However, considering the dating of North Estonian and North Latvian disc brooches, an earlier dating (3rd–4th centuries) might be possible for the disc brooches of groups one and two but further research into the accompanying finds needs to be done to confirm that.

The brooches of the third group (16 items) have sparsely placed knobs on the rim and an openwork circulating motif in the middle. Three subgroups have been distinguished on the basis of the motif: triskele (3.1), closed cross (3.2) and four circles (3.3). Three of them have a different central motif: a whirlpool, a swastika with curved arms, and a wheel with openwork circles. Their main area of distribution is Northeast Estonia but some have been found in North Latvia and one in Northwest Estonia. This group has also been distinguished by Vaska (2013, 98–99), who pointed out that the Latvian decoration differs from the Estonian (Vaska 2013, 99), which has also been confirmed by this study. The Latvian brooch, which has a wheel motif, resembles the group 4 brooches found in Latvia (below). Brooches of this group mainly date to the 3rd century, but subgroup 3.2 to the 4th century (Шмидехельм 1955, 146, 199). Two of the brooches have a hinged pin fixed between two lugs but the others have an eye-and-hook construction. The former could have an earlier date and perhaps be a copy, albeit crude, of the hinged pin found in the Roman world. However, in the absence of an exact find context in the cemetery, a more precise dating would be difficult. The sparse knobs on the rim connect this group stylistically with provincial Roman examples (e.g. Exner 1939, Taf. 13; Riha 1994, Taf. 51, type 3.15). The same can be said of their motifs, as the triskele is a Celtic motif used on Roman brooches in 1st-century Britain (Bayley and Butcher 2004,173). The brooches from the second subgroup are similar to 2nd–3rd-century openwork brooches that match ones from various parts of the Roman Empire (Exner 1939, Taf. 15; Hattatt 1989, 345, 357). The same four-circle-motif is also present on 2nd–3rd century plate brooches found in all the western provinces of the Roman Empire (Heeren and van der Feijst 2017, 155). The brooch with openwork circles (A 110: 33) also resembles Rhine-area enamelled brooches with similarly placed circles (Exner 1939, Taf. 13, 1. III 21).

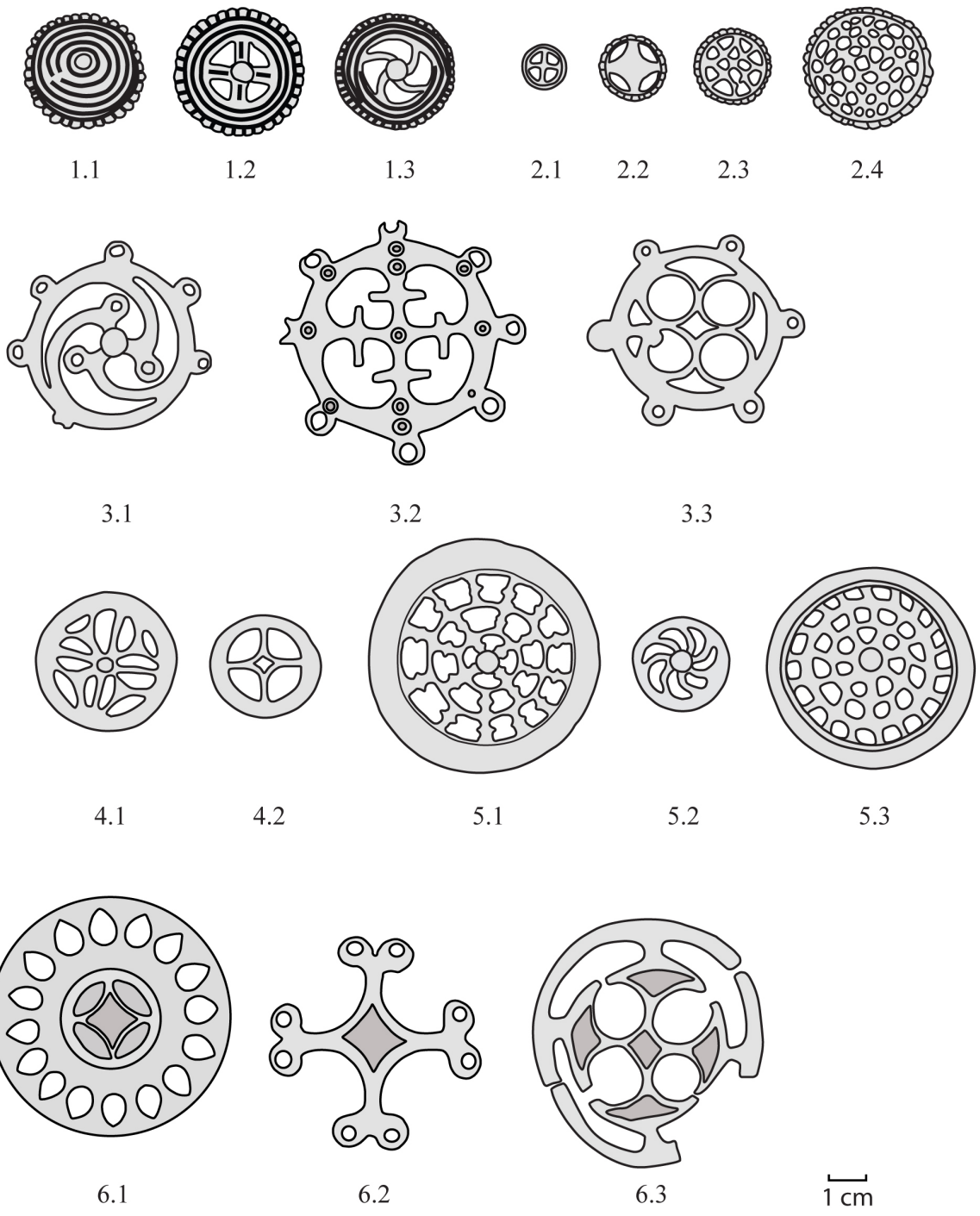


Fig. 4. Disc brooches from groups 1–6. *Drawing by M. Olli.*

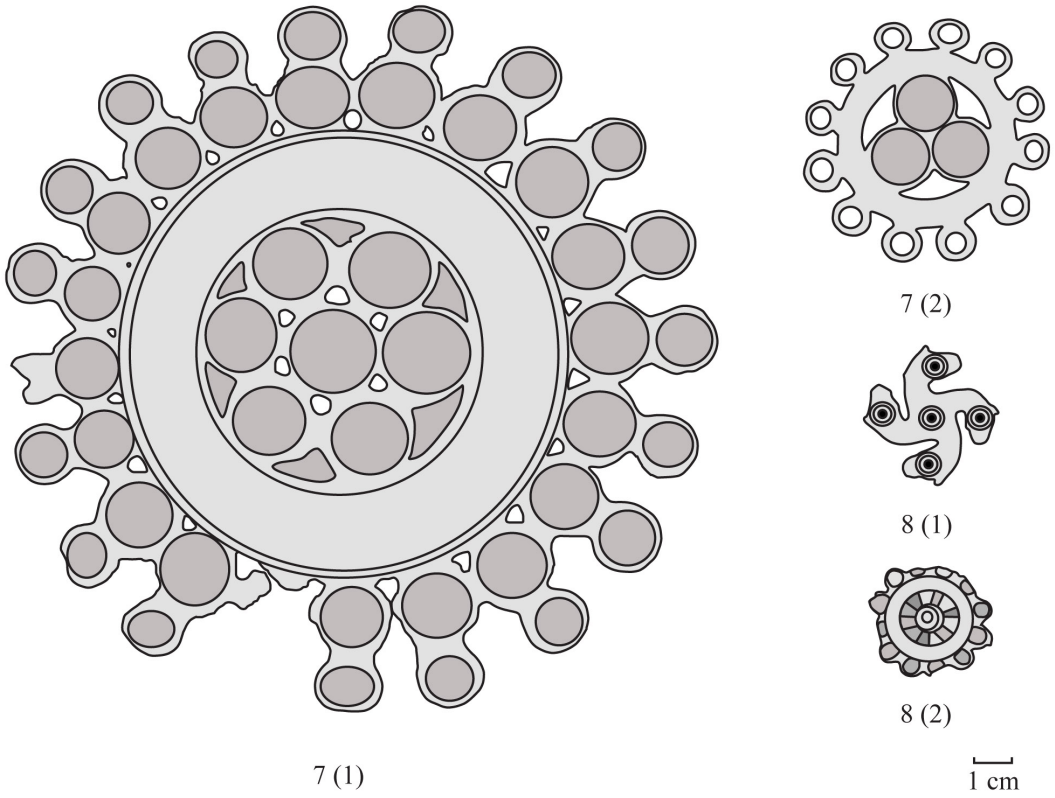


Fig. 5. Disc brooches from groups 7–8. *Drawing by M. Olli.*

The brooches of the fourth group (seven items) have openwork decoration, often have a side turned in, and lack knobs on the rim. They bear only one decorative element. Three brooches have a compass decoration (4.1), two almost identical ones an openwork rhombus (4.2), and two others a swastika and a rhombus combined with a cross. The compass decoration of the first subgroup is more elaborate than the Latvian one (another has been found in Latvia but at an unknown location, see Vaska 2013, 106). The brooches of the second subgroup have a centre identical to that of an enamelled disc brooch from Slavēka Cemetery in North Latvia (AI 1194: 39), where another of this subgroup's brooches was found (AI 1194: 38). It can, therefore, be suggested that they were made in one batch or at least to the same production standard, possibly near Slavēka, and perhaps based on the example of brooches from Masuria or the Sambian Peninsula. This is because almost identical brooches have been found there, but with a different pin construction and an earlier date: 150–250 or a bit later (Khomiakova 2015, 25). The cemetery at Jaagupi in Southeast Estonia stands out as the main find spot for this group, but they were probably made in North Latvia from an original design or in imitation of a design from elsewhere and brought to Estonia as a result of close contact between the two areas. Furthermore, all of the brooches have an eye-and-hook pin construction. The compass decoration has been dated

to the 3rd century (Vaska 2013, 106). In Estonia, the brooches of this group have a broader date to the 4th–5th centuries (Laul 2001, 114) but subgroup 4.1 could be earlier (3rd century), based on the dating of the decoration. If it is true that the brooches of subgroup 4.2 are copies of Sambian Peninsula brooches, then a slightly earlier date: late 2nd–4th century can be suggested. The other brooches of this group may likewise date to the 3rd–4th centuries.

The brooches of the fifth group (13 items) are characterised by decoration surrounding a central knob or opening. A higher rim may or may not be present around the openwork decoration. While they are quite diverse in design, only three subgroups were distinguished: a baluster motif (4.1), a whirlpool motif (4.2), and a wheel motif (4.3). One brooch also has an openwork cross motif. Their main distribution area is North Latvia, but a few have been found in Southeast Estonia and isolated specimens in East and Northeast Estonia. All but one has an eye-and-hook pin construction. In Latvia these brooches date to the second half of the 3rd–first half of the 4th century (Vaska 2013, p.99), but in Estonia to the 4th–5th centuries or even later (Laul 2001, p.114). The wheel and baluster motifs are common among Lithuanian disc brooches where they date more closely to 220–350 (Michelbertas 1986, p.122). It is possible that brooches with these motifs existed at the same time as the Lithuanian ones and subgroup 5.2 may date earlier to the 3rd–4th centuries, which would correspond to the dating of the other group 5 brooches. The style of these first three subgroups is also present in other ornaments from Latvia, Lithuania, and the Sambian Peninsula (Bitner-Wróblewska 2009, 385–399; Vaska 2013,106; Banytė-Rowell 2001, annex II, pav. 70–72). It seems that the brooches of this group, especially subgroups 5.1 and 5.2, are stylistically more connected to the Baltic region and they are also found in North Latvia, which is on the edge of the *tarand* cemetery tradition.

The sixth group consists of enamelled disc brooches (17 items), which, although quite different in style, are linked by their enamelling. The three subgroups (9 items): with a rhombus (6.1), cruciform (6.2), and four circles (6.3) motif are stylistically similar and found only in the *tarand* cemetery area, which means they could be of local origin. Most of the enamelled brooches were discovered in Eastern Estonia and North Latvia. Subgroup 6.3, which occurs only in Northeast Estonia and dates to the 3rd–4th centuries (Шмидехельм 1955, 100, 120), is stylistically connected to subgroup 3.2, which is also found in the same area. It can likewise be suggested that the brooches of subgroups 6.3 and 3.2 were all made locally in a unique Northeast Estonian style. One subgroup 6.3 brooch has a hinged pin, fixed between two lugs, which, in combination with its difference in style to the subgroup's other brooches, means it could have a slightly earlier date. The three brooches with a rhombus motif (6.1) are, however, all very similar. While brooches like those of the cruciform subgroup (6.2) occur in almost every part of the Roman Empire in contexts dating to the 1st–3rd centuries, they differ from the *tarand* cemetery specimens in size (Roman examples being smaller) and decorative elements (Böhme 1972, 38; Riha 1994, 154). It is thought that this subgroup originated with Roman brooches brought to the *tarand* cemetery area via sea routes without Baltic mediators (Banytė-Rowell *et al.* 2016, 144). Although a Roman origin can be attributed to no other brooches from this area, the cultural ideas behind the motifs could have travelled as knowledge instead of as physical brooches. The enamelled brooches in Southeast Estonia date to broadly the 4th–5th centuries or even later (Laul 2001, 114; Vaska 2013, 99).

While the other eight brooches of this group are stylistically different and do not form subgroups, they have many similar stylistic elements, such as rotating motifs (swastikas, whirlpools, and wheels), lace and rhombus decorations, and the style of edge decoration, many of

which are common among Eastern European enamelled disc brooches (Корзухина 1978). The brooches with four swastikas (RDM I 2746, AI 5101: CVIII: 1) are very similar in design to each other and to brooches found in the Dnieper area (Kiev culture area, modern day Ukraine) (Левада 2010, 583, рис. 22). It is, therefore, likely that they originated in this area or were strongly influenced by that culture. The style, execution, and pin construction of one enamelled brooch (A 92: 5), which has an enamelled rhombus motif in the middle, a single lug pin construction, and a riveted catch, are not typical for *tarand*-cemetery brooches, which leads to the suggestion that it may have originated in the Dnieper area (Шмидехельм 1955, 217–219). Nevertheless other Eastern European regions should not be excluded as the only confirmed production site for enamelled objects is located in Northern Belarus (Bitner-Wróblewska 2011, 19–20 and the cited literature). The composite, enamelled disc brooch is likewise unique among the *tarand* cemetery brooches (AI 1918: 23) but the technique it exhibits is not uncommon in the Dnieper area (Левада 2010, 580–584). The brooch with a central enamelled rhombus (AI 1260: 5) surrounded by lace decoration has turned-in sides, which is a common element of some *tarand*-cemetery disc brooches (e.g. group 4). Another enamelled brooch (AI 2626) demonstrates several elements from different influences: the baluster motif found in subgroup 4.1 and the lace decoration and whirlpool motif exhibited by many Dnieper-area enamelled brooches. A Dnieper-area origin has already been suggested for it (Tamla, Kiudsoo 2009, 18). Nevertheless its origin remains open owing to its hybrid nature: local style elements such as baluster and lace decoration and its extreme similarity to a brooch fragment that was a stray find in Finland (Kivikoski 1973, 44).

The brooches of the seventh group (two items) are decorated with small, semispherical depressions. Both were found in Nurmsi *tarand* cemetery in Central Estonia. The bigger, slightly more elaborate brooch has a hinged pin fixed between two lugs (Fig. 5:7 (1)) while the smaller one has widely spaced knobs on the rim and an eye-and-hook pin construction (Fig. 5:7 (2)). Both date to the 3rd century (Vassar 1943, 71). The knobs and pin construction of the smaller brooch connect it to the third disc brooch group and might therefore be a local version of a bigger brooch. As no exact parallels exist for comparison, it is thought that they were made locally in imitation of an older Pre-Roman Iron Age style (Vassar 1943, 70–71). A couple of non-brooch artefacts that exhibit similar depressions date to the Roman Iron Age: a disc from the *tarand* cemetery at Mūsina, Latvia (AI 1252: 1) and an item with a central part similar to a rosette tutulus brooch (see below) from the *tarand* cemetery at Jäbara, Northeast Estonia (AI 2617: 56). A local origin is possible for these brooches as they could be a hybrid between the rosette tutulus form from the Sambian Peninsula (see the ninth group below) and local traditions.

The eighth group contains two brooches from the Roman Empire. The first dates to the 3rd century and belongs to a type of swastika brooches with horsehead terminals (Fig. 5:8 (1), Buora 2005, 117). It was a stray find in a secondary context at an excavation at the Livonian Order castle in Viljandi (Olli 2016). The second is a plate brooch with a central knob decorated with red, turquoise, and blue enamel (Fig. 5:8 (2)). It belongs to Exner group III of enamelled brooches, which come from the northern Roman provinces in the Rhine area and date to the second quarter of the 2nd–early 3rd century (Exner 1939, 63, 103–105). Both have a hinged pin fixed between two very finely made lugs. This level of fineness is unlike anything found on similar brooch pin constructions from the *tarand* cemetery area, an observation that also reflects their Roman origin.

The ninth group likewise consists of two rosette-shaped tutulus brooches (for an image, see Шмидехельм 1955 160, рис. 43:2). This type is common for West Lithuania in the Late Roman

Iron Age (Banytė-Rowell 2009, 40–41). However, the ones found in North Estonia are from the so called Samland-style, which dates to the late 1st–early 2nd century. It is interesting that this style has not been found in either Lithuania or Latvia (Banytė-Rowell 2009, 41), which suggests direct contact between the Sambian Peninsula and Northeast Estonia (Banytė-Rowell, Bitner-Wróblewska 2005, 112–113). They have an eye-and-two-hook pin construction, the second hook probably being for fastening a chain across the chest.

Five brooches do not belong to any of these nine groups owing to their design or shape. Several reasons could explain this. First, wider variation occurs in individually produced items. Second, under certain circumstances, a craftsman may have had the freedom to design ornaments in accordance with a customer's wishes, designed in the style of the era. Third, they could be imports. If an artefact has an incongruous style or the technology involved in its production is foreign to the area, this may infer a non-local origin or production during a different time period.

COMPOSITIONAL RESULTS

The following ternary diagram (Fig. 6) visualises the alloy ratios of all 69 analysed brooches. This enables a direct comparison to the published results on disc brooches from Northwest Europe as published by Bayley and Butcher (Fig. 1:b). Table 2 also provides the normalised Cu, Zn, Sn, Pb values for each measurement. Each dot represents a single measurement on each of the disc brooches and the results are very dispersed, populating the bronze, leaded bronze and leaded gunmetal areas of the graph as shown in Fig. 1a. Conversely the distribution pattern of the results is not comparable to the clustered examples given in Figs. 1c and 1d.

DISCUSSION

Production of disc brooches

The alloy choices used in the production of the disc brooches appear to be highly varied (see Fig. 6). This result is a close match to those disc brooches measured from continental Northwest Europe and subsequently published by Bayley and Butcher (2004, 176; also see Fig. 2:b). They proposed that the level of design standardisation was very suggestive of large-scale production, but the high variation in the alloys suggests the opposite to a degree, or at least that no standardisation existed in alloy choice for disc brooches. There are many bow brooch types whose alloy choice seems to have been strictly controlled (see Fig. 2:c, d for examples). This, however, was not the case for disc brooches, whose alloys range from brass, through gunmetal, to bronze, with varying degrees of added lead in most cases. It can, therefore, be suggested that the production organisation that led to this variable alloy use was the same as for those found in Northwest Europe. Perhaps large numbers of scrap copper-alloy items were available to craftsmen at this time, allowing the production of disc brooches to be an outlet for recycled material.

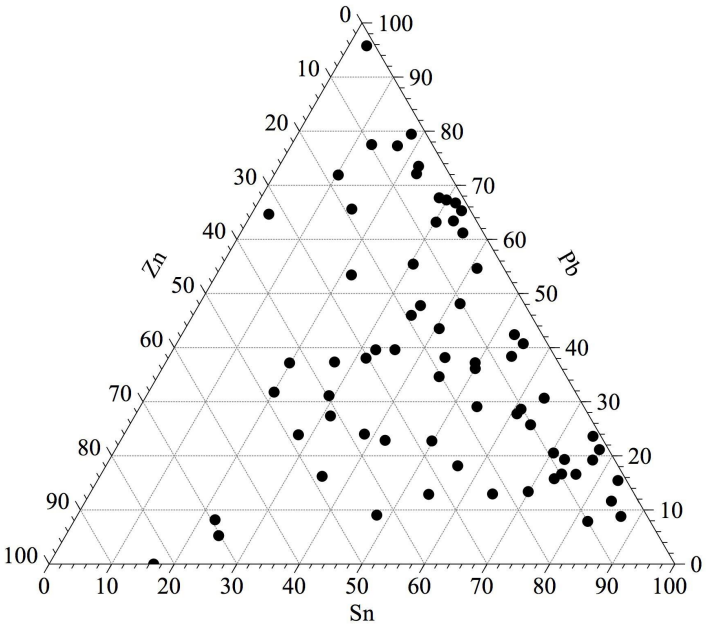


Fig. 6. Ternary diagram displaying the Sn-Zn-Pb alloy ratios. *Drawing by M. A. Roxburgh.*

Nr	**Find ID**	**Type**	**Cu**	**Zn**	**Pb**	**Sn**
1	AI 4262: 30	1.1	77.5	8.5	5.5	8.5
2	A 349: 71	1.2	83	6	6.5	4.5
3	A 7991: 23	1.2	59.5	3	8	29.5
4	A 17:92	1.2	88	3.5	4.5	4
5	A 10876: 20	1.2	62.5	2	29	6.5
6	AI 1239: 4	1.2	87.5	5.5	1	6
7	AI 2339: 8	1.2	31	1	45	23
8	AI 4262: 303	1.2	69.5	5	4	21.5
9	AI 3236: 291	1.3	57.5	0.5	41	1
10	AI 4161: 642	1.3	74	2.5	6.5	17
11	AI 1702: 2	2.0	64.5	1	28	6.5
12	AI 4262: 69	2.1	82	3	5	9.5
13	AI 1996: 45	2.1	79.5	3	7.5	10.5
14	AI 4262: 34	2.2	68	2	20	9.5
15	TÜ 320:177	2.2	68.5	3	5	23
16	AI 1996:159	2.2	79.5	3	9	8.5
17	AI 3235: 203	2.2	70.5	1.5	9	19
18	AI 1995: 43	2.2	63.5	1	24.5	11
19	AI 2901: 2	2.2	82.5	2.5	6.5	8.5

20	AI 1995: 62	2.2	27	2.5	44.56	26
21	TÜ 2668: 8	2.2	51.5	2.5	35	11
22	AI 4262: 88	2.2	85.5	5	2	8
23	TÜ 2668: 9	2.3	70.5	2.5	6	20.5
24	AI 3235: 202	2.3	76.5	8	5.5	10
25	AI 1993: 17	2.3	87.5	6	2	4.5
26	AI 4262: 403	2.3	77	4	9	10.5
27	AI 4262: 413	2.3	74.5	3	7	15.5
28	AI 2339: 11	2.3	35	1	43.5	20.5
29	AI 2415c: 4	2.3	32	5	11.5	52
30	AI 1996:103	2.4	89	3	2.5	5.5
31	A 9966: 72	2.4	74	2.5	7.5	16
32	A 110: 32	3.0	91	0.5	1.5	7
33	AI 1195: 138	3.0	86	2.5	6.5	5
34	AI 2655: 358	3.1	84	11.5	1.5	3.5
35	AI 3447: 3	3.2	86.5	5.5	3.5	4.5
36	AI 618	3.3	85.5	2.5	7	5
37	A 25: 4	3.3	91	2.5	3.5	3
38	AI 2655:104	3.3	92.5	6.5	0	1.5
39	AI 1702: 33	4.0	54	2	25	19
40	AI 3236:75	4.0	65	6.5	23	5.5
41	RDM I 2745	4.1	82.5	1	6.5	9.5
42	AI 1702: 35	4.1	42	2.5	24.5	31
43	AI 3236: 250	4.1	91.5	1.5	6.5	1
44	RDM I 102	5.1	86	3.5	5.5	5
45	RDM I 2713	5.1	88.5	0.5	1.5	10
46	RDM I 103	5.2	88	5	4	3.5
47	AI 3236: 275	5.2	86.5	1.5	6.5	5.5
48	TÜ 2668:10	5.2	76.5	2.5	3.5	17
49	AI 1252:12	5.2	78	4.5	7.5	10
50	AI 1195: 124	5.2, 5.3	87	0	3	9.5
51	AI 1195: 107	5.3	84.5	0.5	6.5	8.5
52	AI 1237:1	6.0	46	2.5	39.5	12
53	AI 1918 23	6.0	88	4	8	0.5
54	AI 1260: 5	6.0	91.5	2	4.5	2
55	A 235: 12	6.0	88	6	4	2.5
56	AI 5101: CVIII: 1	6.0	81	8	7	3.5
57	TÜ 2410: 416	6.1	35	2.5	5.5	56.5
58	AI 1237:9	6.1	51.5	2	31	16
59	AI 1194: 39	6.1	56.5	4.5	3.5	35.5
60	AI 4262: 804	6.2	58	6	23.5	13
61	AI 2604:161	6.3	89.5	7.5	0.5	2.5

62	AI 2655: 179	6.3	88.5	3	2	6.5
63	AI 2486: 169	7.0	64	1.5	24.5	10
64	AI 2486: 23	7.0	70	7	4	19.5
65	AI 3791: 3	8.0	24.5	7.5	58.5	9.5
66	AI 2013: 3	9.0	70	0.5	4.5	25
67	AI 2013: 4	9.0	83	0.5	3.5	13
68	A 313: 5	no group	91.5	4	2	2.5

Table 2. Table of Compositional Results (%).

A different hypothesis for this wide variation in alloy may be related to the nature of the non-destructive, surface measurement technique employed by HHXRF and the original surface treatments employed by the craftsmen. As discussed above, both tin and lead were applied for various purposes on the surface of brooches. Tinning and lead wetting are two techniques to be considered in particular, as well as the lead that would have been present on enamelled areas. These past techniques, applied on outer surfaces, would have been on the first part of the brooch to corrode when deposited in the ground. In most cases, the visual evidence of these outer surface treatments will have long disappeared into the surface corrosion. The HHXRF technique, which measures these corroded outer surfaces, may therefore record variable levels of additional tin and lead, left behind by the vanished surface treatment. This has a twofold effect on the interpretation of the disc brooch results. First, any attempt to measure the brooch's actual alloy composition becomes highly problematic because the additional lead and tin caused by vanished surface treatments would mask brass and gunmetal results in particular and create artificially high tin bronze results as well. Whilst this could be considered as a negative if the purpose was to estimate a brooch's basic alloy type, it can be seen as a positive in that it could infer that more than one metallic colour could have been visible on newly decorated disc brooches. All uncorroded copper-alloy items have a bronze-like metallic colour that can have a reddish, yellowish, or silvery tint. The surface application of tin changes the area of application to a white shiny metal colour, perhaps simulating silver to some degree, while a lead or a lead-tin mix would create a duller grey metallic colour.

A possibility, therefore, exists that a large percentage of the disc brooches had a white metal 'silvery' appearance, either in part or in whole, when they were new and the highly variable HHXRF results are due to the varying amounts of these surface colour treatments that have survived on the corroded surface. These colour treatments would certainly have set them apart from other copper-alloy brooches, whose colour perhaps remained bronze-like. A visual inspection of all the brooches in this study identified 21 that still had fragmentary patches of 'silvery' tin on their surfaces (20%). This is unlikely to have been the total number to have received this treatment as visible signs of tinning are inclined to disappear during the corrosion process. Furthermore this does not include the number of brooches that have been over cleaned of all outer patina (see the Appendix).

Decoration

Two main groups of motifs were used to decorate the disc brooches: rhombus and rotating motifs, but other designs also occur on occasion.

The rhombus is the most commonly used motif on the disc brooches, mainly the small Southeast Estonian brooches (group 2) but is also a central motif on many of the enamelled brooches. It was combined with a rotating motif of four circles where a rhombus is surrounded by the circles and other decorative elements. It also adorned other types of contemporaneous ornaments: mostly pendants but also other brooch types, neck rings, and bracelets (Olli 2013, 63, 71–72, 110). Thus, it was a very popular motif in Southeast Estonia at that time (Olli 2013, 110). Disc brooches with a rhombus motif were also likewise in the Roman Empire, Britain, Gaul, and the Rhine area during mainly the 1st century (Feugére 1985, Planche 147; Riha, 1994, 154; Bayley and Butcher 2004, 155, Fig. 121). In addition, a few disc brooches with an openwork rhombic centre are known from the Sambian Peninsula and date to the 1st–2nd centuries (B_2/C_1 and C_{1a}) (Khomiakova 2015, 25). In Latvia and Lithuania, it was used to decorate various ornaments, but not so much disc brooches (Vaska 2013, 102–104). Thus the rhombus, as the dominant motif of many disc brooches, can be considered inherent to the local *tarand* cemetery area.

All the rotating motifs, including standard and curved swastika, triskele, wheel, spiral, and four circle motifs, share the common feature of seeming to rotate within the disc. They were also used to decorate Roman Iron Age disc brooches throughout Europe (see previous chapters).

All of the rhombus and rotating motifs are common in Roman, Germanic, Dnieper area, and Baltic ornamentation. This means that the motifs were international to an extent, with some additional local preferences. It could be argued that certain cosmopolitan motifs were fashionable and that people wanted to reproduce and refine them locally. They were then adopted by the local culture because they were aesthetically pleasing and fashionable at that time. The symbolic meaning, however, has yet to be determined but some motifs may have been more suitable for the local cultural system than others. Brooches, as a new form of clothing fastener, spread into the *tarand* cemetery area in the early Roman Iron Age (Lang 2007, 206). Many of the motifs depicted on disc brooches were likewise new in the region as they do not have traceable origins in the local material culture (Olli 2013, 84). Therefore a possibility exists that the beliefs connected to the motifs and brooches themselves were also adopted because they suited the local context. However, it is very likely that only the motifs that suited the needs of the local culture were taken in and the elements that did not hold any meaning among the locals were left aside (e.g. for a rosette form which was popular among the Balts, see Vaska 2013, 106–107; for popular types of Roman provincial brooches, see Riha 1994, Taf. 51). It is known that the barbarians in general reworked selected Roman item forms, in addition to materials and techniques, for their own purposes (Hakenbeck 2011, 54 and the cited literature). They also sometimes combined them with local traditions, thereby creating new meaning (Ekengren 2009). The people of the *tarand* cemetery area likewise reworked selected Roman and Baltic forms (and perhaps some others?), adopted new techniques, and created new items in their own style, imbuing them with their own meaning.

Regionality in disc brooches

Regional differences are present among the disc brooches in the *tarand* cemetery area. Two regions come to fore, first, Northeast Estonia and second, Southeast Estonia together with North Latvia, based on the colour of the brooches and the groups found there.

Most of the disc brooches were surface treated, giving them a 'silvery' look, except in Northeast Estonia where the bronze-like look predominated among the locally produced items. The choice to keep the bronze-like colour was probably deliberate and cannot be associated with technological limitations because other types of contemporaneous brooches still bear visible signs of previous ('silvery') surface treatments (e.g. a head-shield brooch from Erra *tarand* cemetery in Northeast Estonia, A 313: 3, 3rd century). Unlike with the bronze-like Northeast disc brooches, the 'silvery' look predominated among the Southeast Estonian and North Latvian disc brooches.

Differences likewise exist in the geographic distribution of the various disc brooch groups (Fig. 7). The Northeast Estonian coast is the region where group three brooches are mainly distributed. Southeast Estonia comes strongly to the fore with its small disc brooches (group two), which have almost exclusively been found in the western part of the region. North Latvia and Southeast Estonia have many similarities to each other, as the first, fourth, and fifth groups are represented in both of these modern regions. The fifth group however is mainly confined to North Latvia. It is remarkable that these disc brooch groups are found only in certain regions and are absent in others, even though *tarand* cemeteries occur throughout.

Enamelled disc brooches seem to be distributed across the entire area where disc brooches occur, but if the design is taken into consideration, it appears that certain motifs are concentrated in smaller regions: the four-circle motif in Northeast Estonia and the rhombus in Southeast Estonia and North Latvia; these motifs and associated regions are also connected to other disc brooch groups. The enamelling technique may well have been known by local craftsmen and not just reserved for imported items as it has been used on local brooches. According to Anna Bitner-Wróblewska (2011, 21), identical or very similar ornaments in one region may reflect the presence of a local workshop or a craftsman who travelled on a local scale. The skill level of the local craftsmen was very likely to have been quite high if most of the enamelled brooches were made locally.

Disc brooches of a similar style are clearly concentrated in small regions, where they were probably produced in local workshops together with other copper alloy items. Similar brooches that have been found outside of these concentrations are probably the result of travelling, trade, and other similar connections, which could also be how rare, non-local types of disc brooches reached Finland, Central Estonia, and Northwest Estonia. The disc brooches of the first and second groups are quite homogeneous in their style and manufacturing technique and so could have been made for local use in larger numbers, probably on a bespoke basis by specific members of the community. The wearing of a disc brooch inherent to a specific region, might have communicated the wearer's ties to that region as well as other possible social identities.

A noticeable distinction seems to exist between the coastal area of Northeast Estonia and Southeast Estonia–North Latvia. The regional variation in certain ornaments is one marker for localised production along the lines of regional identities (see Swift 2000, 232–233; Hakenbeck 2011, 54).

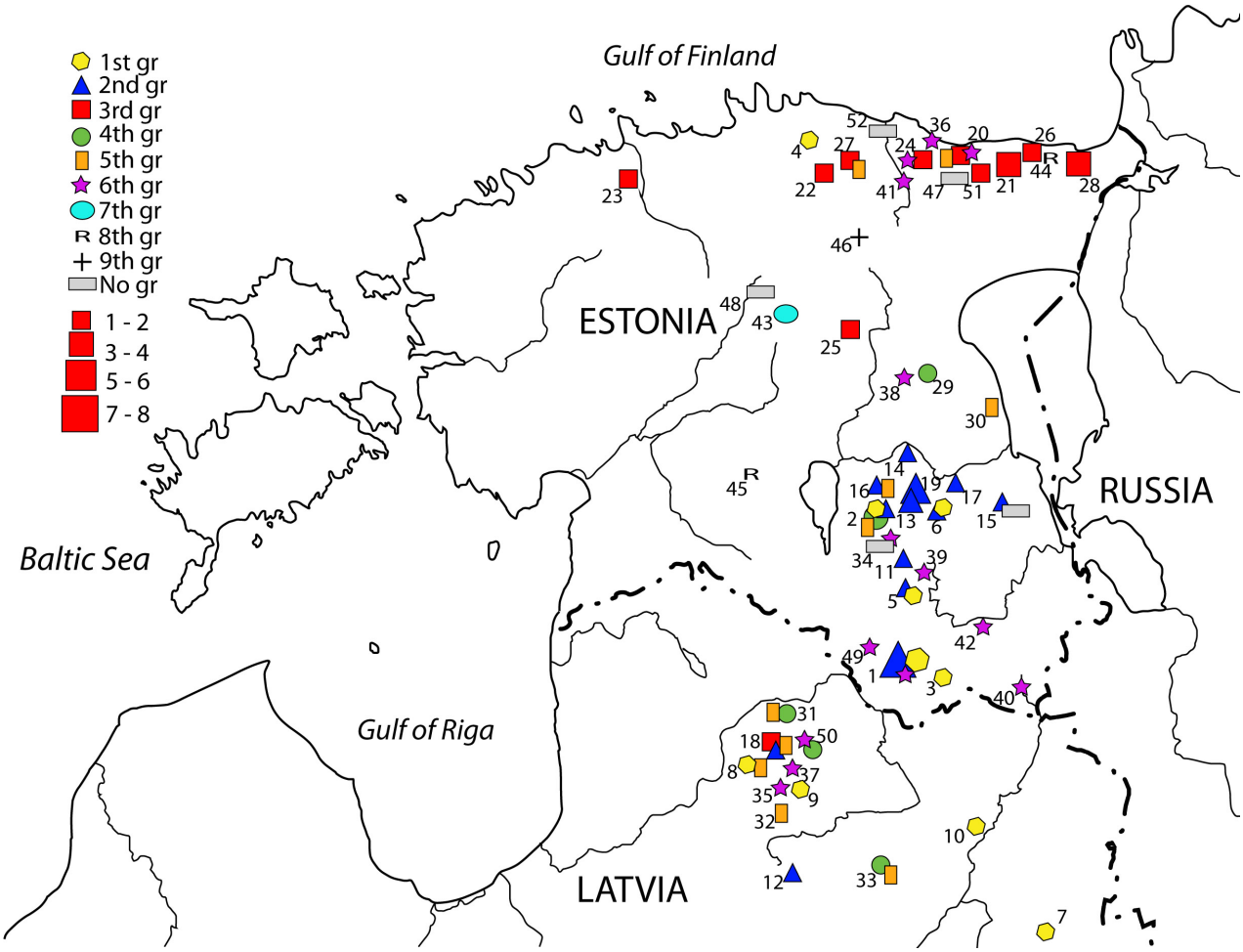


Fig. 7. Disc brooch distribution in the *tarand* cemetery area. 1 – Virunuka, 2 – Jaagupi, 3 – Sadrametsa, 4 – Hõbeda, 5 – Truuta, 6 – Tatra, 7 – Salenieki, 8 – Mūri, 9 – Vīksnas Kapusils, 10 – Leški, 11 – Ala-Pika, 12 – Gailīši, 13 – Kambja, 14 – Kardla, 15 – Kõnnu, 16 – Meeri, 17 – Paali, 18 – Slavēka, 19 – Unipiha, 20 – Jäbara, 21 – Kukruse, 22 – Laanemõisa, 23 – Lagedi, 24 – Pada, 25 – Ripuka, 26 – Toila, 27 – Tõrma, 28 – Türsamäe, 29 – Kõrenduse, 30 – Lahepera, 31 – Libriti, 32 – Mūsina, 33 – Jaunzemji, 34 – Aakre, 35 – Jauntēvēns, 36 – Kalvi, 37 – Kaugars II, 38 – Kärde, 39 – Pikkjärve, 40 – Siksälä, 41 – Ulvi, 42 – Vagula, 43 – Nurmsi, 44 – Künnapuu, 45 – Viljandi, 46 – Triigi, 47 – Erra, 48 – Tarbja, 49 – Kirbu, 50 – Velna Kravanda, 51 – Järve, 52 – Malla. *Drawing by M. Olli.*

Although style in itself cannot define cultural groups *per se*, it provides a context for where they were active. It is also important to compare both style and production elements because together they form a whole (Conkey 1993, 15). As the differences between these two geographic areas (Northeast Estonia and Southeast Estonia–North Latvia) are noticeable in many ways, the existence of two cultural groups can be proposed. Such a division can also be seen in the occurrence of the Roman Iron Age ceramic types. In particular the textile-impressed ceramics in Southeast Estonia and North Latvia, and the Nurmsi-style ceramics in Northern, Western, and

Central Estonia (Lang 2018, 242–243). The South-North difference is also observable in the direction of long distance contacts.

Contacts with other areas

Thanks to the Amber Road, an ancient route connecting the coastal areas of the Southeast Baltic Sea with the distant Mediterranean, trading was intense during the first centuries (Nowakowski 1996, 107). People very likely came from far and wide to the southeast shore of the Baltic Sea to trade and exchange ideas. Because of this connection with the wider world, crafts, skills, people, and fashion must have spread throughout the region. In addition to amber, other goods were exchanged among the Balts, Germanic peoples, Romans, and others, who came there to trade (Sidrys 2001, 167–168). The different cultures and traditions met, and favoured elements were taken back home with the traders. Many trade routes existed (Sidrys 2001, 160) and the existence of fixed trade relations between certain groups of people from different areas is possible. People knew what they needed for their local market and for the people from the *tarand* cemetery area it was not foreign ornaments, it was scrap and fresh metal (amongst other things) and the know-how of different techniques (enamelling, tinning, etc.) to support local needs. This was mainly due to the lack of locally sourced raw materials, which forced the importation of all copper-alloy related metals. The creation and maintenance of trade relations played an important role in satisfying these needs.

This analysis clearly shows that influences from various directions were present at that time. Northeast Estonian disc brooches differ from other disc brooches, both in the *tarand* cemetery area and the Southeast Baltic area. They have more in common stylistically with provincial Roman brooches than the Baltic or Dnieper area variants (although contacts also existed in those directions as well). It is likely that the connections were via sea routes and therefore more directly with Germanic peoples or even traders from beyond the Roman frontier. Maybe in some trading centres along the southeast shore of the Baltic Sea, new ideas were acquired and it is not impossible that the traders from these distant regions reached the shores of Northeast Estonia.
Similarities very clearly exist between West Lithuanian disc brooches and the Southeast Estonian and North Latvian examples, these being especially evident in brooches from group five, which mostly occur in North Latvia. Contacts between the two areas were probably via land and river routes. Direct connections must have existed as the decorative motifs reaching the *tarand* cemetery areas where adapted and subsequently applied to locally produced disc brooches. It is also evident in examples of other brooch types (Banytė-Rowell, Bitner-Wróblewska 2005, 114–116).

Judging by some of the enamelled brooches, contact not only occurred with Western Europe, but also areas further east, e.g. the Kiev culture area, where brooches and other artefacts have been found with similar decorations (Шмидехельм 1955, 218–219; Корзухина 1978; Левада 2010). The existence of close ties between the Eastern European enamelling centres has already been suggested on the basis of the many similarities in the design and technological elements (Bitner-Wróblewska 2011, 15) and been confirmed by this study, which has shown that some foreign stylistic elements were also used on locally produced artefacts. Many brooches, for example, share a similar edge decoration (group 6.1 brooches, A 235:12, AI 2616, RDM I 2746, AI 5101: CVIII: 1).

CONCLUSIONS

Disc brooches from the Roman Iron Age in all Europe are very diverse, and many regional differences have been identified because of this. The disc brooches of the Roman Iron Age found from the tarand cemetery area of Estonia and North Latvia was studied to detect further regional differences based on typology, motifs and composition. Contact with other areas was also explored to identify influences from various non-local directions. The typology of the brooches was re-examined and nine groups were subsequently distinguished. A large number of the disc brooches were also analysed using handheld X-Ray florescence spectrometry (HHXRF).

Two geographic areas came to fore as a result of this study: Northeast Estonia and Southeast Estonia–North Latvia. Thus the presence of two cultural groups can be suggested on the basis of the distribution of the typological groups, styles, and surface treatments and the direction of the long distance trade. The people living in the vicinity of the *tarand* cemeteries were in active contact with others both near and far and traded with them. Due to this contact, the craftsmen were technologically skilled and mastered many techniques including surface treatments and enamelling methods. They created local brooches based on foreign ideas and imported examples, but with a unique local touch. Access to raw material was limited and therefore only production on a local scale was possible, which may have been targeted to and/or ordered from the local elite, or specific groups of people.

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APPENDIX

List of brooches included in this study.

AI 1993: 22	AI 1993: 21	AI 1239:4	A 7991: 23	A 349 :71	A 17:92	A 10876: 20	AI 4262: 30	AI 3236: 215	AI 4161: 591	**Find ID**
Truuta, Urvaste, Võrumaa	Truuta, Urvaste, Võrumaa	Vīksnas Kapusils, Branti, Cēsis	Mūri, Baižkalna, Cēsis	Hõbeda, Kadrina, Virumaa	Sadrametsa , Rõuge, Võrumaa	Salenieki, Makašānu, Rēzekne	Virunuka, Rõuge, Võrumaa	Jaagupi, Nõo, Tartumaa	Virunuka, Rõuge, Võrumaa	**Find Loc.**
?	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook?	?	**Hinge construction**
1	1	1	1	1	1	1	1	1	1	**Group**
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	?	**Subgroup**
?	no	no	yes?	no	no	yes	no	no	no	**Visible tin**
cross	cross	cross	cross	cross	cross	cross				**Motif**
?	35	37	36	29	29	34	30	35	?	**Diam. (mm)**
Southeast Estonia	Southeast Estonia	North Latvia	North Latvia	Northeast Estonia	Southeast Estonia	North Latvia	Southeast Estonia	Southeast Estonia	Southeast Estonia	**Area**
Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	**Reference of dating**
4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	4^{th}–5^{th} c.	**Dating**
										New dating

AI 1995: 62	AI 1995: 43	AI 4447: 1	AI 4262: 69	AI 1996: 45	AI 1702: 2	AI 4252: 27	AI 4161: 642	AI 3236: 291	?	AI 4262: 303	AI 2339: 8
Unipiha, Nõo, Tartumaa	Unipiha, Nõo, Tartumaa	Kõnnu, Võnnu, Tartumaa	Virunuka, Rõuge, Võrumaa	Kambja, Kambja, Tartumaa	Jaagupi, Nõo, Tartumaa	Sadrametsa, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Jaagupi, Nõo, Tartumaa	Leški, Litenes, Madona	Virunuka, Rõuge, Võrumaa	Tatra, Kambja, Tartumaa
eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook
2	2	2	2	2	2	1	1	1	1	1	1
2.2	2.2	2.1	2.1	2.1		1.3	1.3	1.3	1.3	1.2	1.2
no	no	no	no	no	no	no	no	no	?	no	yes
rhombus	rhombus	cross	cross	cross		swastica	swastica	whirlpool	whirlpool	cross	cross
19	19	18	25	19	19	32	31	36	?	33	30
Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	North Latvia	Southeast Estonia	Southeast Estonia
Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114
4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.

AI 1996: 66	AI 1995: 77	AI 1993: 17	AI 1195: 65	TÜ 320:177	TÜ 2668: 8	AI 4262: 88	AI 4262: 34	AI 4161: 34	AI 3235: 203	AI 2901: 2	AI 1996:159
Kambja, Kambja, Tartumaa	Unipiha, Nõo, Tartumaa	Truuta, Urvaste, Võrumaa	Slavēka, Rauna, Cēsis	Ala-Pika, Kanepi, Võrumaa	Meeri, Nõo, Tartumaa	Virunuka, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Paali, Kambja, Tartumaa	Unipiha, Nõo, Tartumaa	Kambja, Kambja, Tartumaa
eye-and-hook	eye-and-hook	eye-and-hook	tubular	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	?	eye-and-hook	eye-and-hook	eye-and-hook
2	2	2	2	2	2	2	2	2	2	2	2
2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
?	?	no	no	yes	yes	no	no	no	no	no	no
rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus
?	26	24	27	18	20	19	17	16	20	20	19
Southeast Estonia	Southeast Estonia	Southeast Estonia	North Latvia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia
Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114		Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.115	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114
4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.

A 111: 48	A 110: 33	A 110: 32	AI 1996:103	A 9966: 72	TÜ 2668: 9	AI 4262: 413	AI 4262: 403	AI 4262: 1164	AI 3235: 202	AI 2415c: 4	AI 2339: 11
Järve, Jõhvi, Virumaa	Kukruse, Jõhvi, Virumaa	Kukruse, Jõhvi, Virumaa	Kambja, Kambja, Tartumaa	Gailīši, Taurenes, Cēsis	Meeri, Nõo, Tartumaa	Virunuka, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Paali, Kambja, Tartumaa	Kardla, Nõo, Tartumaa	Tatra, Kambja, Tartumaa
eye-and-hook?	?	two lugs	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	?	eye-and-hook	eye-and-hook	eye-and-hook
3	3	3	2	2	2	2	2	2	2	2	2
			2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3
?	no?	no	no	possibly?	no	no?	no	no	no	no	yes
swastica with curved arms	circles	whirlpool	sieve	sieve	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus	rhombus
45	60	48	23	36	18	21	21	?	25	21	20
Northeast Estonia	Northeast Estonia	Northeast Estonia	Southeast Estonia	North Latvia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia
	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Laul 2001, p.114	Laul 2001, p.115	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114
	3rd c.	3rd c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.

3rd c.

AI 2655: 104	AI 2012: II: 13	A 25: 4	AI 3735: 4	AI 3447: 3	AI 2488: 9	AI 2012: I: 14	AI 3953: 1	AI 2655: 358	AI 2012: I: 13	A 110: 31	AI 1195: 138
Pada, Viru-Nigula, Virumaa	Türsamäe, Vaivara, Virumaa	Lagedi, Jüri, Harjumaa	Jäbara, Lüganuse, Virumaa	Laanemõisa, Rakvere, Virumaa	Tõrma, Rakvere, Virumaa	Türsamäe, Vaivara, Virumaa	Toila, Jõhvi, Virumaa	Pada, Viru-Nigula, Virumaa	Türsamäe, Vaivara, Virumaa	Kukruse, Jõhvi, Virumaa	Slavēka, Rauna, Cēsis
eye-and-hook	eye-and-hook	two lugs	?	eye-and-hook	eye-and-hook	?	?	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook
3	3	3	3	3	3	3	3	3	3	3	3
3.3	3.3	3.3	3.2	3.2	3.2	3.2	3.1	3.1	3.1	3.1	
no	no	no	?	no	no	no	?	no	no	no	no
4 circles, rhombus	4 circles	4 circles, rhombus	closed cross	closed cross	closed cross	closed cross	triskele	triskele	triskele	triskele	wheel
55	62	62	47	51	65	?	56	58	55	59	50
Northeast Estonia	Northeast Estonia	Northwest Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	Northeast Estonia	North Latvia
Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Шмидехельм 1955, p.146, 199	Шмидехельм 1955, p.146	Шмидехельм 1955, p.146	Шмидехельм 1955, p.146	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199	Шмидехельм 1955, p.199
3rd c.	3rd c.	3rd c.	4th c.	4th c.	4th c.	4th c.	3rd c.	3rd c.	3rd c.	3rd c.	3rd c.

RDM I 2713	AI 2604: 262	AI 1195: 107	VM VMT 91: 6	AI 4866: 261	AI 1194: 38	RDM I 102	AI 3236: 250	AI 1702: 35	AI 3236: 75	AI 1702: 33	AI 618
Libriti, Trikāta, Valka	Jäbara, Lüganuse, Virumaa	Slavēka, Rauna, Cēsis	Unknown	Kõrenduse, Maarja-Magdaleena, Tartumaa	Velna Kravanda, Rauna, Cēsis	Dzelzava, Jaunzemji	Jaagupi, Nõo, Tartumaa	Jaagupi, Nõo, Tartumaa	Jaagupi, Nõo, Tartumaa	Jaagupi, Nõo, Tartumaa	Ripuka, Laiuse, Tartumaa
eye-and-hook	eye-and-hook	two lugs?	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook
5	5	5	5	4	4	4	4	4	4	4	3
5.1	5.1	5.1		4.2	4.2	4.1	4.1	4.1			3.3
yes, surface is cleaned	yes	yes?	no	no	yes	yes	yes?	no	no?	in the centre	no
baluster	baluster	baluster	cross	rhombus	rhombus	compass, rhombus	compass	compass	rhombus?	swastica	4 circles, rhombus
59	59	48	31	28	29	67	41	43	39	38	67
North Latvia	Northeast Estonia	North Latvia	unknown	East Estonia	North Latvia	North Latvia	Southeast Estonia	Southeast Estonia	Southeast Estonia	Southeast Estonia	East Estonia
Laul 2001, p.114	Шмидехельм 1955, p.100	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Шмидехельм 1955, p.199
4th–5th c.	5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	3rd c.
3rd–4th c.	3rd–4th c.	3rd–4th c.		(2nd) 3rd–4th c.	(2nd) 3rd–4th c.	3rd c.	3rd c.	3rd c.	3rd–4th c.	3rd–4th c.	

AI 1237: 1	A 92: 5	A 235: 12	RDM I 2745	RDM I 103	AI 1984: 3	AI 1195: 124	TÜ 2668: 10	AI 3236: 275	AI 2488: 10	AI 1252: 12	A 7991: 53
Kaugars II, Rauna, Cēsis	Kalvi, Viru-Nigula, Virumaa	Ulvi, Viru-Nigula, Virumaa	Libriti, Trikāta, Valka	Jaunzemji, Dzelzava, Madona	Lahepera, Kodavere, Tartumaa	Slavēka, Rauna, Cēsis	Meeri, Nõo, Tartumaa	Jaagupi, Nõo, Tartumaa	Tõrma, Rakvere, Virumaa	Mūsina, Rauna, Cēsis	Mūri, Baižkalna, Cēsis
eye-and-hook	one lug	eye-and-hook	eye-and-hook	eye-and-hook	two lugs	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	?
6	6	6	5	5	5	5	5	5	5	5	5
			5.3	5.3	5.3	5.2, 5.3	5.2	5.2	5.2	5.2	5.1, 5.2
yes	no?	no	yes?	no, surface is cleaned	no	no	yes	no	yes	no	?
cross, wheel	rhombus	whirlpool	wheel, zigzag	wheel	circle and wheel	whirlpool, wheel	whirlpool	whirlpool	whirlpool	whirlpool	whirlpool and baluster
70	53	60	82	53	35	51	28	49	63	42	?
North Latvia	Northeast Estonia	Northeast Estonia	North Latvia	North Latvia	East Estonia	North Latvia	Southeast Estonia	Southeast Estonia	Northeast Estonia	North Latvia	North Latvia
Vaska 2013, p.99			Vaska 2013, p.106	Laul 2001, p.114		Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114
4th c.			4th c.	4th–5th c.		4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.
			3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.	3rd–4th c.

AI 4262: 804	AI 4262: 613	AI 1253: 2	TÜ 2410: 416	AI 1237: 9	AI 1194: 39	TÜ 2264	RDM I 2746	AI 5101: CVIII: 1	AI 2616	AI 1918 23	AI 1260: 5
Virunuka, Rõuge, Võrumaa	Virunuka, Rõuge, Võrumaa	Jauntēvēns, Rauna, Cēsis	Aakre, Rõngu, Tartumaa	Kaugars II, Rauna, Cēsis	Velna Kravanda, Rauna, Cēsis	Kirbu, Karula, Võrumaa	Libriti, Trikāta, Valka	Siksälä, Vastseliina, Võrumaa	Vagula, Rõuge, Võrumaa	Kärde, Laiuse, Tartumaa	Pikkjärve, Kanepi, Võrumaa
eye-and-hook	?	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook	?	?	eye-and-hook	eye-and-hook	eye-and-hook	eye-and-hook
6	6	6	6	6	6	6	6	6	6	6	6
6.2	6.2	6.2	6.1	6.1	6.1						
yes	?	?	yes	yes	yes	no	?	no	yes	yes	possibly?
cross	cross	cross	rhombus	rhombus	rhombus	triskele	swastica	swastica	baluster, lace, whirlpool		rhombus, lace
54	54	50	63	58	52	31	?	99	120	47	71
Southeast Estonia	Southeast Estonia	North Latvia	Southeast Estonia	North Latvia	North Latvia	Southeast Estonia	North Latvia	Southeast Estonia	Southeast Estonia	Central Estonia	Southeast Estonia
Laul 2001, p.114	Laul 2001, p.114	Vaska 2013, p.107	Laul 2001, p.114	Vaska 2013, p.99	Vaska 2013, p.99	Laul 2001, p.114	Vaska 2013, p.107	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114	Laul 2001, p.114
4th–5th c.	4th–5th c.	4th–5th c	4th–5th c.	4th c.	4th c.	4th–5th c.	4th c.	4th–5th c.	4th–5th c.	4th–5th c.	4th–5th c.

?	AI 690	AI 2011: 2	A 313: 5	AI 4447: 15	AI 2013: 4	AI 2013: 3	VM 11501 A	AI 3791: 3	AI 2486: 23	AI 2486: 169	AI 2655: 179	AI 2604: 161	RDM 2719
Malla, Viru-Nigula, Virumaa	Tarbja, Paide, Järvamaa	Aakre, Rõngu, Tartumaa	Erra, Lüganuse, Virumaa	Kõnnu, Võnnu, Tartumaa	Triigi, Väike-Maarja, Virumaa	Triigi, Väike-Maarja, Virumaa	Viljandi, Viljandi, Viljandima a	Künnapuu, Jõhvi, Virumaa	Nurmsi, Peetri, Järvamaa	Nurmsi, Peetri, Järvamaa	Pada, Viru-Nigula, Virumaa	Jäbara, Lüganuse, Virumaa	Libriti, Trikāta, Valka
?	eye-and-hook	two lugs	eye-and-hook?	eye-and-hook	eye and 2 hooks	eye and 2 hooks	two lugs	two lugs	eye-and-hook?	two lugs	two lugs	eye-and-hook	?
no group	no group	no group	no group	no group	9	9	8	8	7	7	6	6	6
				Rosette	Rosette tutulus	Rosette tutulus	Roman	Roman			6.3	6.3	6.2
?	no, surface is cleaned	no	no	no	no	no	no	no	yes	no	no	no	yes
four loops			circles	rosette							4 circles, rhombus	4 circles, rhombus	cross
?	58	24	35	164	80	78	35	33	63	100	60	55	?
Northeast Estonia	Central Estonia	Southeast Estonia	Northeast Estonia	Southeast Estonia	Northeast Estonia	Northeast Estonia	Southwest Estonia	Northeast Estonia	Central Estonia	Central Estonia	Northeast Estonia	Northeast Estonia	North Latvia
		Laul 2001, p.117	Шмидехельм 1955, p.199	Banytė-Rowell 2001, p.46	Banytė-Rowell 2009, p.41	Banytė-Rowell 2009, p.41	Buora 2005, p.117	Exner 1939 p.63	Vassar 1943, p.71	Vassar 1943, p.71	Шмидехельм 1955, p.199	Шмидехельм 1955, p.100	Vaska 2013, p.107
		4th–5th c.	3rd c.	3rd–4th c.	1st–2nd c.	1st–2nd c.	3rd (4th–5th) c.	125–200 AD	3rd c.	3rd c.	3rd c.	4th c.	4th–5th c

Chapter 5

The Cross & the Crucible: The production of Carolingian disc brooches as objects of religious exchange?

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INTRODUCTION

The economic nature of the early medieval world has been the subject of much debate (e.g. Hodges 1982; Pestel and Ulmschneider, 2003; Wickham, 2005; Skre, 2008), with much discussion focusing on the role of elite exchange and long distance trade (e.g. Malinowksi, 1922; Pirenne, 1939; Lebecq, 1983). But this study has been considerably restricted as only metal, glass and ceramics tend to survive in the archaeological record, amongst a wide spectrum of goods that must have existed at the time. Luxury goods in particular those destined for elite consumption, have been central to these debates but as Wickham puts it these are not reliable guides to the genuine scale of economic activity in the early middle ages (Wickham 2005, 701), also that non-luxury goods need to be analysed instead and in a different way. The disc brooches of the Carolingian and Ottonian periods fall into this category. These mass-produced goods need to be analysed in a different way if their contribution and role in the early medieval economy is to be understood. The technology behind their production could be studied for example, through the archaeological evidence left by furnaces. But as this evidence is generally missing, the quantities found, and morphological consistency of finished items, can tell us something about the economic scale of production and therefore the likely contribution these items had to the wider economy.

Unlike ceramic studies, which benefit from fairly accurate provenance, this is not the case for metalwork. Provenance studies of copper-alloy artefacts are particularly problematical. Much research in this area has been undertaken without fully understanding the life history of an artefact. The impact that scrap metal recycling has on trace element or lead isotope analysis also presents a serious problem. Scrap metal from several sources, once remelted into a new item can easily lead to a misleading signal (Bray et al. 2015, 1). A different model is needed such as that proposed by Bray et al. whereby the bulk composition of the alloys become the central focus. These alloys can be considered as 'streams' of metal available to the craftsman. An object; such as a brooch is made by removing a small amount of alloy from a 'stream', which when cast, cooled and shaped, becomes an item for personal use or exchange. Different streams co-existed in early
medieval production, such as bronze, brass or leaded mixtures of the two and some streams were reserved for different types of objects, such as gold and silver for more elite items. But if an item reenters a stream of metal as scrap, perhaps many years

later, its original alloy composition and especially a provenance signal will be much diluted by the composition of the stream it is entering, which is itself under the constant influence of the levels of raw versus recycled metals entering it. An exception to this provenance issue is for coins, which bear mint-marks. These marks are well understood and can be accurately provenanced (Wickham 2005, 702), but this is not the case for brooches, whose value in economic terms is less clear. A combined interpretation is necessary, incorporating new compositional evidence, allowing us to examine brooches and the relation between gift and commodity in, as Theuws suggests (2004, 132), a Christian imaginary world.

In this article, aspects of the production and economic exchange of Carolingian/Ottonian disc brooches are examined through a compositional analysis of 281 brooches selected from collections across The Netherlands, 133 of which were also measured dimensionally. The areas (see fig. 1) from which they were recovered were: 1. Nijmegen 2. Friesland 3. Groningen 4. Naarden 5. Zeeland.



Fig. 1 Find areas for the brooches in this study.

THEORETICAL ORIENTATION

In an attempt to model early medieval craft production the Flemish historianVerhulst suggested that artisan activities were mainly located around abbeys, royal courts, large estates and urban centres, with the addition of a small proportion of travelling

artisans, perhaps less regulated than those living within more static environments (Verhulst 2002, 72). The exact nature of these craft activities and the social position of the artisans who produced them is still attracting some debate. However, different organisational structures for artisan activities must have existed. Söderberg, a Swedish archaeologist and craftsman (Söderberg 2004, 8) also attempted a classification for copper-alloy craft activities by differentiating between casting at, or by:

a) Royal centres, possibly with craftsmen engaged as bondsmen.
b) Super-regional, permanent workshops, with the products destined for periodic markets.
c) Permanent administered urban production sites, such as Emporia, e.g.
Dorestad and Hamwic,
d) Infrequently used primitive workshops, making socially determined
goods and exhibiting little experimentation.
e) Merchants, whilst travelling, producing simple ingots and weights.
f) Domestic households, nonprofessional, including simple jewellery and repairs.

The technology and artisanal skill required to mass-produce disc brooches can be compared to these theoretical workshop models. Artisans are frequently able to choose the raw materials involved and in the quantities required to repeatedly produce the artefacts that they are skilled at making. Typological evidence in terms of morphological consistency can also be combined with a comparison of alloy choice. Consistency (or otherwise) when studied over wide geographic areas, can suggest how standardised production was in terms of intentional choice (Martinón-Torres et al. 2012, 536). The level of standardisation present therefore, can then be modeled conceptually against Söderberg's organisational structures and subsequently something can be suggested about how brooch production interacted within the wider Carolingian economy.

MATERIAL & METHODS

Material

Disc brooches are one of the most frequent metal finds of the Carolingian/Ottonian period and much work has been undertaken to produce detailed typologies (Frick, 1992; Bergman, 1999; Bos, 2006). 10 Disc brooches make their first appearance in the Roman period and the shape continues to be popular in the Merovingian period as well, especially silvered and gilded, garnet and filigree decorated types commonly found in furnished graves from this time. Over a hundred types have already been

classified for the Carolingian/Ottonian period by Frick and by Bos in particular. Bos's groups 2.5 (types with one or more crosses) and 2.7 (types with human and animal figures) are the subjects of this paper as they are decorated with overt Christian motifs (Crosses, Saints, Christ figures).

Other Carolingian/Ottonian period groups such as 2.3, 2.4 (stars), 2.7.2 and 2.6 (Pseudo Coin types) may also have carried a Christian message - perhaps in terms of references to Christ, or heaven. It is possible therefore that a greater proportion of the brooches from this period carried Christian messages. However as this is still uncertain we chose to focus on those groups bearing
more recognised Christian motifs. These groups were also chosen because of their high find frequency, which was necessaryfor the approach deployed in this research. The groups that concern us (fig. 2 for examples) are those found to primarily date between the 8th and 10th centuries but with a gradual dwindling off of certain types lasting until the 12th century (Bos 2006a, 709).

Morphological method

The overall diameter and the thickness of the brooches were measured with a plastic vernier calliper once the brooch had been passed through the HH-XRF device. One aspect of being granted access to these brooches was that the research would be non destructive. This meant that any measurements taken would be on uncleaned artefacts, where varying degrees of corrosion existed. Taking into account wear during use, post depositional corrosion and the unknown dimensional standards employed by the artisans in production; measurements were recorded to the nearest 0.5 millimetre. Manufacturing accuracy beyond this was deemed unlikely.

Compositional method

A single Niton XL3t GOLDD XRF analyser was used for the compositional study. These machines are factory calibrated with standards for metals and alloys and the electronic metals mode was selected and used throughout the data gathering phase. The advantage of this mode is that the same metals are used (Cu, Sn, Ag, Zn, Au) in modern electronic equipment, or are marked as potential hazardous materials (Pb, Hg, As, Se) as can be found in medieval alloys. In the field the analyser was mounted on a lead covered portable test bench to provide a consistent operating environment and protecting the user from radiation. After testing with longer measuring times, the signal was found to be stable after a reading time of 35 seconds, so this was deemed sufficient to
determine an elemental count of 10ppm for most elements. Two spectrum readings per 35 second interval were taken, the first for the main range of elements at 50kV (Cu-K to Ba-K, and Au-L to Pb-L) and the second for the low range at 10kV (Al-K to Cu-K). After the analyses, the spectra were checked for inconsistencies.

An external normalization of the completed dataset in Microsoft Excel™ was undertaken which corrected for the contribution of the light elements that would be

present due to contamination from soil residues (such as sand, clay and iron hydroxides). The elemental concentrations of the alloying elements were normalised on a light elements (Si-Fe) free basis. In the present paper, only the main alloying elements (Cu, Sn, Zn,Pb) are considered. The factory calibration of the device was checked against the CHARM copper-alloy reference set (See fig. 3 and Heginbotham et al. 2014). Further bias introduced by corrosion effects were also evaluated by comparison to studies by Fernandes et al. on corroded Roman finds (Fernandes et al. 2013).

Interpretation of compositional data

The classification scheme developed by Bayley and Butcher for their compositional study of Roman brooches was adopted here (Bayley and Butcher 2004, 24). They used ternary graphs to visualise three variable groupings. In this case (see fig. 3) the three main alloying elements in copper-alloy; tin (Sn), zinc (Zn) and lead (Pb). The names given to the areas of the graph are of course associated with terminology employed in modern metallurgy.

It is important to understand however, that ancient names and their corresponding alloy ratios are less well understood (Bayley and Butcher 2004, 14). Any attempt to apply modern borders to these classifications would less likely represent historical boundaries laid down by ancient craftsmen. But by visualising large numbers of measurements this way reveals patterning that better reflects historical boundaries and therefore technical choice. The results below are presented with this in mind.

To enable a better comparison of the results below, two Merovingian brooches are included here (fig. 4). Bos type 2.11.1 is a Cross-shaped brooch (Bos 2006a, 779), the other is the Bos 1.1 'Domburg' type, with kidney shaped terminals (Bos 2006, 459). These results are typical of Merovingian alloys (Roxburgh et al. 2014, 24), which appear to be a continuation of late Roman compositional choice seen in crossbow, and supporting arm brooches (Roxburgh et al. 2017, 187, fig. 5.3.21 and fig. 5.3.23). These diagrams show deliberate use of tin and lead to produce brooches in leaded bronze.



Fig. 2 Carolingian/Ottonian period disc brooches bearing Christian motifs (drawn by author)

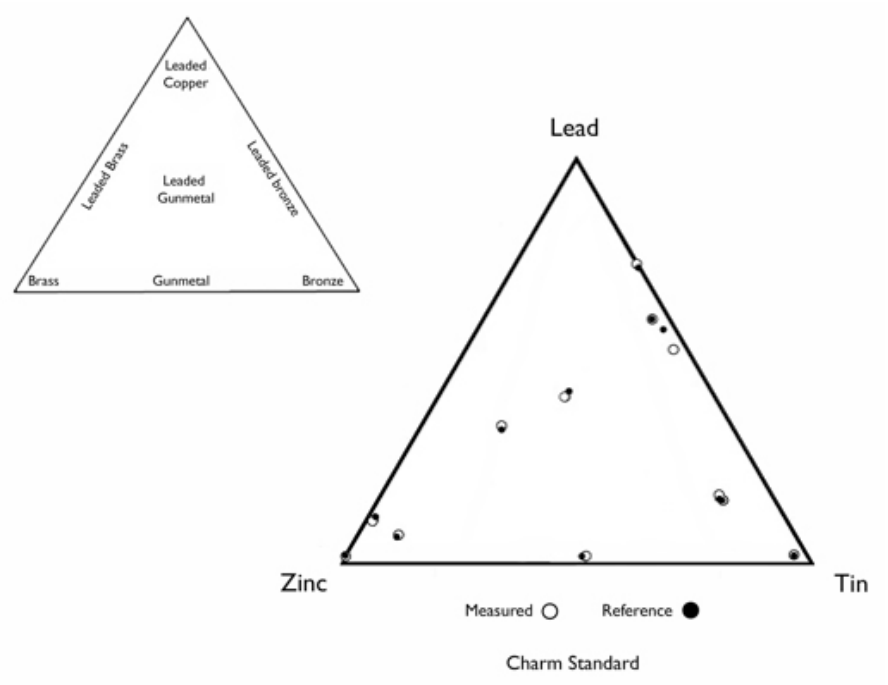


Fig. 3 Ternary graphs showing compositional classifications (after Bayley and Butcher 2004, 24) and measurement bias compared to CHARM standard (drawn by author).

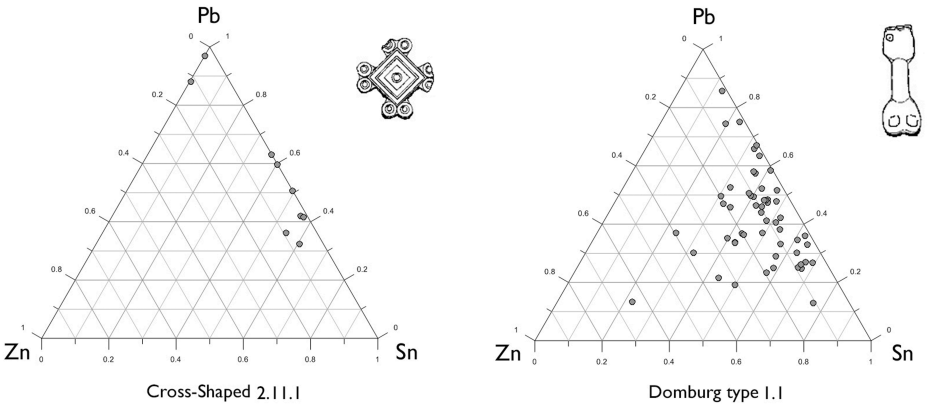


Fig. 4. Ternary graphs showing compositional ratios of Merovingian brooches.

RESULTS

Of the brooches included in the dimensional study, 36 were constructed using the Cloisonné technique with the remainder being cast. All brooches were enameled, with the exception of the 6 examples of Bos type 2.7.2.2. The measurement of both thickness and diameter was relatively straightforward with the exception of Bos type 2.7.2.2 where corrosion and variable edge decoration made the measurement of thickness unreliable.

Type	Construction	Enamel	Description	Thickness (mm)				n.
				Max.	Min.	Average	StDev	
2.5.1.1	Cloisonné	Yes	Cross	3.5	1.5	2.7	0.7	24
2.5.1.8	Cloisonné	Yes	Cross	3.5	2	2.7	0.6	5
2.5.1.7	Cloisonné	Yes	Cross	3	2	2.7	0.4	7
2.5.1.1	Cast	Yes	Cross	3	1.2	1.8	0.4	26
2.5.1.14	Cast	Yes	Cross	2	1	1.7	0.4	9
2.5.1.6	Cast	Yes	Cross	2	1	1.4	0.4	10
2.5.1.5	Cast	Yes	Cross	2.5	1	1.7	0.5	6
2.5.3.1	Cast	Yes	Cross	1.5	1	1.3	0.3	8
2.5.1.30	Cast	Yes	Cross	3	1	1.5	0.6	10
2.5.2.3	Cast	Yes	Cross	2	1	1.2	0.3	13
2.7.1.2	Cast	Yes	Saint	3	1	1.8	0.5	9
2.7.2.2	Cast	No	Head of Christ	n/a	n/a	n/a	n/a	6

Table 1 Thickness.

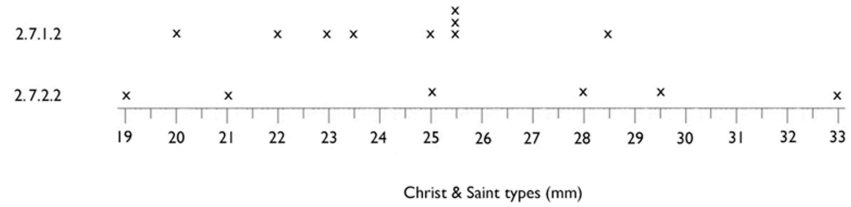
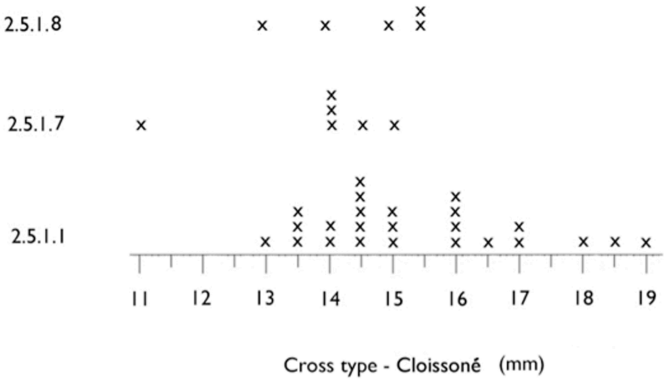


Table 2 Diameter of types displaying human images.



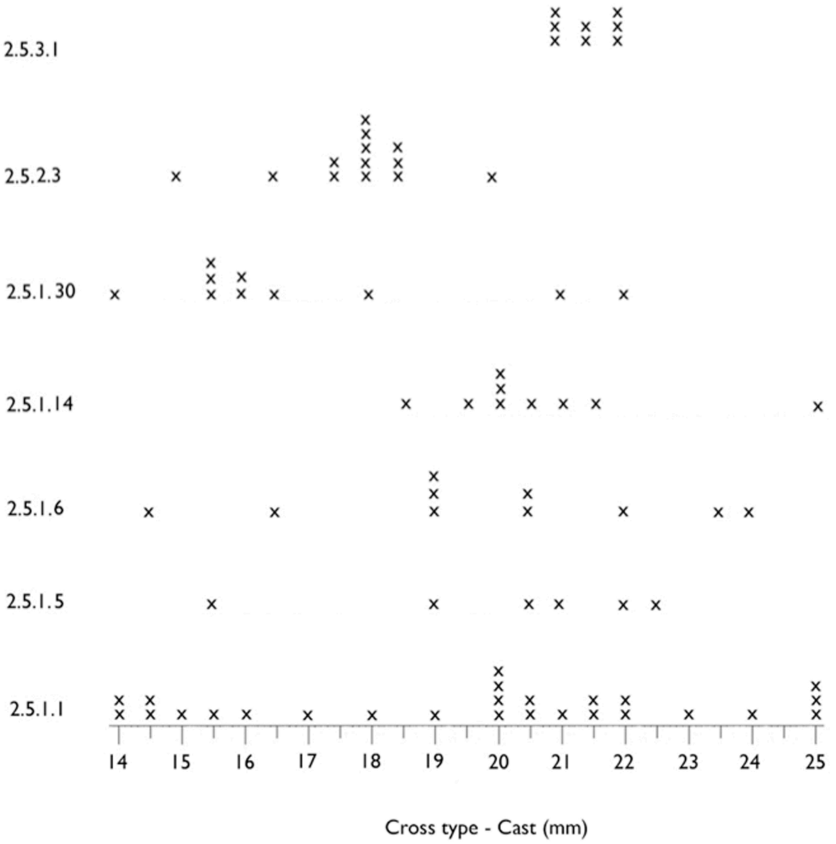


Table 3 Diameter of types displaying crosses

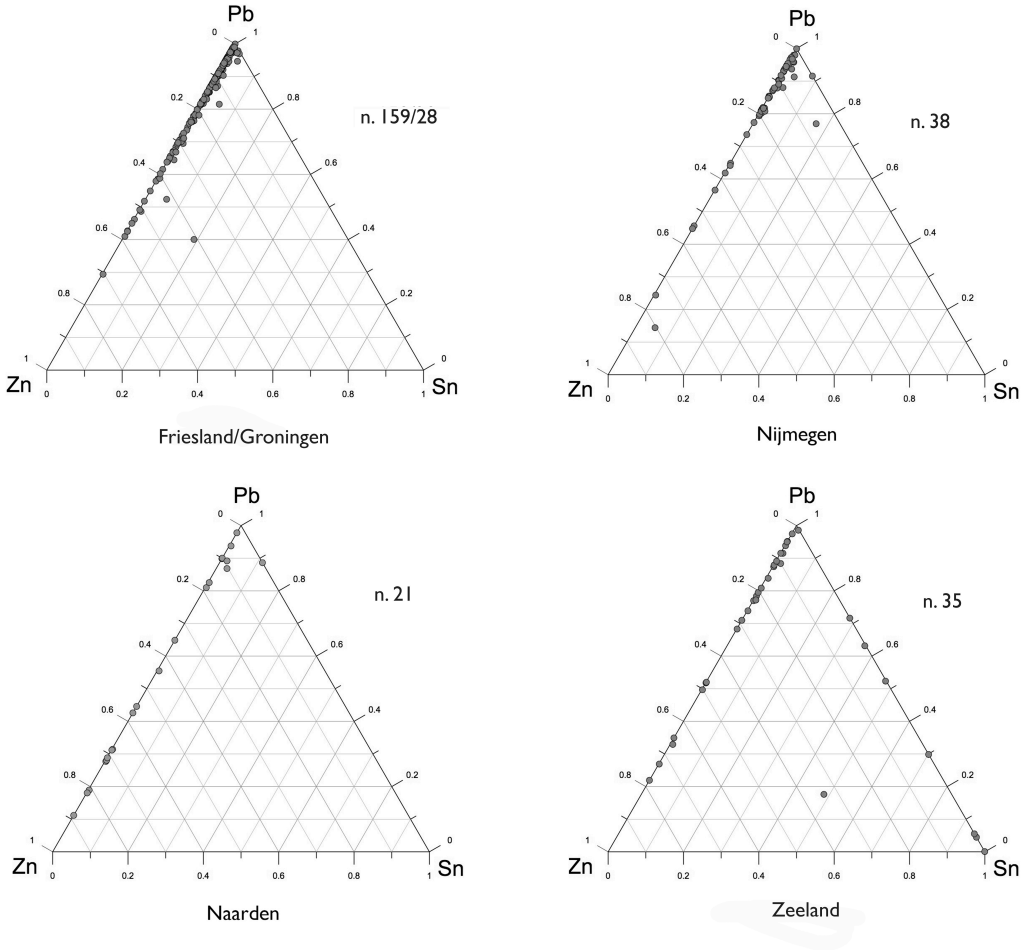


Fig. 5 Ternary graphs showing compositional ratios for Carolingian/Ottonian disc brooches.

DISCUSSION

Morphological similarities

The 36 brooches manufactured using the Cloisonné technique were found to have an average thickness of 2.7mm (see table1), with a standard deviation of less than1, suggesting that the craftsmen were aiming for a thickness of around 3mm for these brooch types. Conversely the 82 cross types using the cast cell technique, were thinner with an average around 1.5mm. The standard deviation across these brooch types was approximately 0.5, indicating very little deviation from the average values. The difference in thickness between the two groups could be explained by the enameling techniques employed. The Cloisonné technique requires a deeper dish in

order to place the wire cell dividers into it. Subsequently the amount of enamel laid into these cells is proportionally deep. The cast technique creates much shallower cells, which trap a much shallower pool of enamel. The thickness of the 9 saint type brooches appears to conform to the same standards as the cross type brooches. This is not surprising as they both use the cast cell technique for enameling.

Brooches could have easily been made with thicknesses beyond that which were necessary to take the enamel and variation in this thickness would have been invisible when viewed from the decorative front. This consistency of thickness measured on both techniques suggests therefore a good level of control.

The diameters of the brooches require a little more interpretation. The Cloisonné brooches display the least deviation. Of the 36 brooches, 72% of them fell between 13.5 and 16 mm (see table 3), indicating a preference for a diameter around 15mm. The measurements of the cast technique brooches revealed a variety of preferred diameters with groupings around 22, 20, 18 and 16 mm. The Saint and Head of Christ types displayed the widest range of diameters (see table 2). The Saints type varied between 20 and 28.5mm with a slight preference for 25mm. The Head of Christ type displayed values between 19 and 33mm with no preferred diameter apparent at all. This type would have presumably been the easiest to make, as they were not enameled. Maintaining a standard diameter for this type was certainly less important than it was for many of the cross types.

All these different diameters could have been related to fashion rather than technical limitations. Diameter could also have varied over time, or perhaps was linked to individual workshops, working to different dimensional standards. The grouping around preferred diameters does seem to indicate a degree of standardization, but this dimension is not as closely controlled as that for the thicknesses.

Compositional similarities

All of the brooches in the study were measured with the HH-XRF device and the results in Fig. 5 show a sharp deviation from the alloys seen in brooches from earlier periods (see fig. 4). The alloy consists of a mixture of copper, zinc and lead, but no tin. If recycling practices were present in the making of these brooches, then you might expect an element of tin to enter the mixture, as bronze items such as the Merovingian period brooches entered the alloy recycling stream. But this appears not to be the case. The new Carolingian/Ottonian period alloy can be classified by the scheme in fig. 3 as being made of leaded brass or leaded copper (but still with a small proportion of brass). What is more interesting is that the choice of alloy ratio is standard for brooches found across the whole of the geographic area, with one exception. At Domburg in Zeeland a small number of the cast, cross type brooches appear to have been made in bronze, or leaded bronze, like those from the earlier tradition. This difference in alloy choice deviates from the alloy chosen for the 125 other brooches in this study. It could suggest copying, perhaps at a different place of manufacture, a temporary shortage in the preferred alloying ingredients, or even

another source of production out side of the study area. That said, the evidence points to the adoption of a standard alloy for brooches from the Carolingian period onwards.

Workshop organisation

The results of the compositional study indicated a consistent alloy choice over a large geographic area. The morphological inspection also demonstrated a fairly reasonable control in terms of size and overall craftsmanship. Therefore an hypothesis can be formed by comparing the results to the workshop models presented earlier.

Söderberg's model for domestic household production (f), has to be discarded, as both the skill level and the technology would not be available to consistently produce enameled brooches in a domestic setting. Infrequently used primitive workshops (d) also present a problem in terms of the consistency seen in the results. Brooches could be mass produced in infrequent batches, but you would expect more variation in the finished quality in a primitive setting, as semiskilled artisans copied existing pieces to fulfil a social demand. Also the technology is unlikely to have been available under primitive workshop conditions. Moreover, as the composition shows that alloys were the same over a large area, this points to a centralised input of raw materials. Infrequent batches would more likely show a greater variation in composition.

Casting by merchants (e) is also unlikely. The skill level required to produce these brooches would not lend itself to being learned by travelling merchants. It is also very unlikely that the technology (including casting and enameling) was mobile enough to opportunistically manufacture brooches as the merchant travelled. Also you might expect more recycled material to enter the alloy flow, as a merchant was tempted to reuse traded metal.

All of the previous options can also be discounted when you consider the symbolic nature of the motifs carried on the brooches. A feature of the churches role in the early medieval west was its increasing involvement in politics, whereby religious authority was increasingly overtaking that of the Royal elite (De Jong 2009, 243). It is less likely therefore that all craftsmen at this time, regardless of position or status would be free to mass-produce items bearing religious images. These brooches could well have been produced widely for more secular reasons, for sale at local markets or for commercial gain, but an option that needs consideration is that the ecclesiastical elite controlled these images to some degree; especially in the way they promoted the churches political ambitions.

Royal centres (a), would have had access to the correct skills and technology and could well have possessed the authority to produce religious images. We interpret royal production in this instance as having a preoccupation for production for the elite, such as the casting of the solid bronze doors at the Palace Chapel in Aachen (Schutz 2004, 386). Therefore, this option seems less likely. Brooches with 'Emperor's' images do exist as a category among the Carolingian/Ottonian, disc

brooches. E.g. Bos' group 2.6 the pseudo-coin brooches. This category appears to be inspired by gold coins from the reigns of Chlotarius II and later Louis the Pious and therefore may reasonably be linked to the copying earlier coin types (Bos 2006, 755). But how closely associated these pseudo-coin brooches are to coin production or their motifs to royal patronage, remains unclear. They could still for example have carried a degree of Christian meaning.

Permanent administered urban production sites such as emporia (c) provide a possible solution. The technology and skills required to mass-produce enameled brooches could be available under this model. However the evidence for religious involvement at emporia appears to be limited and again would the religious elite allow secular mass production of items bearing the Christian message (Hodges 2004, 138), if they were not directly benefiting from it? The Church could of course had them made at an emporia on their behalf, although it begs the question why would they not use their own monastic workshops where production, both in an economic and spiritual sense, could be controlled?

Production at Super-Regional permanent workshops (b) appears to offer the most likely solution. The consistency in alloy choice, skill and technology levels required to mass-produce these items would have needed cross craft interaction especially in terms of glass, ceramic and tool production, entangled within a broader social structure, to maintain the artisans at a consistent skill level (Shimada, 2007).This organisation of production is very likely to have stretched over several generations and knowledge to maintain this craft would most likely to have transferred via apprenticeship or parental teaching (Tehrani and Ried, 2008). At a time when artisan production was centralising on the great abbeys this model seems the most likely fit for enameled disc brooches (Lebecq 2000, 129-133). The overtly Christian messages also point to permanent monastic workshops. How super-regional these workshops were remains to be seen, as the archaeological evidence is still elusive. High levels of communication between many monastic workshops over wide geographic distances could make it possible for technical standards to be maintained between distant groups. Ecclesiastical maintenance of tradition could then be responsible for the consistent morphological and compositional standards over several generations of craftsmen. Alternatively, production could have been centred at one or two super-regional centres specialising in these items. Brooches are small and easily portable so many thousands could have been produced and then transported to other central places (including other monastic centres) for further distribution.

Production at emporia or monastic workshops?

The most likely source of production for these brooches appears to be at superregional permanent workshops. Certainly the use of Christian symbolism on these items would suggest a link to monastic production at the large abbeys.

But emporia could have provided the permanent workshops needed for brooch production as well, however this is far less likely. The archaeological evidence for

metal production at Dorestad for example is elusive (Van Es 1990, 173-175), as is the case for Medemblik (Besteman 1974). As suggested by Theuws the function of emporia could have been more dominated by 'cross-cultural' exchange rather than of production (Theuws 2004, 134).

The "separate" nature of emporia therefore places them on the edge of Latin Christendom, acting as communications centres between the Christian and pagan spheres of exchange. The production of disc brooches at emporia would be anchored in the profane sector of society, with goods destined for open market, perhaps destined for pagan lands. These disc brooches are found within the Christian sphere of influence therefore unlikely to have been an item created for export.

Monasteries in contrast were primarily cult places, where business in terms of production and subsequent exchange was a secondary affair (Theuws 2004, 135). This exchange was firmly anchored in a Christian imaginary world, a world where brooches carrying Christian symbols could have engaged in a different reciprocal arrangement than those distributed from the emporia. Whilst the secular nature of emporia is attested by numerous discussions surrounding a large number of archaeological excavations (E.g. Brisbane 1988; Besteman 1974; Van Es and Verwers 1980; Lebecq 1995; Loveluck and Tys 2006), the archaeological evidence for monastic workshops remains elusive.

There is some archaeological evidence for metal production within monastic centres such as Fulda and St Denis (Henning 2005, 17-18), but the only monastery dating to this period to have received detailed archaeological study, is the Benedictine monastery at Vincenzo al Volturno, Italy. The permanent workshops discovered during the excavation were found to be an integrated part of the monastic complex, situated close to the main cult area dedicated to St. Vincent, as opposed to being housed somewhat further away, perhaps in the vicus (Hodges 2004, 138). Therefore production seems to have been strategically placed well within the cosmological environment of the monastic precinct. The excavations in this area demonstrated mixed craft activities where artisans engaged in metalworking, glass production, enamelling, bone and ivory carving. The organisation of these craft activities being comparable to those described by the 12th century Benedictine monk, Theophilus in his book De Divers Artibus (Hodges 2004, 140). Lebecq suggests that production at monasteries was quite specialised (Lebecq 2000, 131), especially in coastal regions, in order to exploit local conditions. Such as salt production and livestock rearing at monastic estates in Zeeland. This suggests that the workshops producing brooches could have been at a fewer select specialist monastic sites, possibly situated in the Frankish hinterland some distance away from the coastal areas of Magna Frisia. This again supports a super-regional model serving a larger geographic area.

Wherever these workshops were situated, the activities appear to have all the ingredients necessary to produce items enriched with religious meaning, located in an environment where social power as Härke suggests is created through an interconnectivity of symbols and ritual acts (Härke 2000, 377). The manufacture of objects imbued with ritual and symbolic meaning could therefore serve in a system of exchange that generates or maintains the social hierarchy. Production therefore is

much more likely to have taken place in a permanent monastic workshop where imaginary value could be added, rather than at the more secular emporia.

Exchange between Church and peasantry in the Christian imaginary world.

Before the 9th century peasant society was relatively free and autonomous. But as more and more land slipped into private ownership the peasantry became increasingly 'caged' as Wickham puts it by the power of the church and aristocracy (Wickham 2009, 956). Throughout Carolingian Europe ownership of property shifted away from peasant landowners into the hands of local lords. More and more, peasants became dependent, rent paying tenants, with an increasing obligation in terms of services to their aristocratic or ecclesiastical Landlords.

Land was increasingly donated to the church by peasant farmers; in a reciprocal arrangement where the value of the exchange as Theuws puts it (Theuws 2004, 135), was anchored in a different imaginary world. 'Gifts for the soul' where the reward is received many times over in heaven, perhaps including acts of prayer on earth by the professional clergy (Wickham 2009, 956), represents an exchange system that is clearly different from one of strict economic value. The selling of commodities whether they were surplus or deliberately created for local markets, requires a different socioeconomic relationship than exchange operated through reciprocity (Wickham 2005, 697). The extraction of surplus from the peasant tenant, by the church in the form of rent, would likely include an element of reciprocity involving the imaginary world. Power is created in this situation over the peasant tenant. Godelier distinguishes between inalienable objects and alienable goods in developing Weiner's thoughts on cosmological authentication (Godelier 1999 (1996), 90, 94-95,100-1). In this case the alienable goods are the surplus, in terms of rents being extracted by the church, whereas the reciprocity, given perhaps in the form of prayers would form an inalienable bond with the religious institution. As suggested by Rosenwein (1989, 138), this could have been an exchange system between heaven and earth, from God to men and vice versa. The inalienable elements of this exchange system, therefore contributing to Wickham's 'caging' of the tenant peasantry.

But peasants needed to undertake transactions for alienable goods as well. Those engaging in agrarian farming would attempt to produce as varied a range of foodstuffs as possible, a survival strategy common in all societies. Pastoralists, in all known societies, exchanged surpluses of wool, leather, meat and cheese, with agrarian producers (Wickham 2005, 698).

However any of these surpluses could be exchanged for other foodstuffs or various artisanal products including clothing, ceramic vessels, metal and wooden utensils and tools. Exchange of this nature could have been with the relevant local craft specialists, from wandering pedlars or from local or periodic markets.44 Artisanal products of this type would likely to have had an hierarchy of exchange linked to the complexity of their production. In peasant spheres of exchange, it would be easy to assume that foodstuffs, clothing and essential tools would have had a

greater day to day priority than the acquisition of a brooch. However it could also be possible that owning a brooch was a necessity, needed to fulfil certain social relations. Therefore demand for this type of artisan product could have been higher, especially if the need was driven by cosmological authentication.

The peasant populations of the Frankish and Frisian coastal and riverine areas may have engaged in various pastoral and agrarian exchange systems, but their requirements in terms of metal goods would have brought them increasingly into contact with artisan production from monastic centres. Whether the peasants in question were dependant peoples, 'trader farmers' (Hodges 1982, 88), or merchants engaged in large-scale trade (Lebecq 1992), to them a brooch could remain alienable, if it remained a profane functional dress accessory. But if the source of brooches carrying a Christian message (those bearing crosses, saints and Christ motifs) was known either by the peasant or the merchant, to be from the Christian imaginary world of the great abbeys, their value would likely to be enriched with additional religious meaning.

Documentary records show that the Abbeys at Fulda and Warden received numerous donations by devoted Frisians during the 8th and 9th Centuries (Lebecq 2000, 132). But rather than donations of land, they took the form of large quantities of cloth mainly as payment of annual rents. If brooch production and their subsequent involvement in transactions, be they as commodities or gifts (Gregory 1982, 71), was located at these large monastic centres, the activities were situated a good distance from the Frisian coastal homelands. Periodic markets such as those described as taking place at the abbey of Saint Denis (Lebecq 2000), allowed visiting Frisians to participate in exchange activities at cult places (Theuws 2004, 129). These activities were likely therefore to have taken place within a Christian sphere of influence, where ritual and political acts formed an integral part of the transaction. Transactions that included the receipt of a disc brooch, bearing a Christian message in terms of a cross, saint or Christ motif would have re-enforced the relationship between the individual and the Church. The brooch in this context would become inalienable to the owner, reinforcing the hierarchy between the powerful ecclesiastical elite and those below it. The owner a brooch from this inalienable transaction could also benefit socially when returning to Frisia. The display of a brooch, imbued with 'cosmological authentication' (Theuws 2004, 129), would further serve to equalise or generate a new hierarchy amongst social groups who were not free to undertake the journey. This could in turn create a desire for those able, to undertake the same journey and just as pilgrims in the middle ages sought to possess pilgrim badges, more people would undertake the journey in order to return with a prestige object, not because of its material value but of its immaterial worth; a value that enabled a shift in social hierarchy based on events firmly embedded in the Christian imaginary world.

CONCLUSION

This article presents a combined study of the morphological and compositional characteristics of 133 Carolingian/Ottonian disc brooches, bearing overt Christian motifs. The aim was to assess the degree of consistency present in these brooches recovered from across a wide geographic area. Then to form an hypothesis of how production was organised based on suggested models for this period. Once done, their place in the early medieval economy could be more readily understood.

The results indicated a high level of consistency in alloy choice and to a lesser extent in morphological characteristics. This consistency, when compared to organisational models for the time, rules out production by travelling merchants or in primitive or domestic settings. It suggests that production was organised on a regional or even super regional scale. An analysis of production at royal estates, emporia and the great abbeys found the latter to be the most likely source of these objects. Furthermore, the Christian nature of these brooches, if produced within monastic centres such as the great Benedictine monastery at Vincenzo al Volturno, would imbue them with religious meaning and allow for a fresh interpretation of their methods of exchange. An exchange system is proposed that takes us beyond secular, social and economic values to a world of reciprocity between the Church and its congregation. Linking production to the Christian imaginary world, these small, mass-produced brooches may have served to reinforce the social hierarchy between the powerful ecclesiastical elite and the individual. This model of exchange brings us closer to the essence of the early medieval Christian world, at a time when peasant society was increasingly becoming 'caged', as dependant, rent paying tenants of aristocratic and ecclesiastical landlords.

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Chapter 6

Where Worlds Collide: A typological and compositional analysis of the copper-alloy mounts from Viking Age Walcheren.

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INTRODUCTION

In this article we present a typological analysis for a group of ninety Viking-Age mounts, found in and around the North Sea coastal town of Domburg (Walcheren, The Netherlands). This new analysis is supported by compositional data gathered using Handheld X-Ray Fluorescence Spectrometry, also known as portable XRF (pXRF) and Handheld portable XRF (HHXRF). The new data sheds light not only on the character of the technology available at the time, but also allows a reconsideration of their functional use together with their role in expressing social identity within a Viking-Age, North Sea world.

Typological interest in ancient copper-alloy objects can be traced back well over 200 years, but it has only been since the 1950s with the invention of X-ray techniques such as Optical Emission Spectrometry (OEM), Neutron Activation Analysis (NAA) and X-Ray Fluorescence Spectrometry (XRF), that much compositional research has been undertaken. Studies using these techniques have revealed a lot about the technical choices presented to these ancient craftsmen. The technical choice of alloying agents added to copper, namely tin to make bronze or zinc to make brass - with or without a quantity of lead - has revealed much about the complex relationship between composition and typology (Dungworth 1997, 902). The technological limitations imposed on certain artefact types by the use of different alloy mixtures have been given particular attention, especially differentiating between items cast in a liquid form into a mould or wrought, by beating into a desired shape with a hammer (For example see Smythe 1938; Unglick 1991; Bayley and Butcher 1995, 2004; Craddock 1988). But a combined typological and compositional approach to studying copper-alloy items - especially those from the early medieval period - has up until now been limited (For example see Bayley and Butcher 2004; Martinón-Torres et al. 2012; Roxburgh et al. 2014), particularly in The Netherlands where research has mainly centred upon typological concerns (See Capelle 1976; Frick 1992; Thörle 2001; Bos 2006). We therefore present this combined analysis of this interesting group of mounts and formulate a new hypothesis about their purpose and cultural associations.

The selection of material

A great many of the copper-alloy mounts selected for this article were recovered from the beach adjacent to the modern seaside town of Domburg, and subsequently published in a catalogue by Capelle in 1976 (p. 28, taf. 20 - 22). These mounts along

with a great many more beach finds found their way into the collections of the Zeeuws Museum and the Cultural Heritage Agency of Zeeland's archaeological depot (SCEZ), partly as the collection of the Koninklijk Zeeuwsch Genootschap der Wetenschappen (KZGW; the Royal Zeelandic Society of Sciences, Many thanks to Aagje Feldbrugge for providing photographs of the collection), in Middelburg. Access to the material was initially granted for a compositional study, to Pim van Tendeloo, from the Vrije University, Amsterdam, with additional scientific support from the Dutch Cultural Heritage Agency (see Van Tendeloo 2017). In 2014, the data from this study was kindly donated to a much larger compositional survey undertaken by the first author, as part of his ongoing PhD research project ('Charlemagne's Workshops' - based at the department - Roman Provinces, Middle ages and modern period, faculty of archaeology, Leiden University - is an investigation into the composition of early medieval copper-alloys). A follow up visit was subsequently undertaken in late 2014 to gather more compositional data from finds from a wider geographic area (Walcheren and the province of Zeeland) and it was observed at this point that the large number of Viking-Age mounts being presented for analysis warranted more detailed investigation. This same conclusion had also been reached by the second author, after conducting an examination of a number of the mounts, within a wider selection of Zeeland objects, undertaken as part of her ongoing PhD project (Interdisciplinary PhD project at the University of Groningen on Frisia in a Viking Age North Sea World. Material from Zeeland was examined in October 2013 during the *Workshop on the Early Medieval metalwork from Domburg* (Middelburg, 15 Oct 2013, and during a visit to the SCEZ. With thanks to Henk Hendrikse, Aagje Feldbrugge and Pieterjan Deckers). Therefore, the decision was made to select a coherent group of items from the Domburg collections and to study them from a combined, compositional, typological and contextual point of view.

The mounts and associated items selected for this study were classified as follows (fig. 1). The first group consists of five items that have been assigned the name pendants (fig. 1, a1, a2). They appear to be designed to hang from another object, which could possibly have been an object similar to the pendant mounts (fig. 1, b1, b2) discussed below. If these objects were intended to swing freely then the term pendant is valid. However, they may equally have been used as a clasp or closing mechanism, perhaps for a bag or box. The holes running through the centres of the pendants could have been functional rather than decorative, allowing them to be pushed onto a peg or similar mechanism, thus acting as a closing device.

The second group of six items has been assigned the name pendant mounts (fig. 1, b1, b2). This is because we have already made an association with the pendant group mentioned above. These objects appear to have been designed for mounting to another object, perhaps a leather strap or a box lid. Another object, perhaps similar to fig. 1, a1, a2, would have completed the assembly by being attached to the lower end via a retaining pin (discussed later in section 4.3 with reference to drawings in fig. 7, d, f).

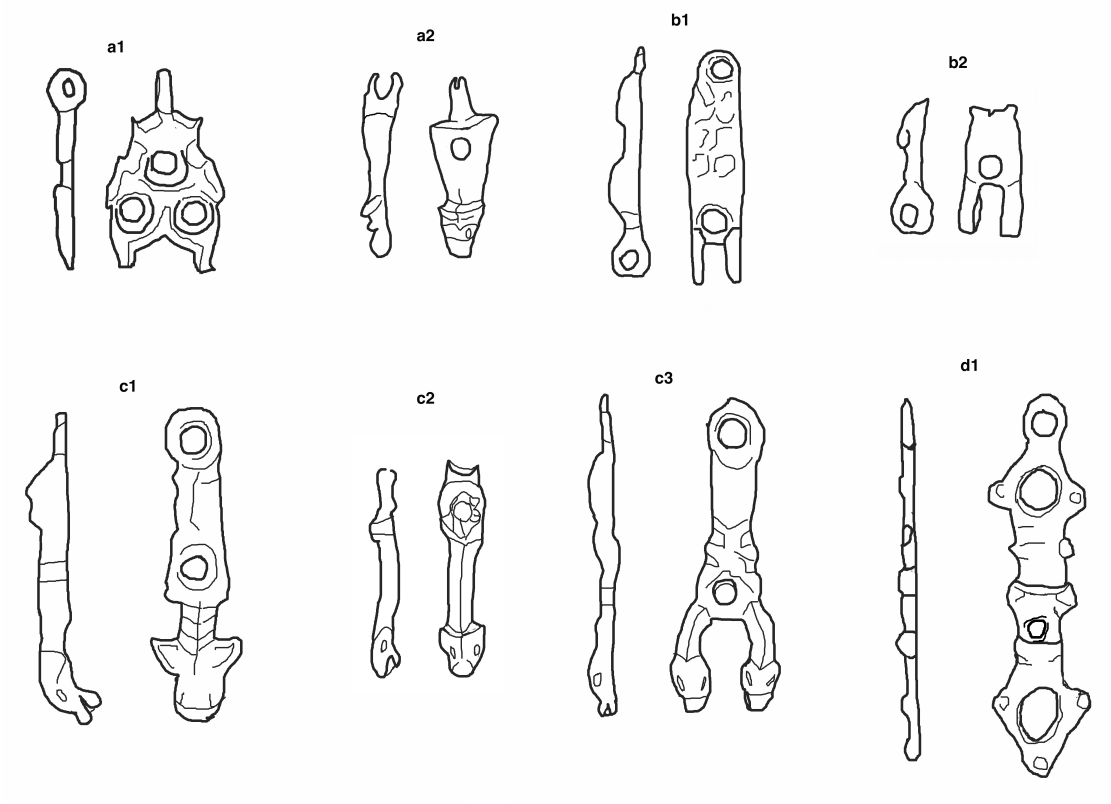


Figure 1. Pendant (a), Pendant mounts (b), Strap-end mounts (c), Strap-links (d). Drawn by first author.

The third group, the largest with fifty three items, has been assigned the name strap-end mounts. They typically have two holes to allow them to be riveted onto another item (a number of these survive with rivets still in place). This other item again could have been a leather strap or possibly wood, either of which would have corroded very quickly after deposition. A common theme throughout this group is that they all bear decorative animal heads at one end, either singularly (fig.1, c1, c2) or in some cases two, perhaps representing a double-headed creature (fig.1, c3). Many of these animal heads appear to curve inwards slightly as if conforming to the shape of the object they were once attached to (e.g. fig. 1, c1).

The last group of twenty two items is distinguished by two lozengiform holes alongside two smaller rivet holes (fig. 1, d1). These have been assigned the name strap-links and initial observations suggest that they may link two thin leather straps together. However this is less clear when the rivet holes are analysed. As per the other groups just described, these strap-links seem to have been riveted to another item such as a leather strap or piece of wood. They may therefore have functioned as a closing device or for hanging another object off.

Find locations and historical context

Most of the mounts presented in this study came from locations near to modern day Domburg These were mainly beach finds from an early medieval settlement and grave fields now lost under the sea. A lot of the beach finds made their way into the KZGW-collection, which was collected between Oostkapelle and Domburg in the 19 th and early 20 th century (With thanks to Aagje Feldbrugge for providing the information). An additional five mounts came from excavations in the *Ringwalburg* or circular fort (built in the 9th century) in the present day town, which were found during excavations by ARC in 2010 (Ufkes 2011). An additional two mounts were presented from the area around Middelburg and a further mount is known from Oost-Souburg but was not available for the compositional study.

The present seaside town of Domburg lies on the Northwest coast of Walcheren. Walcheren, as well as other parts of the Dutch coastal area, belonged to the historical region of Frisia, which stretched from the border of Belgium in the south-west to the river Weser in Germany in the north-east. Even after incorporation in the Frankish realm in the 8 th century, the area remained known as Frisian. From time to time the North Sea reveals Domburg's earlier origins along the beach, at very low tides, in the form of settlement structures, grave fields and thousands of metal finds, which were frequently washed ashore after heavy storms (Op Den Velde and Klassen 2004, 3). It is thought that activities may have continued into the 10 th and 11 th centuries, during which time the area was gradually covered in drifting sand and eventually lost under large dunes, primarily due to coastal erosion and the prevailing westerly winds (see Jelgersma and Van Regteren Altena 1969; Kooijmans 1980). The first record of beach finds is from January 1647 (Macaré 1992) when sandstone altars from a roman temple were revealed along with numerous coins, which were subsequently collected from the beach by the local inhabitants. From this point onwards a combination of storms and low tides have at intervals revealed more settlement structures, graves and much metalwork including the largest number of sceattas and Merovingian deniers found by far at one location, of all the North Sea countries (Op Den Velde and Klassen 5). It has been proposed that this lost settlement was called *Walichrum* from which the island takes its name, and as the archaeology suggests that it must have been quite an important settlement and trading site in early medieval times (Capelle 1976; van Heeringen et al 1995, 34-44).

It has also been suggested by the number of finds, especially coins, that this was the site of an emporium, a trading post originating in the late 6 th century - facilitating interregional trade around the North sea and Britain especially - trade that lasted well into 9 th century (van Heeringen et al. 1995, 2). Its importance in the Carolingian period could have almost matched that of Dorestad (Capelle 1976, 5), but during the 9 th century however, this role appears to have been taken over by other trading sites (Capelle 1976, 5; van Heeringen et al. 1995, 230). The situation was possibly made worse by subsequent Viking raids resulting in Walcheren being given to Danish warlords as a fiefdom by the Frankish emperor Lothar I. It is thought that the trading post declined rapidly during the last quarter of the 9 th century, the time in

which a large defensive ring fort or 'burg' was built nearby, possibly as a refuge from on going Viking raids (van Heeringen et al. 1995, 230; This identification has been questioned and the idea was proposed that it could have indeed been a Viking construction. See Ten Harkel 2013). This 'burg' subsequently formed the nucleus around which the later town of Domburg grew. Danish rule is thought to have come to an end by at least 884AD, when the last Danish benefice-holder died and from this time onwards, power transfers to local counts (Coupland 1998). It also appears the region at this time is used for the production and export of Frisian cloth - *pallia fresonica* (van Heeringen et al. 1995, 233-235). From the late 9 th until the early 11 th century, the ring fortress at Domburg remained inhabited and during this Viking Age, connections between the Frisian coast, Scandinavia and the British Isles seem to have continued (IJssennagger 2015). This history is indicated by a handful of Viking finds (in particular of the Borre style) that were recovered from excavations in the fortress in 2010 and are dated to the late 9 th or early 10 th century (Ufkes 2011). The material selected for our current analysis therefore is all generally thought to date from the 9 th century to the end of the 11 th and thus falls within this Viking Period.

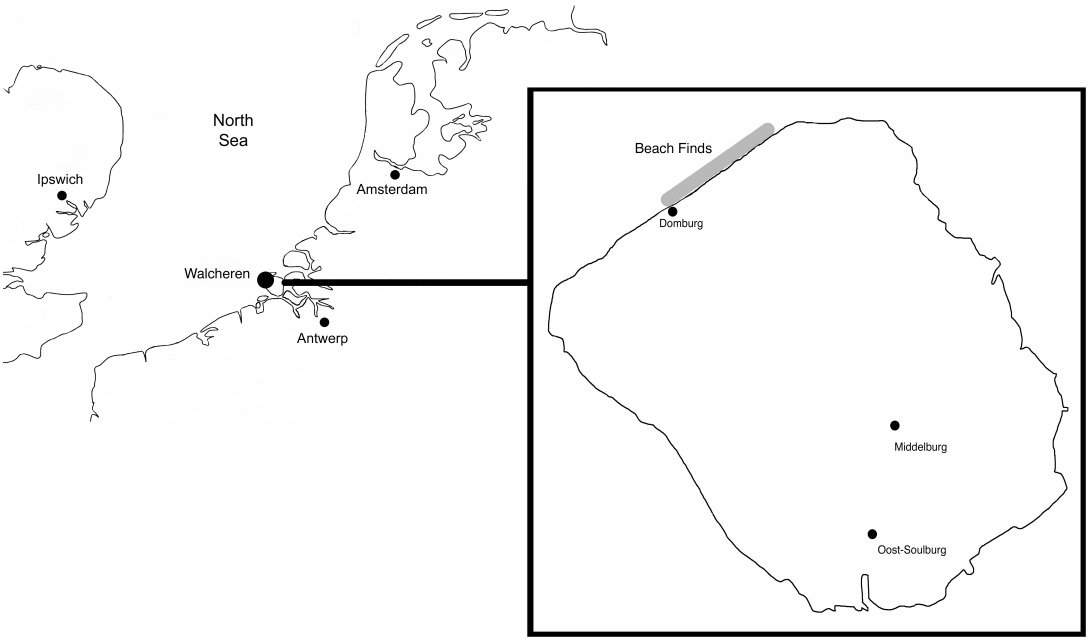


Figure 2. Find locations for the mounts in this study.

Research orientation and questions

A literature search of early medieval copper-alloys revealed that much had already been published on fibulae, strap-ends, stirrup-strap mounts and horse harness. Useful typologies now exist for the fibulae found around Domburg (Thörle 2001; Bos 2006a, 2006b*)*. Strap-ends are also a frequent find and can be compared to some extent to the typologies created by Thomas for Viking-Age Britain (Thomas 2000). However the

mounts presented here bear little similarity to either fibulae or strap-ends so other associations need to be considered. The lozengiform shape of the strap-links in fig.1, d. provides a worthwhile lead and similarities to Anglo-Scandinavian horse harness become apparent when reviewing the literature (Williams 2007). But the size of the individual items makes this interpretation problematic as if you consider the width of modern horse harness, the Walcheren mounts are very small (See Capelle, drawings 334, 335, 336 as examples. The overall lengths are between 4 - 5cm), the holes especially seem too small to take a leather strap strong enough to withstand equestrian activities. Viking-Age stirrup-strap mounts (see Williams 1997) are the other class of item that need to be considered as there are a number of stylistic similarities, which will be discussed further below. But as already stated, the mounts we are concerned with appear to be too small for an equestrian application.

So the questions we address here are straightforward. Firstly can we gain a clearer understanding of their function through a combined compositional/typological approach? In doing so can we say something from the composition for example, about the likely organisation of production and their subsequent distribution? Secondly can we infer anything new about the cultural associations the decoration of these objects may hold? By comparison to finds from other area's, both within the Netherlands and beyond, can we provide a wider (historical) context for the phenomenon? For example, can we support an Anglo-Saxon or Anglo-Scandinavian context to these objects, or do we need to consider a more local continental origin?

THEORY AND METHODOLOGY

Theory

The main assumption is that through a combined compositional/typological approach, something useful can be gained about the social organisation behind the production and use of these objects. To do this we must draw on what is already known about the organisation of craft production at this time.

In an attempt to model early medieval craft production the Flemish historian Verhulst suggested that artisan activities were mainly located around abbeys, royal courts, large estates and urban centres, with the addition of a small proportion of travelling artisans, perhaps less regulated than those living within more static environments (Verhulst 2002, 72).

The exact nature of these craft activities and the social position of the artisans who produced them is still attracting some debate. However, different organisational structures for artisan activities must have existed. Söderberg, a Swedish archaeologist and craftsman, adopted the classification proposed by Hedegaard in his attempt to study Viking age workshop organisation (Hedegaard 1992; Söderberg 2004). Models for copper-alloy craft activities could therefore be differentiated between casting at, or by:

a) Royal centres, with professional craftsmen possibly engaged as bondsmen.
b) Supra-regional, professional, permanent workshops, with the products destined for periodic markets.
c) Permanent administered urban production sites, such as Emporia, e.g. Dorestad and Hamwic,
d) Infrequently used primitive workshops, making socially determined goods and exhibiting little experimentation.
e) Merchants, whilst travelling, producing simple ingots and weights.
f) Domestic households, non-professional, including simple jewellery and repairs.

The technology and artisanal skill required to produce copper-alloy mounts can be compared to these theoretical workshop models. Artisans are frequently able to choose the raw materials involved and in the quantities required to repeatedly produce the artefacts that they are skilled at making. For copper alloy this can take the form of the melting of fresh or recycled metal supplies or even the smelting of ores if perhaps production is close to the area of extraction. Typological evidence in terms of morphological consistency can also be combined with a comparison of alloy choice. Consistency (or otherwise) when studied over wide geographic areas, can suggest how standardised production was in terms of intentional choice (Martinón-Torres et al. 2012, 536). The level of standardisation present therefore, can then be modeled conceptually against Söderberg's organisational structures and subsequently something can be suggested about how their production interacted within the wider North Sea economy.

How does Hand-Held XRF work?

The technique employed for the compositional research is Handheld XRF, the principles of which are the same as for more conventional laboratory based XRF, but typically being hand-held, working in the field, at a lower wattage (For more technical details and applications in archaeology see Shackley 2011; Shugar and Mass 2012; Potts and West 2008). An X-Ray tube with a silver anode fires a primary X-Ray beam at the object of interest. As a result, this beam causes the atoms in this object to become excited resulting in the release of electrons, freed from their place within their normal atomic structure. The energy given off by the release of electrons is measured by a detector; mounted within the equipment and as this energy level is unique for each element, it can be characterised and an assessment of the ratio of each elements present can be made.

A single Niton XL3t GOLDD XRF analyser was used for the compositional study. These machines automatically adjust anode current settings to ensure optimal counts and are factory calibrated, using a fundamental parameters method, with standards for metals and alloys. The analyser was fitted with a silicone drift detector with optimised geometry, furthermore the analysis did not use filters or vacuum or

helium purges. The electronic metals mode was selected and used throughout the data-gathering phase. The advantage of this mode is that the same metals are used (Cu, Sn, Ag, Zn, Au) in modern electronic equipment, or are marked as potential hazardous materials (Pb, Hg, As, Se) as can be found in medieval alloys. In the field the analyser was mounted on a lead covered portable test bench to provide a consistent operating environment and protecting the user from radiation. After testing with longer measuring times, the signal was found to be stable after a reading time of 35 seconds, so this was deemed sufficient to determine an elemental count of 10ppm for most elements. The lower limit of detection was determined for each measurement separately, as it was affected by the matrix (i.e. alloy composition). If the matrix is favourable, the 10ppm detection limit is obtainable. Analyses where the element concentration was below the matrix-influenced detection limit were equalled to 0. Two spectrum readings per 35 second interval were taken, the first for the main range of elements at 50kV (Cu-K to Ba-K, and Au-L to Pb-L) and the second for the low range at 10kV (Al-K to Cu-K). The spectra processing was done using dedicated Niton software and after the analyses, the spectra were checked for unexpected peak overlaps.

One measurement per mount was taken and an external normalisation of the completed dataset in Microsoft Excel™ was undertaken which corrected for the contribution of the light elements that would be present due to contamination from soil residues (such as sand, clay and iron hydroxides). The elemental concentrations of the alloying elements were normalised on a light elements (Si-Fe) free basis. In the present paper, only the deliberate alloying elements (Sn, Zn, Pb) are considered. The factory calibration of the device was checked against the CHARM - bronze reference set (See fig. 3, left, and Heginbotham et al. 2014) and bias due to corrosion was also evaluated by comparison to studies on corroded Roman finds, which revealed that a depletion in copper and zinc takes place, altering measurements recorded on the outer surface of an item (van Thienen and Lycke 2017; Fernandes et al. 2013). Quantitative analysis using HHXRF is well accepted now on obsidian for example, but there has been some debate on the suitablilty of use on heterogenious materials such as corroded non-ferrous metals (Heginbotham et al. 2014; Shackley 2010). The results presented in this paper are interpreted in a qualitative or semi quantative way.

The ternary diagram (fig. 3, right) demonstrates the difference in graph location for corroded and non-corroded results (using Grapher™ 10, software). In this case values containing zinc move towards the brass corner of the graph as the ratio of zinc to the other elements increases. Therefore if it had been possible to clean the mounts studied in this paper (by destructively removing outer layers), it would be expected that the results in 3.1 (below) would behave in the same way (For further reading on corrosion see Campanella et al. 2009; Nicholas and Manti 2014; Orfanou and Rehren 2014).

The interpretation of compositional data

The classification scheme developed by Bayley and Butcher for their compositional study of Roman brooches was adopted here (Bayley and Butcher 2004, 24). They used ternary graphs to visualise three variable groupings. In this case the three main alloying elements in copper-alloy; tin, zinc and lead, see fig. 3 The names given to the areas of the graph are of course associated with terminology employed in modern metallurgy, but it is important to understand however, that ancient names and their corresponding alloy ratios are less well understood (Bayley and Butcher 2004, 14). Attempts to apply modern classifications could less likely represent working limits set out by ancient craftsmen. But by visualising large numbers of measurements, as presented in this article, the data may reveal patterning that better reflects ancient technical choice. The graphs presented in fig. 4 are of other types of item measured in the larger PhD research program of the first author (Roxburgh et al. in press). They have been included to demonstrate how different artefact types produce classifiable groups when measured in large numbers. Stirrup-strap mounts can be interpreted as a leaded brass, disc fibulae as a higher leaded brass or leaded copper, and a large number of ring pins are of a leaded bronze. The results in section 3.1 are presented with these classifications in mind.

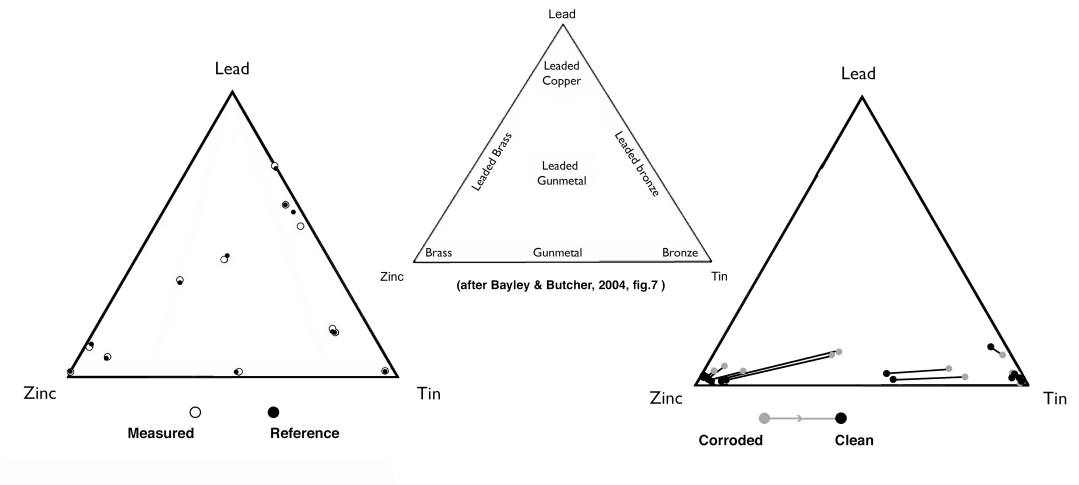


Figure 3. Ternary graphs showing: compositional classifications (after Bayley & Butcher, 2004, fig.7), measurement bias compared to CHARM standard (left) and deviation in measurement due to corrosion (right). Drawn by first author.

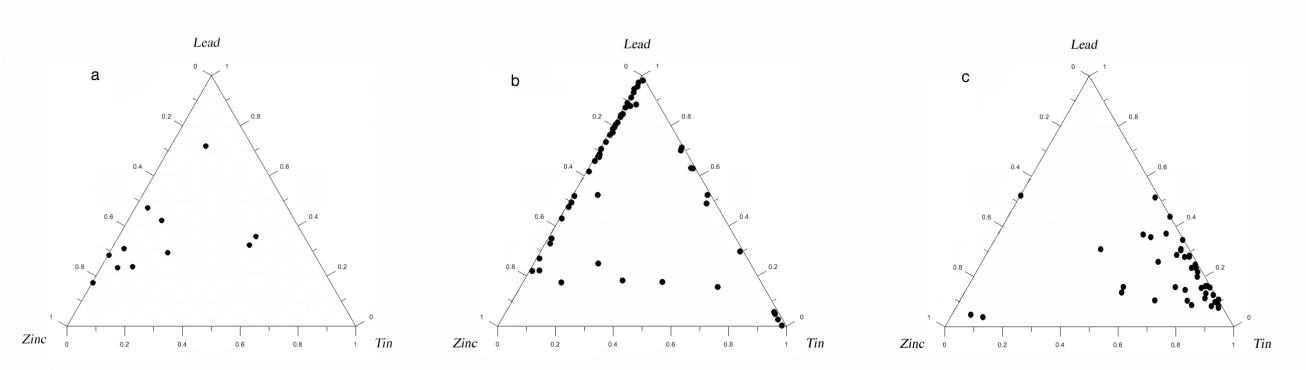


Figure 4. Comparative ternary graphs showing corroded, compositional results for three groups of Walcheren finds, Stirrup-strap mounts (a) Disc fibulae (b) and Ring pins (c).

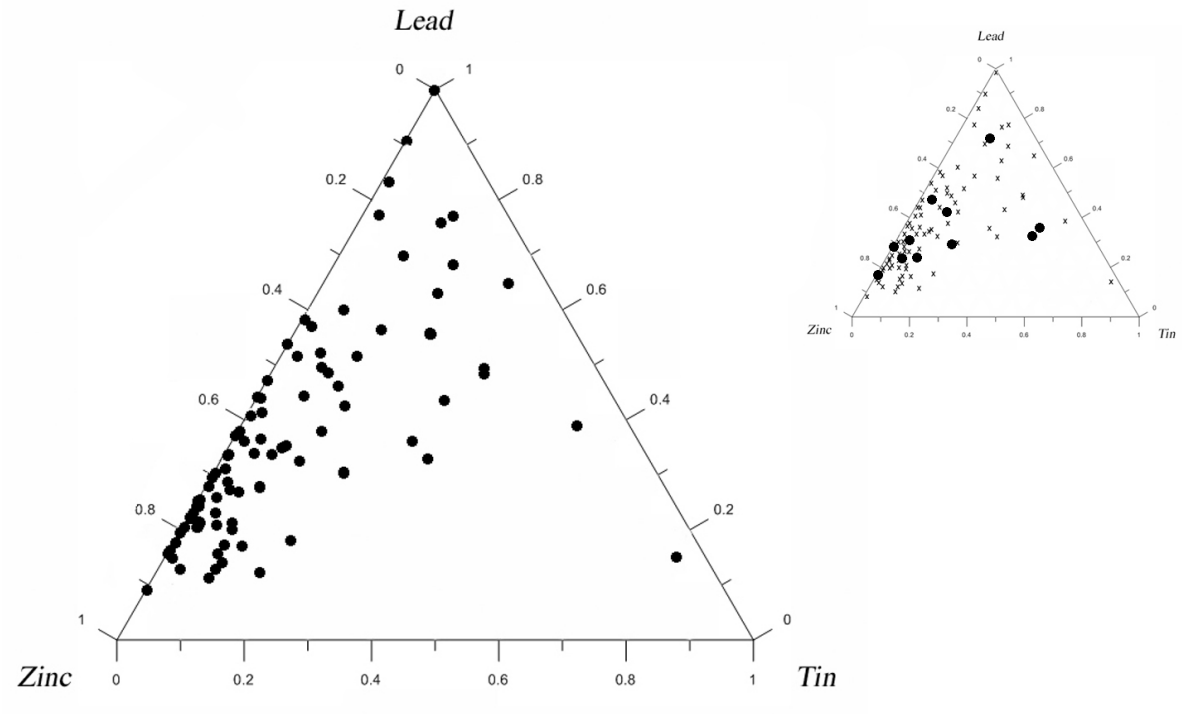


Figure 5. Ternary graph showing corroded, compositional ratios of the 90 mounts in this study (inset: mounts plotted as crosses overlaid with Stirrup-strap mounts (fig.4a) plotted as dots).

RESULTS

Compositional analysis

The results of the compositional analysis (fig. 5), shows a clear grouping, well within the brass making copper-alloy tradition. It has been shown in fig.3 that the effects of corrosion on this data produces lower zinc levels than if we were able to analyse fresh uncorroded alloys. This suggests therefore that if it were possible to measure uncorroded metal, the zinc levels would have been higher, resulting in an even tighter grouping towards the brass corner of the graph, perhaps also resulting in less outliers.

Typological analysis

The mounts are unevenly divided over four groups (a-d) according to their possible function. Within the groups, in particular the largest groups c and d, subdivisions can again be made on the basis of the typological features. All ninety mounts fall into these groups and a typological analysis will be presented in this section. Most mounts in this analysis have already been catalogued and described by Capelle, and his descriptions are taken as a starting point for further discussion. As noted by Capelle, most mounts are characterised by decorative animal heads, or the probable remains of what would originally have been animal heads and he dates them mainly to the 9 th century.

Animal heads and other zoomorphic decoration are a general part of Germanic art styles, from early Migration Period styles into the Viking Age. They are often thought to be related to the mythological world, and in pagan Norse mythology many types of animal were used as personal guardians (Jordan 2001, 101) or as symbols referring to mythological tales. For example, Odin had an eight legged horse called Sleipnir who features in many northern shamanic traditions (Price 2000, 70-71), as well as two Ravens, Huginn and Muninn, representations of which can frequently be found on objects such as fibulae. The Midgard-serpent is also a well-known animal, and serpents figure in pagan symbolism as well. Freyja had a chariot pulled by Bygul and Trjegul, two male cats. The cat features frequently in Viking-age Borre style art, a style popular between 850 - 975 (Hedenstierna-Jonson 2006, 312). Many pre-Christian copper-alloy items from Anglo-Saxon England also feature animal forms, which in some cases have been considered to imbue protective qualities on their wearer (Dickinson 2005, 161). Whether or not they were imbued with a particular mythological meaning, animal-like creatures are also found on objects from Frisia as well, such as fibulae and bracteates. By the Viking age though, this zoomorphic decoration is popular in the Christian sphere of influence as well as the Norse and therefore need not be identified as a purely pagan style.

As already mentioned in 1.3, there are many similarities between the Walcheren material and what is classified as Anglo-Scandinavian horse harness,

decorated in a Ringerike or a related style. A style which may have developed from earlier pagan zoomorphic imagery, but is dated to the 11th century.

Pendants (a)

The first group comprises of five pendants, classified as such because they appear to be designed to hang from another object. These include three animal head pendants with a single rivet hole (fig. 1, a1) and two openwork zoomorphic pendants (fig. 1, a2). Of these, only one of the openwork pendants was described as such by Capelle, the rest are classified as mounts. Indeed, for the three animal head pendants that also have a single rivet hole, their function is not as clear, since they closely resemble other mounts (with one or more rivet holes) with similar animal heads. Animal head decoration frequently appear in different decorative styles, the animal heads on these 3 mounts, however, cannot be assigned to a certain style or exact period at present, but it is most likely they date between the 10th and 11th century. Two of the open-work pendants - GA0095 and 0032-68 - consists of two animals facing each other (fig. 6). GA0095 is most clear in style and mostly resembles a late Viking style, possibly the Ringerike style popular in the 11th century (Kershaw 2010, 3). Two animals facing each other is also a standard feature on Anglo-Scandinavian horse harness pendants (Williams 2007, 6; See also *PUBLIC-1FCD40 in the PAS database (Lincolnshire). Our example is 3.3 cm high, whilst the PAS example is 4.8 cm high*). It should be noted that the two animals on GA0095 differ slightly in size, so the pendant is not entirely symmetrical. The other zoomorphic pendant represents two animals facing each other, albeit highly stylized.



Figure 6. Double animal head pendant Nr. 0032-68 Photo: Koninklijk Zeeuws Genootschap der Wetenschappen, www.zeeuwsgenootschap.nl.

Pendant mounts (b)

Six pendant mounts have been identified with either one or two rivet holes (fig.1b). Only 0039-17 (old id. 2125K to distinguish it from other items numbered 0039-17, and Capelle nr. 361) can be considered as complete, two more may possibly be complete, but the remaining three are certainly fragmented. On three of the pieces we find animal head decoration. On 0039-17 the animal head can be seen in full detail and may possibly relate to the Borre style or a later Viking style, particularly with reference to its pointed ears.

Strap-end mounts (c)

This is by far the largest category of mounts and they can be divided into those with one animal head (fig. 7) with either one (fig.1, c2) or two (fig.1, c1) rivet holes, and those with two animal heads (fig. 1, c3, and fig. 8). A number of the animal heads seem comparable with Borre style and there are similar items in the PAS database, mostly dated to the 11th century, some dated earlier between 900 and 1100AD.

Strap-links (d)

The strap-links with lozengiform holes again have closes parallels in horse harness links and other related pieces (fig. 9). Williams classified this style as Anglo-Scandinavian (2007). These strap-links also bear some stylistic similarity to Viking keys (cf. LVPL-3C07ED) dated around the mid 9th to the end of the 11th century, a number of which have recently been found in the northern Netherlands.

It is possible therefore that some of the mounts date to the 9th or early 10th centuries, particularly if indeed they can be related to a Borre style. For other pieces, a later 10th or 11th century date is most likely, for instance when related to a Ringerike style. In general though, the pieces can be considered to date between the 9th to 11th centuries, the late Viking Age. It must be stressed that whilst seeming related, they are not clear examples of a pure Viking style, as is the case for a number of other items found in the ring fortress excavations of 2010 (Ufkes 2011). However, a resemblance of Viking and Anglo-Scandinavian decoration styles is clear.



Figure 7. Single animal-head mount Nr. 0032-55. Photo Koninklijk Zeeuws Genootschap der Wetenschappen, www.zeeuwsgenootschap.nl.



Figure 8. Double animal-head mount Nr. 0032-80. Photo Koninklijk Zeeuws Genootschap der Wetenschappen, www.zeeuwsgenootschap.nl.



Figure 9. Lozengiform strap-link Nr. 0032-68. Photo Koninklijk Zeeuws Genootschap der Wetenschappen, www.zeeuwsgenootschap.nl.

Parallels

Similar mounts to those recovered at Walcheren have been found elsewhere. As mentioned in section 1.3, the mounts from Walcheren were subjected to a literature search. Metal detector finds from the Flanders coast have revealed a small number of mount like objects decorated in a similar manner, in addition to two Stirrup-strap mounts and other possible horse harness material in a Borre or related art style (Deckers 2012, 23-26 and 31-35). Further close parallels may be present in other collections, both in the Netherlands and abroad. So far, we have identified a number of them. It must be noted that these do not represent a full corpus, or the result of an extensive search program. These are items that have been located at the Noordelijk Archeologische Depot, in Nuis (The Northern Archaeology Depot, Nuis, Groningen) and online in the Portable Antiquities Scheme (PAS) database (The Portable Antiquities Scheme encourages the voluntary recording of archaeological finds by members of the UK Public. The online database (www.finds.org.uk) was accessed on 13 October 2015 and searches conducted for Early Medieval, Strap fitments and mounts in the counties of Lincolnshire, Norfolk, Suffolk, Essex and Kent). A handful of mounts as well as stirrup-strap mounts and other horse harness - similar to those found in Flanders - have been recovered from various locations in the modern-day provinces of Friesland and Groningen, both of which were part of Frisia in early medieval times. There are also a small number of mounts from locations scattered across the county of Norfolk (England), with a further three related mounts from the adjacent county of Suffolk. The PAS-descriptions for the English examples classify them as Middle to Late Saxon, 9th century strap fittings (For example PAS references. NMS3712D, NMS28DA87, NMSA92457, SF5718, SFEBDD47) with a small number of entries describing them as box fittings. The Frisian examples are classified as strap-end mounts (or fragments thereof), only of the single-headed type and have

not been classified in terms of cultural affiliation or style. See fig. 10 for a map of these find areas in relation to Walcheren.

These are all individual pieces found by metal detectorists of course and as such they are not easily recognized as mounts of a distinguished group and therefore could often be overlooked in the field and in collections. In addition, a handful of other pieces were identified as being from horse harness, mainly due to their size as well as their style, but this material was not included in this analysis. However, they need to be borne in mind as they too can provide useful context – in terms of dating, style, function and location. Hopefully further research will identify many more similar pieces in the future, providing us with more information on precise dating, occurrence and cultural affiliations. For now, we can say that these mounts are not exclusive to Walcheren, but have parallels - albeit in small numbers for now - in various North Sea regions, from central Frisia, Flanders to England. Nonetheless, the Walcheren corpus is for now by far the largest cluster of these small characteristic mounts.

DISCUSSION

Composition

The mounts selected in this paper form a compositional group that associates with the stirrup-strap mounts found around Domburg (see fig. 5, inset) but not with items from other copper-alloy types. Disc fibulae, ring pins (fig.4, b, c) produced different results demonstrating that craftsmen were working with different compositions for different types of item (Roxburgh et al. in press). Production in brass may have been chosen for improved technical characteristics and research into Roman alloys for example suggested that wrought items were made in a higher zinc/lower lead ratio than objects that were cast (Dungworth 1997, 902). This observation, if applied to the difference we see between the composition of the mounts (fig. 5) and the disc fibulae (fig. 4, b) becomes interesting.

The mounts could have been cut, hammered, and shaped from bars or ingots rather than cast, as is the case for disc fibulae (Frick 1992, 255). Archaeological evidence for brass bars in Viking Age Europe has been found, not in the areas that were once Frisia, but in hoards and trading centres in the Baltic (See *Sindbæk* 2001). The bars found in the Baltic areas were produced in the 'spill-form' tradition and were typically long and thin. The proportions of which could possibly form a useful starting point in the making of a mount similar to the ones discussed here. Also the brass used in these bars tentatively suggests that it originated in the Rhineland, probably with the reopening of the Roman zinc mines near Aachen, as no other source of zinc is known in Western Europe at this time (*Sindbæk* 2001, 59).

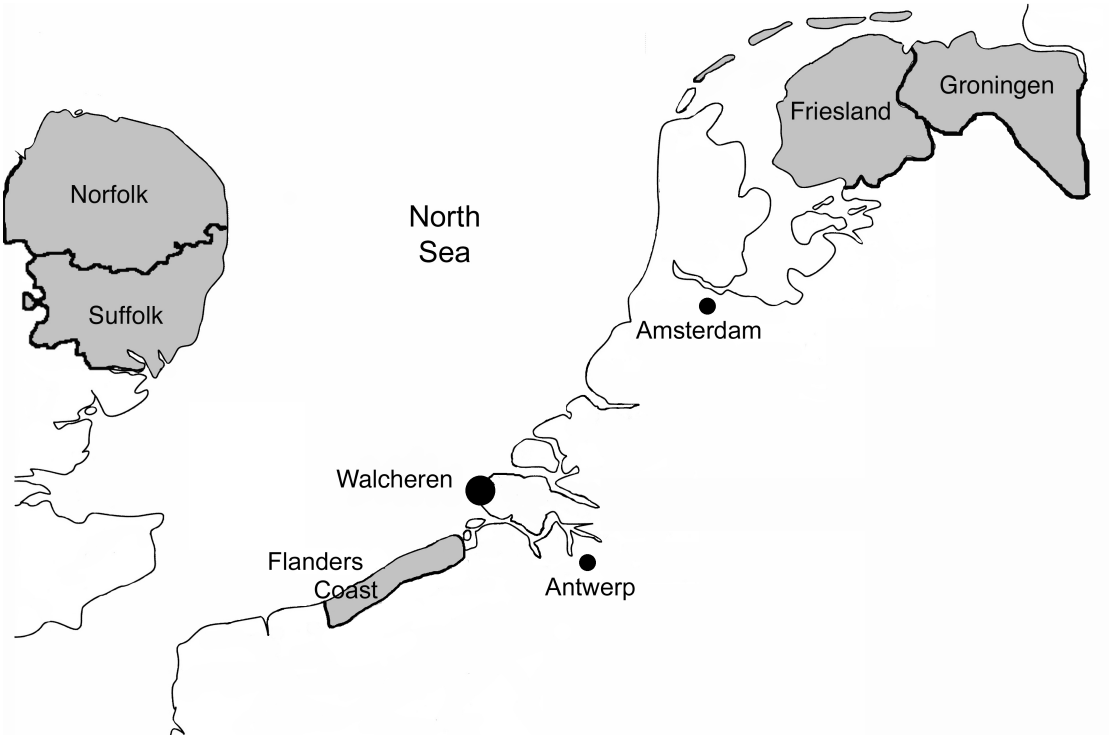


Figure 10. Find Locations of mounts outside of the study (in grey).

However a closer comparison of the composition of the mounts to that of the brass bars suggests that a further casting event has taken place. A significant amount of lead is present in the Walcheren mounts, whereas an analysis of three bars from Gotland revealed an alloy ratio of up to twenty five percent zinc but no lead (*Sindbæk* 2001, 55). A possibility therefore exists that brass bars could have been used as a raw material in a secondary casting process, one where lead is deliberately added.

Workshop organisation and access to materials

The most important observation from the compositional study is that the craftsmen producing these mounts were working within a set of alloy mixing limits, namely a leaded brass. Production in brass is a technologically different process than that of bronze, so the craftsman would have been aware of this when producing these objects (The ore calamine was needed for brass production along with a technical process called cementation, Bayley and Butcher 2004, 12-13). Furthermore a visual inspection of the items reveals that although stylistic groupings are present, they do not appear to have been produced in an exact same way. If copying or massed production took place for example then they are still reasonably different. Suggesting therefore that they were made by a number of different craftsmen working to a common theme, perhaps over a protracted length of time, but with no need for exact duplication. This observation is contrary to disc brooch production for example where a closer duplication of size and decoration seemed to be present (See Roxburgh et al. 2016). The large number found around Domburg by comparison to other areas could suggest

that they were produced locally. This would therefore associate with production at the emporium if it was still active, or at later administered workshop where both the required skills and a continued availability of zinc, either as a raw material or in brass ingot form would have allowed for the mixing ratios seen in the results above, this hypothesis matches Söderberg's model C. a permanent administered workshop site manufacturing objects for trade.

Production seems less likely to have taken place within models A or B, i.e. casting within Frankish controlled royal or supra-regional centres, as the professional craftsmen engaged at these places may have been more concerned with higher quality items in the first instance (Such as the craft production at the Royal Palace at Aachen, see Schutz 2004, 386) and secondly, super regional production would presumably have produced higher volumes distributed over a wider geographic area. Thirdly in considering the Christian nature of the Frankish world, many copper-alloy items found within the hinterlands bear Christian motifs, which is not the case for the mounts in this analysis, indeed the decorations appear to be influenced by animals from earlier Germanic or Norse art styles. Carolingian/Ottonian period disc fibulae are also found around Domburg, but these fibulae are also found in large numbers across the hinterland and it has been shown that they have the same alloy composition across a wide geographic area. The exception to this is a small number of disc fibulae found only around Domburg are produced in a bronze tradition not a brass one - which could potentially be explained by local copying perhaps within model C). Also items bearing non-Christian motifs would seem at odds with production at monastic workshops or at Frankish royal estates. Production here could have presented an ideal opportunity to replace the zoormorphic style with Christian ones, or at least to add Christian element to the mounts. This does not however appear to have taken place. Production at primitive workshops equally seems unlikely (model D), because the skills and knowledge required to apply the zoomorphic decoration would have to have been maintained over long periods of inactivity whilst simultaneously maintaining the technological knowledge required for casting in brass. Bronze casting would seem the easier option in a more primitive setting. It would also seem likely in this scenario that scrap items would be poorly sorted, allowing bronze or gunmetal to enter the 'metal flow', which is not the case for our leaded brass mounts.

The merchants involved in model E may well have had something to do with the production of the brass ingots found in the Baltic, but it is more likely they would have been interested in trading the finished goods that the mounts were destined for rather than overseeing their production. Finally production in a domestic setting (model F) would have been the least likely due to the advanced craft levels needed to work in brass and to decorate in a zoomorphic style.

The most likely option therefore is that of an urban production site (model C) under a non- Christian or at least a Church neutral administration - possibly Scandinavian or Frisian in nature rather than Frankish.

Morphological similarities to horse harness

With a compositional similarity to stirrup-strap mounts established, it is tempting to classify all of this material as horse harness. Especially since there are historical references from the late 9th century onwards of Vikings from the Scheldt area being mounted on horses and travelling over land (van Heeringen 1995, 89-91). However this becomes problematical when you assess the differences in size. The strap-link 0032-79-422 appears to link 3 straps together and GA0082-419 looks like it may have linked 4. Both look almost identical to Anglo-Scandinavian horse harness links (Williams 2007, 5, fig. 6f) but are significantly smaller. The Walcheren strap-links are under 3cm across, whereas the one published by Williams is around 7cm across. Size is also a problem for the lozengiform strap-links. Although very similar to the harness equivalents published by Williams, they are again small, 4 - 5 cm in length compared to 6 - 8 cm in Williams (2007 5, fig. 6a b). But as Williams suggests they could have taken an iron ring - now long corroded away - that allowed a suitable leather strap to be attached. A further difference is the rivet holes drilled into the Walcheren strap-links, suggesting a different purpose than for horse harness links (For example fig. 1 d1).

For comparisons with the strap-end mounts we turn to Williams publication on late Saxon stirrup-strap mounts (1997). These stirrup-strap mounts again date mainly to the 11th century and were originally interpreted as book clasps or as fittings for boxes or chests. But as identified by Margeson they appeared to be too large and cumbersome to have been used as book clasps (Margeson 1986, 327). Equally the idea of box fittings was challenged (Ashley et al. 1991, 228; Robinson 1992). In light of archaeological evidence showing an association with equestrian stirrups, they were finally classified as a decorative mount that is riveted to the leather strap at the point at which it passes through the stirrup (Williams 1997, 2). The strap-end mounts in this study, as well as being compositionally similar were also riveted to another object. Also, a number of the heads turn in slightly as if they follow the line of the material they were originally attached to (see fig. 1 c1). This inward turn is also a feature on many stirrup-strap mounts, suggesting a close functional similarity between these groups (Williams 1997, 2, see angled flange on class B mount in fig.1). Finally the pendants and pendant mounts also appear to function in a similar way to horse harness pendants. But again they appear small. The pendants published by Williams appear to be 3 to 4 cms wide, whereas pendants in this study are only between 1 to 2 cms. That said as decorative rather than functional items this could have been less important.

Combining the observations just mentioned together with the reconstruction drawings put forward by Williams it was possible to attempt a reconstruction of the relationship between the Walcheren mounts and the leather straps they may have been attached to (see fig. 11). It must be remembered that the observations regarding the size (and presumably functional strength) allow for the possibility that these items were personal equipment rather than reserved for equestrian harness. Furthermore there is no evidence to suggest that the decorative style on personal equipment would

differ significantly from the decoration placed on horse harness. Both horse and rider could have worn the same style.

DEBATE

Identity: Frankish, Frisian, Scandinavian or Anglo-Saxon?

Our first impression was that the Walcheren mounts stylistically resemble fragments of 11 th-century equestrian equipment, classified as Anglo-Scandinavian, and found in many areas of England and southern Scandinavia. But our study suggests that we need to reconsider both the use of the Walcheren mounts as horse harness and also as Anglo-Scandinavian. The question that also needs addressing is what cultural affiliation can we assign to these mounts, if any? Additionally however, we must look at the dating of the objects, from the presumed 9 th century origin to a 10 th or 11 th century context.

Lozengiform style horse harness is suggested by Williams to derive from the late Viking Ringerike style, with the harness links themselves being typical of the 11th century. The lozengiform strap-links found at Walcheren exhibit strong style connection to these links, as do they to Williams' Class A, type 12 stirrup-strap mounts, which are found in a wide distribution across South East of England (Williams 1997, 21, fig. 16 distribution map).

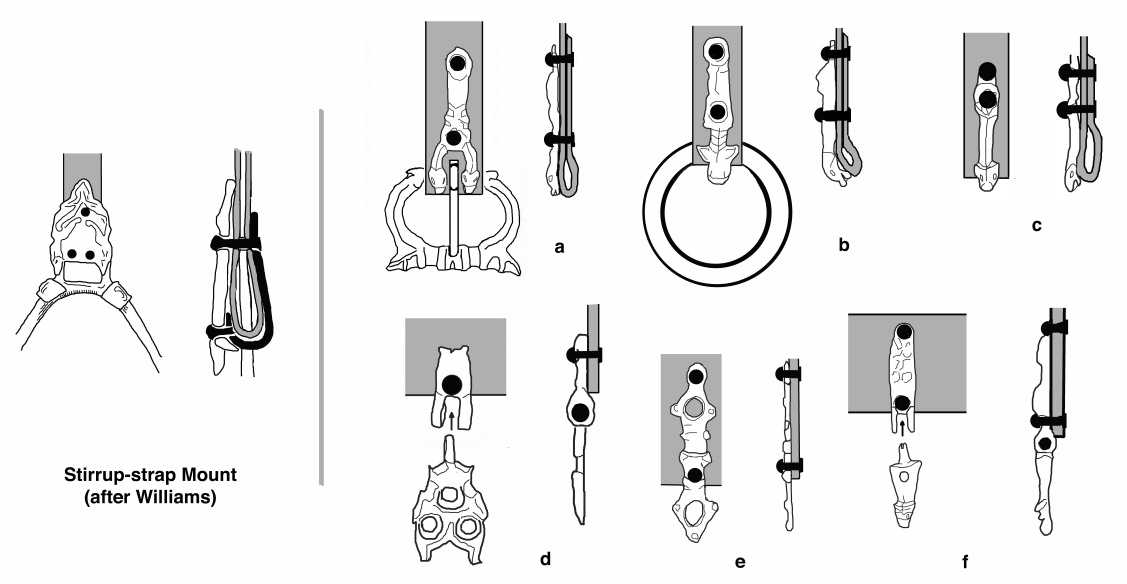


Figure 11. Suggested relationships to leather straps, after Williams, *Late Saxon Stirrup-strap mounts* fig. 4. Drawn by the first author

The decoration found on the Walcheren strap-end mounts especially in terms of the animal heads bear similarities to Williams' stirrup-strap mount classifications;

Class A, type 2, type 8, and to Class B, types 1 and 2. He associates these stirrup-strap mounts with the late Viking Ringerike or Urnes styles of the 11th century. However, the context of the strap-end mounts from Walcheren suggest them to date from the 9th century, which matches the date given to a number of close parallels from Norfolk (see the PAS references above).

As we have demonstrated, the Walcheren mounts are most likely a separate typological group, stylistically and compositionally related to 10th and 11th century horse harness, but smaller and therefore most likely for personal use rather than equestrian. Although these mounts are typologically related to this material, especially to many 11th century pieces, the Walcheren strap-end mounts in particular may have a 9th century context. The possibility also exists that there may be different chronological groups with the strap-end mounts, some dating from the 9th century whilst some of the others more closely related to Borre and Ringerike styles, date to the 10th or possibly early 11th century. Even though uncertainties as to the precise dating remain, the styles suggest that close ties existed between the southern North Sea, Frisian, Viking and Anglo-Scandinavian worlds between the 9th and 11th centuries, the fact that we find similar pieces in Flanders, central Frisia and in the east of England illustrate this. If we assume that the mounts were produced locally in these areas, then we could perhaps expect some local variation composition and type, which could be tested in the future. If these particular mounts were produced locally in Walcheren (i.e. Frisia), then it would be better to describe them as a Friso-Anglo-Scandinavian group of mounts. We may tentatively consider therefore the possibility that these mounts relate to a local group of people who were closely connected to Scandinavian and Frisian inhabitants, (as would be the case in the other areas). Perhaps it was connected to Danish warlords and their followers (or indeed their descendants), a multi-ethnic group, who temporarily settled in Frisia and who travelled back and forth between the Frisian coastal area and England. It has been suggested elsewhere that the Vikings on Walcheren should perhaps be thought of as the *Scaldingi* – the Scheldt Vikings – a group that could have been a multiethnic in character (Mcleod 2014, 134-135). In any case, we argue that the term Anglo-Scandinavian or indeed Frankish does not suffice.

This suggestion fits very well with the general view that Frisia had close connections to southern Scandinavia and eastern England. We usually see this in a passive way, but here we might have an active example of these Viking-age connections (IJssennagger 2013). One way or the other, there is evidence of a cultural group in Walcheren in the (late) Viking-age expressing their visual identity in terms of these non-Christian animal-style decorations and this identity should be considered in a context of continued intensive relations between Frank, Frisian, Viking and Anglo-Saxon.

Amongst the many seafaring travellers in the 9th to 11th centuries, Vikings, Frisians and Anglo-Saxons were constantly travelling back and forth across the North Sea. The Great Danish Army that invaded Anglo-Saxon England in 865AD is believed to have also included contingents from the Frisian coastal areas, which also coincides with the time of the Danish benefices at Walcheren.

It has been argued elsewhere that this has led to a group of Friso-Danes, particularly over several generations (IJssennagger 2013; 2015 and references therein). Part of such a group, if it manifested itself in Walcheren, with connections in the northern Dutch coastal area as well as in East Anglia, may have generated their own form of harness decoration, which we can see here. The island of Walcheren in the Viking age being a Frisian area within the Frankish realm, with continuous contact with eastern England and under pagan Viking administration is a place where worlds collide, a place and a context - perhaps continuing over several decades - for the Walcheren mounts to exist in.

CONCLUSION

In this article we presented a combined analysis of a large group of early medieval mounts, found in and around the North Sea coastal town of Domburg, on Walcheren. This analysis sheds new light on their functional use and their role in expressing social identity within a Viking-Age, North Sea world.

The questions we addressed were straightforward and through them we were able to gain a clearer understanding of the mounts function through this approach, as the composition of the mounts, as well as their typological characteristics matched those of certain forms of Viking-age equestrian gear. Whilst the equestrian gear mainly dated towards the 11th century, the mounts from Walcheren - bearing strong typological similarities - appear to date between the 9th and early 11th century.

Having found that the choice of alloy for making the mounts was controlled to some extent, and that the symbolism was likely to be of pagan rather than Christian origin we were able to suggest that these items were produced at an urban production site under at least a Church neutral administration - possibly Scandinavian or Frisian in nature rather than Frankish. The relative density of finds in Walcheren compared to other areas also suggested that this production was likely to have been local.

The observations regarding the size of these mounts allowed for the possibility that these items were used on personal equipment rather than reserved for equestrian harness. The equipment for both horse and rider could have been decorated in the same style. An analysis of the function of stirrup-strap mounts did however offer a tentative reconstruction of their use, as functional attachments to leather straps, but as just mentioned, for personal equipment rather than equestrian.

Although a question over the exact dating remains, the styles suggest close ties existed between the Frisian, Viking and Anglo-Scandinavian worlds between the 9th and 11th centuries. If we assume that the mounts were produced locally, then it would be more beneficial to describe their cultural associations as being Friso-Anglo-Scandinavian in character, rather than Anglo-Scandinavian.

Our hypothesis therefore proposes the existence of a cultural group in Walcheren in the Viking-age expressing their visual identity in terms of these non-Christian animal-style decorations and this identity should be considered in a context of continued intensive relations between Frisian, Viking and Anglo-Saxon. This is supported by arguments elsewhere of the existence of a group of Friso-Danes, perhaps manifesting itself in Walcheren, and generating their own form of harness decoration which we can see here.

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Chapter 7

A workshop at the edge of the world? A compositional analysis of copper-alloy finds from Early Medieval Walcheren, (in Press).

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INTRODUCTION

Over many years a large and diverse number of early medieval copper-alloy artefacts have been recovered from the former island of Walcheren (Zeeland, the Netherlands). In this chapter we present the results of a combined typological and compositional study of six groups of these artefacts dating between the seventh and twelfth centuries, encapsulating a period in time better known as the (long) Viking-Age. This study employs the use of Handheld X-Ray Fluorescence Spectrometry (hhXRF), a portable device commonly used in archaeology for exploring the compositional nature of ancient materials. The valuable new qualitative data collected by this non-destructive technique sheds light not only on the character of ancient technology and the organization of craft production, but also allows a reconsideration of the role of these personal objects in expressing social identity within an interconnected North Sea world.

We focus therefore on the copper-alloys used to make disc brooches, ansate brooches, dress and ring pins, stirrup-strap mounts and zoomorphic mounts, which have been found in large numbers, particularly along the beach between Domburg and Oostkapelle. Some additional finds will also be discussed for geographical comparison, including items collected in the vicinity of Middelburg and from Westenschouwen on the neighbouring island of Schouwen.

Our aim is to explore the ways in which production was organised for these typological groups, and this will be achieved through a combined typological and compositional analysis of the consistency (or otherwise) found within each group. Hypotheses will be formulated regarding the social organization of production (workshop organization) based on previously proposed models. The distinction between local and non-local production will be discussed, which in turn will allow for a reconsideration of the role of these personal objects in expressing social identity.

In the rest of this introduction the history of typological research and the technical developments of compositional analysis will be expanded upon. Afterwards, we will present the find locations and the associated historical contexts, followed by an explanation of the organizational models for early medieval production. The introduction ends with a broader presentation of our objectives and questions. The

second section of the chapter presents a short explanation of the materials, methodology and equipment, together with a discussion of the biases in alloy research caused by corrosion. The most important section containing the results and a discussion of the compositional study follows next. Finally, before concluding, we present a discussion regarding the organization and likely locations of the production of these objects, together with new hypotheses regarding the roles these objects may have had in expressing social identities.

History of research on early medieval copper-alloys

A literature search of early medieval copper-alloys reveals that much has already been published on disc and ansate brooches, dress and ring pins, stirrup-strap mounts and more recently the zoomorphic mounts. Taking the publication by Capelle as a departure point (Capelle1976), useful typologies now exist for the brooches found on Walcheren (Frick 1992; Thörle 2001; Bos 2006a, 2006b ; Weetch in press), as well as for the dress and ring pins (Rogers et al. 2009), the stirrup-strap mounts (Williams 2007) and to some extent the zoomorphic mounts (Roxburgh et al. in press; Webley in press).

Typological interest in ancient copper-alloy objects can be traced back well over two centuries, but it has only been since the mid-twentieth century, with the invention of X-ray techniques such as Optical Emission Spectrometry (OEM), Neutron Activation Analysis (NAA) and X-Ray Fluorescence Spectrometry (XRF), that research into alloy composition has been widely undertaken. Small metal items were amongst the first material groups to be studied using large immobile laboratory XRF equipment (labXRF) in the late 1950s and 1960s (Feretti 2014). By the early 1970s, however, a new generation of energy dispersive XRF spectrometers (EDXRF) allowed for an increasing miniaturisation of the technology which – being portable – allowed for non-destructive, *in situ* analysis at museums and other storage locations. This miniaturised equipment is commonly known as Portable XRF (pXRF) or Handheld portable XRF (hhXRF, also see Frahm and Doonan 2013). The equipment used in this study was a handheld instrument; therefore we adopted the term hhXRF to distinguish it from the bulkier portable benchtop systems.

Studies using XRF techniques have revealed a lot about the technical choices presented to ancient craftsmen. The technical choices between different alloying agents added to copper, namely tin to make bronze or zinc to make brass – with or without a quantity of lead – have been revealed, telling us much about the complex relationship between composition and typology (Dungworth 1997, 902). The limitations imposed on certain artefact types for example have been given particular attention, especially differentiating between items cast in liquid form into a mould (for example where a small addition of lead is beneficial), or items that have been wrought, or beaten into a desired shape with a hammer, where too much lead for example can cause the item to break (for example, Unglick 1991; Bayley and Butcher 1995, 2004; Craddock 1998). However, combined typological and compositional

approaches to studying copper-alloy items, looking in particular at the level of alloy consistancy within artefact groups – especially those from the early medieval period – have until now been limited (for example, Bayley and Butcher 2004; Martinón-Torres 2012), particularly in the Netherlands, where research has mainly centred upon typological concerns (see Capelle 1976; Thörle 2001; Bos 2006). We therefore present a combined analysis of this interesting range of objects and formulate new ideas about their purpose and cultural associations.

Find locations and their historical context

Of the 299 objects presented in this study, 261 came from locations near to modern-day Domburg. These were mainly beach finds, recovered after heavy storms and collected at low tide between Domburg and Oostkapelle in the nineteenth and early twentieth centuries (Op Den Velde and Klassen 2004). An additional five items came from excavations in the *ringwalburg* or ringfort (constructed in the ninth century) in the present-day town of Domburg, one of three ringforts on the island. These items were found during excavations by a developer funded archaeological company (ARC-Archaeological Research & Consultancy) in 2010 (Ufkes 2011). An additional eleven items are presented from the area around Middelburg and a further twenty-two items from Westenschouwen on the island of Schouwen-Duiveland, which were included for comparative reasons.

The sheer number of finds, particularly of coins, have led to suggestion that this was the site of an emporium, a trading settlement that facilitated interregional trade around the North Sea, a trade that is believed to have taken place between the late sixth and tenth centuries (Ufkes 2011). The late seventh and eighth centuries in particular appear to have been very prosperous (Ten Harkel 2013, 237-238), and arguably its importance in the Carolingian period may almost have matched that of Dorestad (Capelle 1976, 5). Walcheren was given as a fiefdom to Danes by the Frankish emperor Lothar I and from that point trade at the lost settlement appears to decline rapidly. This decline during the last quarter of the century coincides with a large defensive ring fort or 'burg' being built nearby. Traditional interpretations consider these ringforts to be part of the coastal defences that the Franks put in place to resist Viking attacks; however, more recently this interpretation has been questioned by various scholars, who have instead proposed the idea that these fortresses were part of a Danish tradition.

Danish rule is believed to have come to an end by AD 884 at the latest, when power over the Danish benefices transferred to local counts (Coupland 1998). The 'burg' at Domburg remained inhabited from the late ninth until the early eleventh century and connections between the Frisian coast, Scandinavia and the British Isles seem to have continued during this period, despite the end of Danish involvement in the benefices (IJssennagger 2015, 134). A handful of finds recovered from excavations in the fortress in 2010 and dated to the late ninth or early tenth century may be evidence of this Viking past in Domburg (Ufkes 2011), The other place on

Walcheren from which finds are included in this survey is Middelburg, again developed from an early medieval ringfort, but less well studied than Domburg (Ten Harkel 2013, 234). Middelburg is now the capital of the province of Zeeland and is located approximately twelve km inland from Domburg. But the settlement possibly dates back as far as the late eighth or early ninth century. By the start of the second millenium the town had become an important trading centre between England and Flanders in particular. Finds from Westenschouwen, an area on the westerly tip of the neighbouring island of Schouwen, were included in the survey to provide a close comparison for items found on Walcheren. Westenschouwen is situated some fiveteen km north-east of Domburg across the Oosterschelde estuary.

The material selected from these locations and subject to our analysis is generally thought to date between the seventh and eleventh centuries, but the bulk of the finds probably date from the late eighth century onwards, thus dating the assemblage broadly to the Viking Age or 'long'Viking Age.

Alloys and the organization of production

Copper in its pure form is quite soft and therefore not suitable for many uses. But alloying it with other metals such as tin, zinc and lead greatly improves its range of applications (Bayley and Butcher 2004, 15). Choices would need to be made regarding the alloy composition, knowing in advance whether an object was to be cast at high temperatures from a mould, or cold worked, perhaps annealed or finished by hand carving. Bronze was created in a crucible, by heating copper with tin, but brass was created quite differently, using the cementation process developed during the early the Roman period, initially for coins and military equipment (Dungworth 1997, 903). That said an ingot of brass once produced, could be remelted in a similar way to an ingot of brass. Gunmetal alloys were mixtures of both brass and bronze and therefore could contain mixed properties of either, or be a good way to recycle mixed scrap bronze and brass metal. Then, finally lead could sometimes be added to any of the mixtures, to improve casting or machining qualities (Bayley and Butcher 2014, 15). Tin and zinc, as a raw material were also mined from quite different areas to each other, adding a trade and supply aspect to the choices made in production. A major tin source was from Cornwall in England, whereas zinc was probably mined, then supplied from the Ardennes region of modern day Belgium (Roxburgh et al. 2014, 19). All of these factors become interesting when artefact groups of a uniform typological nature become available to study. How uniform or otherwise was the choice in alloy? Especially when considering large geographical distribution areas or lengthy periods of time. The level of uniformity (or standardisation) can subsequently be compared conceptually to the organisation required to maintain that standard. Furthermore, changes in scale and standards of craft production may also be indicative of changes to economic fortune (Wickham 2005, 700).

Although archaeological evidence is scarce, the social organization of early medieval craft production has received much interest (for example, Bayley 1992; Callmer 2001;

Hansen et al. 2015; Hinton 2010). Verhulst suggested that artisan production was mainly centred around royal courts, abbeys, large estates and urban centres, but with a small amount of production by travelling artisans, perhaps less controlled than those working within more sedentary environments (Verhulst 2002, 72). It is clear that different organizational structures for artisan production must have existed. Söderberg, a Swedish archaeologist and craftsman, adopted a classification system for an organizational study of copper-alloy crafting activities (2002, 116, from an earlier suggestion by Hedegaard 1992). This classification system differentiated the activities as follows:

a) Royal centres, with professional craftsmen possibly engaged as bondsmen, concentrating on unique high-status objects. Highly skilled, demonstrating a variety of techniques.
b) Supra-regional, professional, intensive seasonal production at permanent workshops, with the products destined for periodic markets.
c) Permanent administered urban production sites, such as emporia; products destined for market.
d) Infrequently used primitive workshops, making consumer-driven goods and exhibiting little experimentation.
e) Merchants, whilst travelling, producing simple items such as ingots and weights.
f) Domestic households, non-professional, including simple jewellery and repairs.

The available technology together with the artisanal skill required to produce different groups of copper-alloy artefacts can be compared to these theoretical workshop models (by evaluating compositional and typological consistency for example). This allows us to suggest something about the organization of their production. Artisans engaged at royal or elite centres would have had a certain amount of control of the raw materials they chose to work with, both in terms of the quality and in terms of the quantities needed - to regularly create the artefacts that they were skilled at making. Craft activities at domestic households in contrast may have been undertaken with less control, as both access to raw materials, equipment, and specialist knowledge would likely to have been more inconsistent by comparison. Therefore morphological consistency can be assessed in conjunction with alloy choice. Consistency (or otherwise), based on intentional choice, when studied over wide geographic areas can add to our understanding of how standardised production was (Martinón-Torres et al. 2012, 536). An assessment of the level of standardisation can then be compared conceptually against organizational structures such as those presented above and new hypotheses can be formulated about how artefacts interacted within the wider economy (for example Roxburgh et al. 2016; Roxburgh et al. in press Nov).

Objectives and questions

The main hypothesis in this chapter is that a compositional approach to the study of artefacts can tell us something about the social dynamic of craft production A second hypothesis is that something useful can be gained by conceptually modelling the workshop organization behind the production of these objects. This could result in the ability to distinguish between local and regional production, or indeed (in the case of unusual items) be suggestive of non-standard copying - perhaps by local artisans - of items produced elsewhere. Furthermore, based on the alloy choices (consistent or otherwise), present in different object groups, we assume that something new can be inferred regarding their associations to one another and subsequently their cultural context.

The questions we address are as follows: can we draw conclusions about the likely organization of production and the subsequent distribution of these artefact groups from the compositional analysis? If so, can we suggest what, when, how and – indeed – if local production took place, or whether the artefacts from Walcheren represent imports to the island? If the previous questions can be addressed, what can we infer about the cultural associations attached to these objects, either in a local Walcheren or a wider North Sea context? Can we support for example Anglo-Saxon, Anglo-Scandinavian, Frisian or Frankish contexts for these objects, or do we need to consider a more multicultural solution that includes several or all of them?

MATERIALS AND METHODOLOGY

Materials

As mentioned earlier, a large proportion of the objects studied here were beach finds, found near the modern seaside town of Domburg and subsequently catalogued in the publication by Capelle (1976).

These objects were eventually placed into the care of the Zeeuws Museum (Zeeland Museum) and the Stichting Cultureel Erfgoed Zeeland (SCEZ; Zeeland Cultural Heritage Foundation), partly as the collection of the Koninklijk Zeeuwsch Genootschap der Wetenschappen (KZGW; the Royal Zeeland Society of Sciences), located in Middelburg (also see Feldbrugge in press). The material was first accessed for HHpXRF measurements by the third author, Van Tendeloo, with scientific support from the Dutch Cultural Heritage Agency (van Tendeloo 2017, supervised by the fourth author, Huisman). The data from this initial study was subsequently absorbed into the much larger project undertaken by the first author, Roxburgh, as part of his ongoing PhD research ('Charlemagne's Workshops' - is a qualitative and semi quantitative investigation into the composition of early medieval copper-alloys. The project attempts to model the chronological and geographical nature of alloy choice

employed by the craftsmen and those organising production. It then attempts to model the social organization of production and its role in the early medieval economy). A follow-up visit was subsequently undertaken in late 2014, which widened the geographic area to include finds from Middelburg and, as a comparison, from the neighbouring island of Schouwen. It was observed at this point that trends were appearing in the choice of alloy use for some of the typological groups. The groups that presented the clearest trends were disc and ansate brooches, dress and ring pins, stirrup-strap mounts and a large number of zoomorphic mounts, all of which warranted a closer investigation. We selected these coherent typological groups of items from the Walcheren collections and decided to study them from an interrelated compositional, typological and contextual perspective (see also Roxburgh et al. 2016 roman brooches).

Disc brooches - AD 800 to AD 1100

This is an artefact group that is being found in ever increasing numbers across North Western Europe (see fig. 1 and table 1). One of the most useful typologies for this group is the one published by Bos in 2006 (2006b). This is because it draws on earlier typologies from North Western Europe, including chronological criteria, before approaching the subject from a Frisian perspective (see Frick 1992; Hübener 1972; Wamers 1999). The catalogue therefore is a good starting point for studying the disc brooches found across the Netherlands. Bos broadly places these brooch types in the ninth- to eleventh-centuries, but tentatively suggests that a few of the subgroups may start as early as the late eighth century and that a few later groups may still have been in use as late as the twelfth century (for example Bos 2006b, 767, for early subgroup 2.7.1. Saints brooches, 722, for late subgroup, 2.3. central cloisson). Typologically speaking the brooches presented in this study conform reasonable well to the categories in Bos's Frisian study. Although dating from the Carolingian/Ottonian period, from a cultural perspective they cannot be considered uniquely Frisian, and there are great numbers of them all over North-Western Europe

Ansate brooches- AD 600 to AD 1000

The typology chosen for this group of ansate brooches was that proposed by Thörle (2001, this typology is also followed by Weetch, in press). A careful inspection of the ansate brooch classifications proposed by Bos - for Frisia - confirmed his suggestion that the brooches found at Domburg represent a different typological spectrum to those from northern Dutch coastal area (Bos 2006a, 455). The brooches date broadly between the seventh to tenth centuries and therefore possibly include some late Merovingian examples (see fig. 2 and table 2). The larger proportion would seem to date from the Carolingian/Ottonian period; however, Thörle's chronology suggests that they may have gone out of use earlier than the different types found in the north. He considers them to be a Western Frankish group (confined to Neustria, Burgundia, Aquitania).

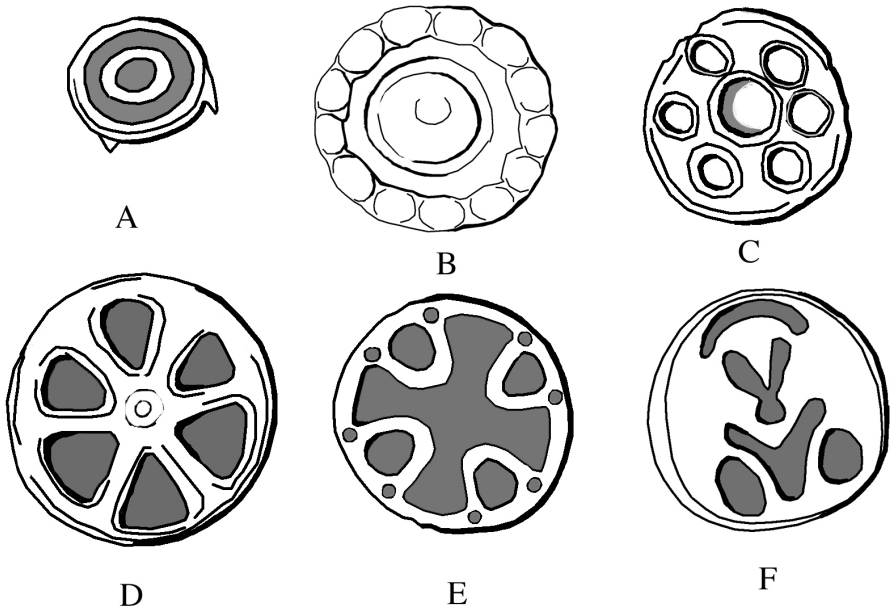


Figure 1. Disc brooches, A - Type 2.1, B - Type 2.2, C - Type 2.3, D - Type 2.4, E - Type 2.5, F - Type 2.7 (schematic drawings by first author).

Location	Domburg	Westenschouwen	Middelburg
No.	23	21	9
Type (Bos)	**Description**	**No.**	
2.1	circle-and-dot(s) or concentric circles	2	
2.2	central convex boss	1	
2.3	central cloison	11	
2.4	pseudo-cloison	3	
2.5	one of more crosses	32	
2.7	human or animal figures	4	

Table 1. Number of disc brooches per location and per type.

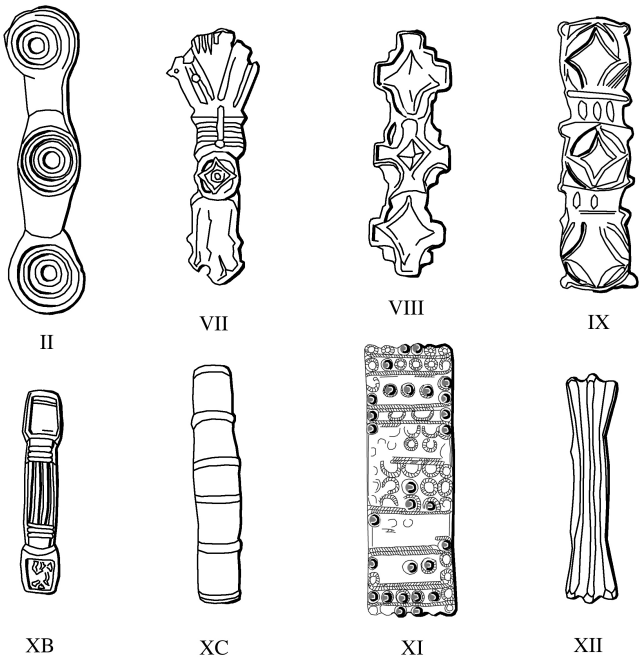


Figure 2. Ansate brooches from Thörle's types (schematic drawings by first author).

Location	Domburg
No.	82
Type (Thörle)	**No.**
II	10
VII	7
VIII A&B	5
IX E&F	3
X B	8
X C	12
XI B&C	6
XII A	30

Table 2. Number of ansate brooches per location and per type.

Dress pins - AD 600 to AD 1100

A detailed typology for non-ferrous dress pins has been published from 407 examples excavated at the contemporary early medieval settlement of Flixborough, England (Rogers et al. 2009, 32). The polyhedral-headed pins from Domburg (see fig. 3 and table 3) seem to conform to the Flixborough Type 2 series. They only account for 18% of the pin types found in Flixborough, whilst the polyhedral-headed type at Domburg accounts for 50% of the measured assemblage. The earliest polyhedral-headed Type 2 pins at Flixborough are from the late seventh- to early eighth-century layers and are accordingly dated as such. The next-largest group of pins from Domburg generally conforms to the Flixborough Type 3 biconical series (see fig 3, - 3a, 3b, and 3c), the earliest of which - for Flixborough - were found in late seventh-century layers, with both types present in the latest tenth-century layers. There is an additional Type 1 globular pin, which were in use at Flixborough from the mid-seventh to early eighth until the tenth century. Like the disc brooches discussed previously, these objects are numerous all along the coast and cannot easily be culturally assigned.



Figure. 3 Dress pins, Type 1 Globular, Type 2 Polyhedral Type 3a Biconical, 'berry' shaped, Type3b - Biconical, Type3c - Biconical with collars (schematic drawings by first author).

Location	Domburg	
No.	26	
Type (Rogers *et al.*)	**Description**	**No.**
1	Globular	1
2	Polyhedral	13
2	Sub Polyhedral	2
3	Biconical	6
3	Biconical, Berry Shaped	4

Table 3. Number of dress pins per location and per type.

Ring pins - AD 600 to AD 1100

Hinton describes this type of pin as a ring pin (see fig. 4 and table 4; and Hinton 2005, 86, fig. 3.5). There are two options for the function of these pins. The first option is that they could have been worn as a dress accessory, perhaps at the opposite ends of a chain (They could therefore be described as linked pins, see Rogers et al. 2009, 36, 62, fig. 1.26). A pair linked by a chain was recorded as being located at the shoulder of the skeleton in a seventh-century grave in England (Meaney and Hawkes 1970, 37). The second option is that they were attached to a ring, (sometimes an adjustable type called a slip ring), presumably for attaching onto a belt or other part of personal apparel. In both cases, the pins are morphologically the same and in many cases they are missing either the ring or the chain, so it is not possible to determine which type the pin belonged, or indeed if they had a ring or chain at all. For that reason, the two types are grouped together (It should also be noted that these pins should not to be confused with the typical Viking ringed pins discussed elsewhere by Fanning, Viking age Ringed Pins from Dublin).

From the Roman period onwards, pins such as these could also be part of toilet sets mounted on chatelaines, usually together with tweezers or ear scoops (D'Ambra 2007, 116-117). A number of tweezers were found at Domburg and published by Capelle (1976, table 35). Capelle also recorded a number of chains (1976, tables 29, 30), some of which conceivably could have had pins attached to them. A silver toilet set from the ninth or tenth century, which comprises of a small ear-spoon and a ring pin with a filigree-decorated head, was found on the beach of Domburg (Collection of the Zeeuws Museum (M97-034). See Van Heeringen 1990).

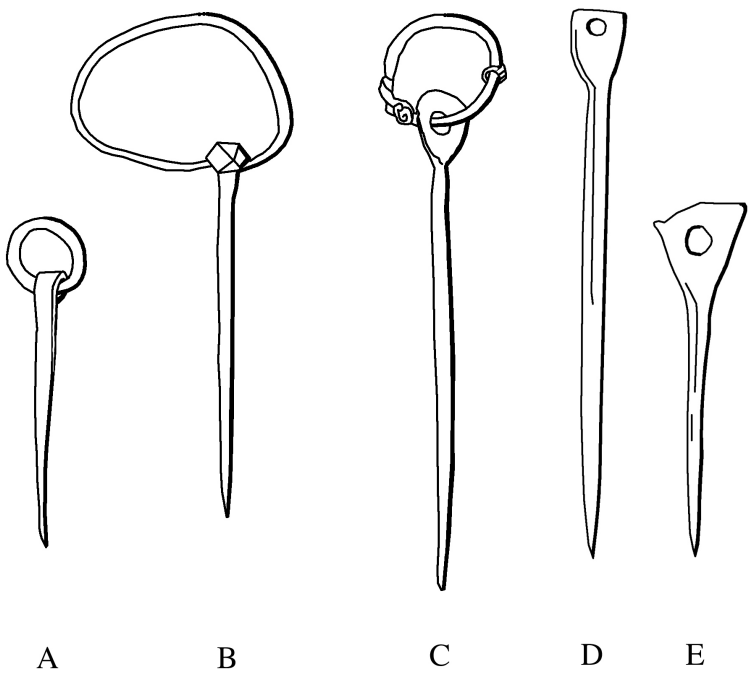


Figure 4. Ring pins, A - Rolled head on ring, B - Polyhedral head on ring, C - Flat round head on slip ring, D - Flat Sub rectangular head, E - Flat triangular head (schematic drawings by first author).

Location	Domburg	
No.	38	
Type	**Description**	**No.**
Pin with ring	Biconical head	1
Pin with ring	Rolled head	2
Pin with ring	Polyhedral head	1
Pin with slip ring	Flat, round head	5
Pin with slip ring	Flat, round head, knob, double collar	1
Pin with slip ring	Flat, sub-rectangular head	2
Pin with slip ring	Polyhedral head	1
Pin with no ring	Flat, round head	11
Pin with no ring	Flat, oval head	2
Pin with no ring	Flat, sub-rectangular head	5
Pin with no ring	Flat triangular head	1
Pin with no ring	Rolled head	4
Pin with no ring	Polyhedral head or collar	3

Table 4. Number of ring pins per location and per type.

Stirrup-strap mounts AD 900 to AD 1100

The typology published by Williams for late Saxon stirrup-strap mounts attempts to classify and catalogue the large number of examples found in England (1997, 105). In achieving this aim, however, some attention is given to mounts found on the continent, including those found at Domburg (see fig. 5 and table 5). The objects included in our compositional study have been classified as stirrup-strap mounts either because they are directly referenced in Capelle, by Williams, or they are fragmentary objects that have strong morphological affiliation to Williams's Class B typology, i.e. other possible continental types. All eleven of the objects therefore show a close similarity to the class B typology. Williams suggests that the Netherlands could be the source of origin for Class B mounts, which first appear on the English east coast before spreading westwards into the interior (1997, 105). One item (similar to Class B Type 3) was included from Westenschouwen for comparative purposes.

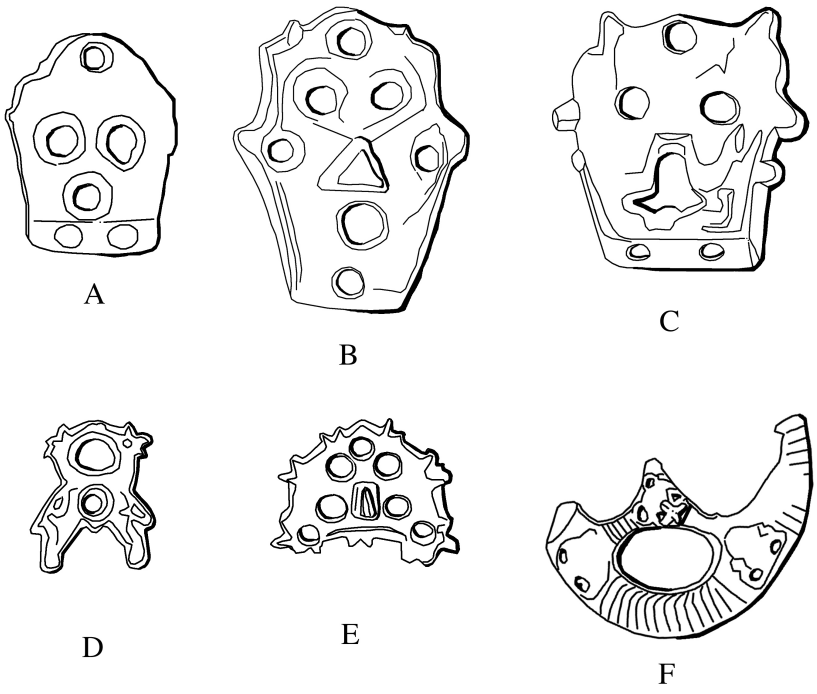


Figure 5. Stirrup-Strap mounts - Class B; A - Type 2, B - Type 2, C - Type 2, D - Type 2 similar, E - Type 3 similar., F - Type 1 similar (schematic drawings by first author).

Location	Domburg	Westenshouwen
No.	10	1
Type (Williams)	**No.**	
1	1	
2	6	
3	4	

Table 5. Number of stirrup-strap mounts per location and per type.

Zoomorphic mounts and associated items, AD 800 to AD 1200

In our study area the largest number of zoomorphic mounts and associated items were found at the beach near Domburg (see fig. 6 and table 6) and were subsequently published in a catalogue by Capelle (1976). A more recent study was undertaken in 2015 and subsequently published by the authors, and the classification presented above stems from this article (Roxburgh et al. 2018 in press). Also the reader can refer to Webley (in press). A few similar items have been found in other areas around the North Sea but in relatively small numbers by comparison to Walcheren. Also, mounts like these in the northern Dutch coastal area are usually decorated with an antropomorphic head rather than a zoomorphic one and may be slightly different in size. The results of the study of the Domburg mounts suggested that the production was likely to have been local and that their compositional and typological characteristics matched certain forms of Viking-Age equestrian gear, such as Williams Class B stirrup-strap mounts, mentioned above. The small size of these zoomorphic mounts in comparison to equestrian harness fittings allowed for discussions around their use as personal dress accessories, suggesting that the decorative style was not just reserved for equestrian gear.

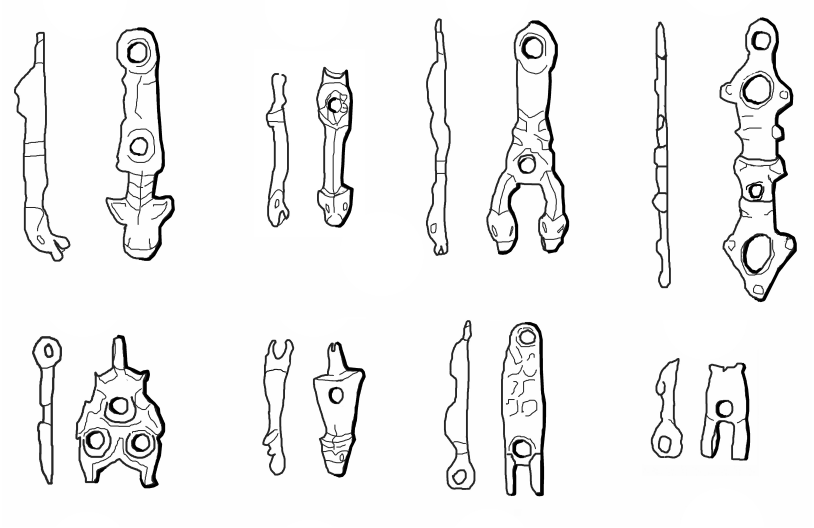


Figure 6. Zoomorphic mounts (schematic drawings by first author).

Location	Domburg - beach finds	Domburg - ring fort	Middelburg
No.	83	5	2
Classification	**No.**		
Pendant	5		
Pendant mount	6		
Strap-end mount	57		
Strap-link	22		

Table 6. Number of zoomorphic mounts per location and per type.

METHODOLOGY

As stated in the introduction, the compositional study that underlies this chapter was carried out with hhXRF (see Shackley 2011; Shurgar and Mass 2012, for more technical details and applications in archaeology). An X-Ray tube with a silver anode fires a primary X-Ray beam at the object of interest. As a result, this beam causes the atoms in the object to become excited, resulting in the release of electrons. The energy given off by the release of electrons is unique for each chemical element present, and can be measured by a detector, mounted within the equipment. From

these measurements, an assessment of the ratio of each element present in the object can then be made.

A Niton XL3t GOLDD XRF device was used for the study. These are factory calibrated, with different internal standards for metals and alloys, and consequently the 'electronic metals mode' was used to gather the data. The advantage of this mode is that it was developed for measuring the metals used in modern electronic equipment (Cu, Sn, Ag, Zn, Au), including a number of - as identified in modern times - potentially hazardous ones as well (Pb, Hg, As, Se), all of which can be found in medieval alloys. After testing with longer measuring times, the signal was found to be stable after a reading time of 35 seconds, so this was deemed sufficient to determine a minimal elemental count of 10ppm for most elements. Two spectrum readings per 35 second intervals were taken, the first for the main range of elements at 50kV (Cu-K to Ba-K, and Au-L to Pb-L) and the second for the low range at 10kV (Al-K to Cu-K). One measurement per artefact was taken and after the analyses, the spectra were processed using dedicated Niton software and subsequently checked for unexpected peak overlaps.

An external normalization of the completed dataset was undertaken using Microsoft Excel, which corrected for the contribution of light elements present due to contamination from soil residues (such as sand, clay and iron hydroxides). The elemental concentrations of the alloying elements were subsequently normalised on a light elements (Si-Fe) free basis. For the purpose of our research, only the alloying elements (Sn, Zn, Pb) were considered. This is because in addition to copper, which is always present in a copper-alloy, the addition of these elements can be considered as a deliberate act, especially in terms of their mixing ratios. The factory calibration of the device was also checked against the CHARM - bronze reference set (See fig.7, left; also see Heginbotham et al. 2015) and bias due to corrosion was evaluated by comparison to recent studies on corroded Roman finds, which revealed that copper and zinc are the main elements that degrade during the corrosion process, creating the green or brown patina and also permanently altering the original metal surface layer (see Fernandes et al. 2013; and also Roxburgh et al. 2016a). The ternary diagram (fig.7, right) demonstrates the deviation in alloy ratio between corroded and non-corroded measurements. The trend in zinc loss is clear, therefore if it had been possible to destructively clean all the artefacts measured for this paper, it could be expected that the results presented in the diagrams in fig. 8 (below) would deviate in a similar way.

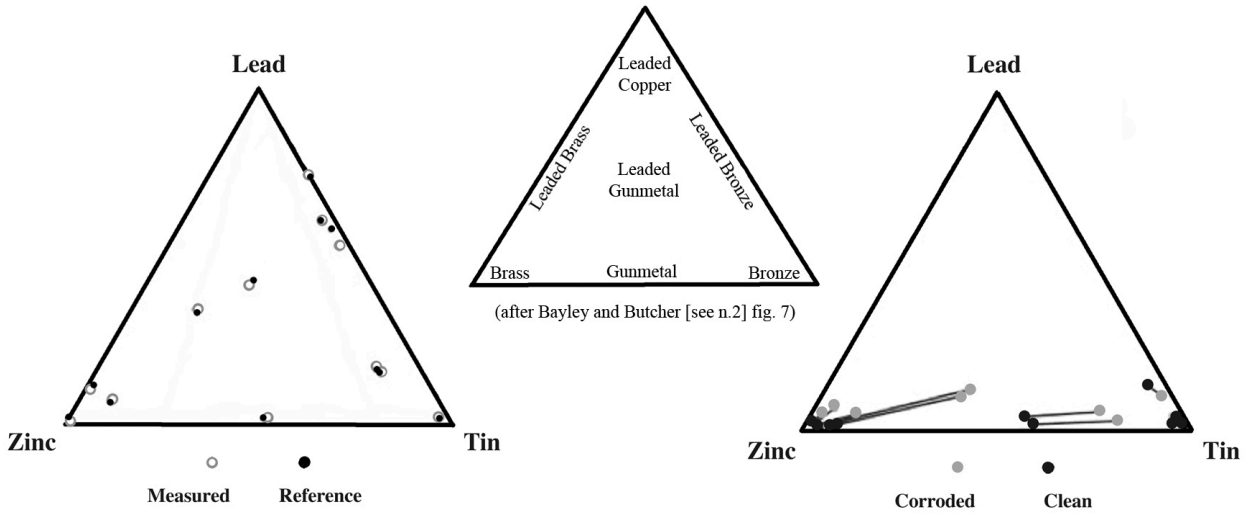


Figure 7. Ternary graphs showing - compositional classifications in centre (after Bayley and Butcher, 2004, fig.7); measurement bias compared to the CHARM standard (left) and deviation in measurement due to corrosion (right). Drawn by first author.

RESULTS

The compositional survey initially included a number of other object types that have not been included in these results. Belt buckles, strap-ends and keys were so diverse typologically that, not surprisingly, their alloys were equally diverse as well, not conforming to any trend in compositional choice. This could be due to the types being created over an uncertain length of time and over an uncertain distance from Walcheren. More and more of these artefacts are being recovered all the time, which may reveal more standardised groups, but at the moment the lack of objects belonging to distinct typological subgroups and that are available for analysis is a drawback. The other hypothesis of course is that the early medieval craftsmen (deliberately) chose not to organise the production of these items along compositional guidelines, perhaps as an outlet for recycled metal, which would also have produced the unorganised result. The wide range of stylistic variability for strap-ends found at Domburg bears some comparison to the variability found at excavations at Flixborough in England. Thomas has suggested for Flixborough that this may be because the markets were supplied by many different workshops rather than a limited number of more standardised regional production centres (Thomas et al. 2009). This model could be true of the Domburg strap-ends as well, but a more seductive argument links this to identity, perhaps the diversity in strap-end styles at Domburg together with the diverse alloy choices within them are representative of a diversity of people or their fashions and affiliations passing through a central place. Further investigations of these diverse and fascinating objects, combining typological and compositional research, may reveal more in the future.

The results presented in the following ternary diagrams (fig. 9) are for groups of objects that demonstrated a compositional trend, typically in a brass or a bronze alloying tradition. The results are discussed in more detail in the next section.

DISCUSSION

Disc brooches - Fig. 8, graph A

The measurements on thirty-eight of the brooches showed a strong correlation to the results found in other parts of the Netherlands. These brooches were produced from a leaded copper-zinc-alloy containing no tin (For comparable results from Friesland/Groningen and Nijmegen in particular see Roxburgh et al. 2016, fig. 5). But the remaining fifteen brooches, even considering changes introduced by corrosion, have been produced with different alloys. Middelburg has four brooches made from tin, and two from gunmetal. Domburg has four made from bronze, two from pewter, and three from gunmetal. Noticeably, the brooches from across the Oosterschelde at Westenschouwen conform to the rest of the Netherlands, so it is only at Domburg and Middelburg that these differences are present (For the fiveteen deviating alloy results see measurements plotted as circles in fig. 8, graph A).

Ansate brooches - Fig. 9, graph B

The measurements on these brooches strongly suggest a preference for production in a leaded bronze or leaded gunmetal tradition. Only eight of the brooches appear to have been produced from brass. Two groups appear to be present in this brass category: one group of five appears to have been made in a high-quality brass, whilst the other three may have had more lead in them or possibly lost more zinc in the corrosion process. From the brooches just mentioned, three of those produced in the brass tradition are group II brooches (Thörle 2009, group II E2; Capelle 1976, table 5, fig 54, fig 56). A further three brooches belong to group X C. Another brooch belongs to group XII A1 (Capelle 1976, table 4, fig. 47), and the final one can be identified as group VIII B (Capelle 1976, table 3, fig.21).

All of the other brooches appear to be made in the bronze or gunmetal traditions.Bos suggested that the northern Dutch (Friesland) anseat brooches are regionally different to those from Belgium and Northern France, and importantly from Domburg (Bos 2006a, 455, comparing studies by Hübener 1972; Van Bellingen 1988; and Capelle 1976). The choice of gunmetal or bronze in the production of the brooches found at Domburg appears to support this as the Frisian ansate brooches were made in a different leaded brass alloy (Roxburgh et al. 2014, 25).

Dress pins - Fig. 8, graph C

Two alloy groups are present amongst these dress pins. The largest, comprising 80% of the assemblage, is a group in the leaded bronze tradition. The smaller group has been made in a brass tradition, two of which may have contained a higher proportion

of lead than the others. There is no typological trend to the compositional results. Ross suggests that the late seventh century sees the beginning of the mass production of cast pins (1991, 110). The preferred composition for these items was perhaps a leaded bronze because of its ability to be finished by cold working, either by filing or beating with a hammer. The few made in brass may indicate the recycling of older objects. Good-quality brass was produced in the Roman period up until the second century (Bayley and Butcher 1995, 118). In other words, it is possible that this alloy was Roman in origin and cold-worked into the new pin shape.

Ring pins - Fig. 8, graph D

For the ring pins, the composition of the pins was measured, and not the wire ring. The results demonstrate a clear preference for production in a leaded bronze or leaded gunmetal. The craftsmen may have had a choice between hammering these items from ingots or scrap pieces of copper-alloy or casting them in a mould, or using a combination of both techniques. Unfortunately, perhaps due to the lack of better chronological dating, no other alloy trends can be detected using hhXRF.

Stirrup-strap mounts - Fig. 8, graph E

The results for the stirrup-strap mounts and associated items show that they group well within the brass making tradition. It has been shown in figure 7 (right) that the effects of corrosion on this data produces lower zinc levels than if we were able to analyse fresh, uncorroded alloys. This suggests therefore that the stirrup-strap group of measurements (if destructive cleaning took place) would cluster more closely together and that originally they were produced with a higher zinc content, more than for example, the majority of the disc brooches in Figure 8, graph A.

Zoomorphic Mounts - Fig. 8, graph F

The results also show that zoomorphic mounts group well within the brass-making copper-alloy tradition. A comparison to the other artefact types in the survey reveals a strong relation to the group of measurements taken for the stirrup-strap mounts. The measurements for the zoomorphic mounts suggest that they share the same composition as the stirrup-strap mounts.

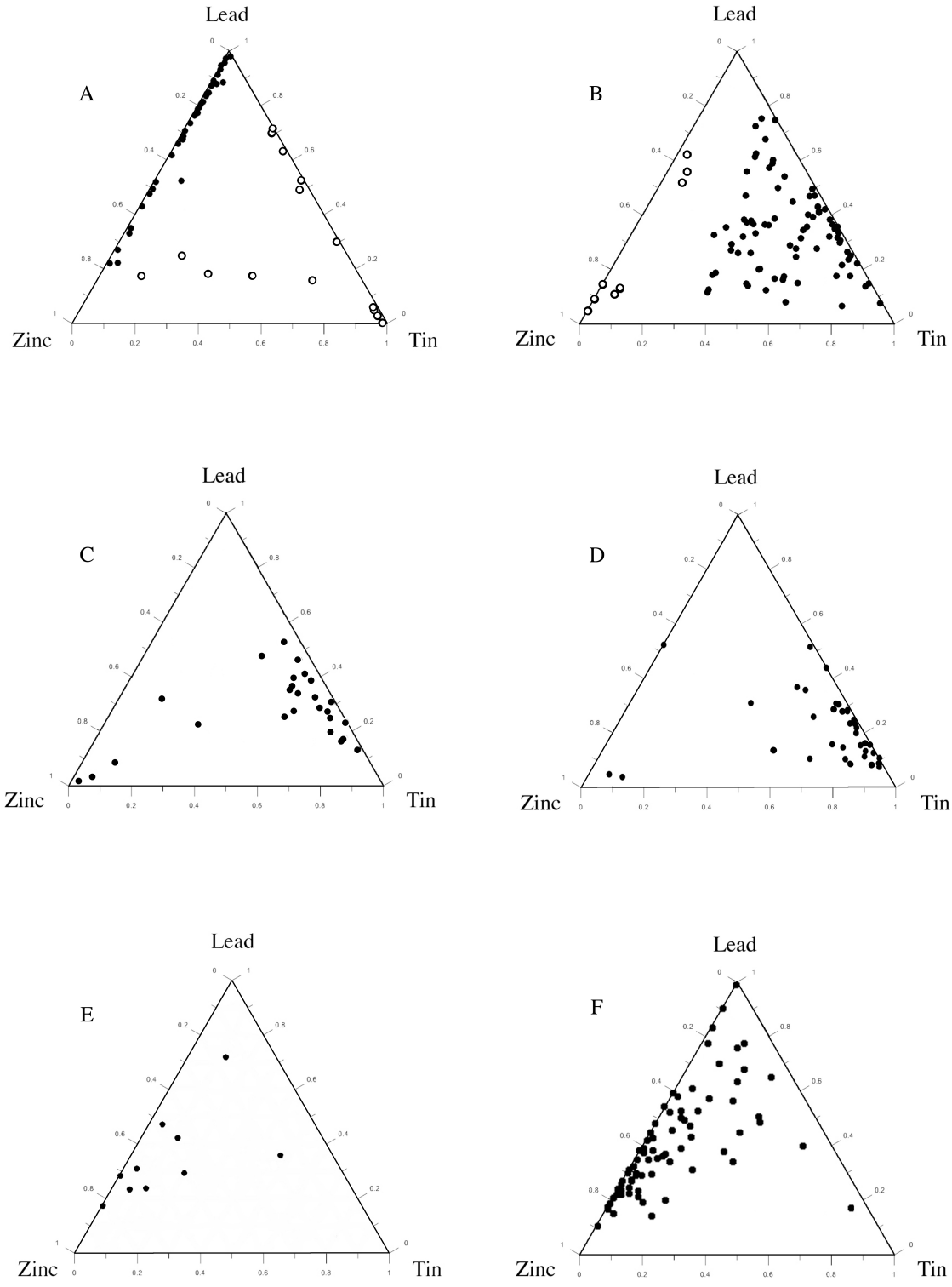


Figure 8. Ternary graphs, A - Disc brooches, B - Ansate brooches, C - Ring pins, D - Dress pins, E - Stirrup-strap mounts, F - Zoomorphic mounts.

Discussion

The most important observation from the compositional analysis is that the craftsmen were controlling the use of different alloys. Whilst corrosion has affected the original metal composition to an extent, we can see that different alloys tended to be reserved for different artefact groups. The production of brass at this time - needing lidded crucibles to trap the gasses - was a technologically different process than that used to produce bronze. The craftsmen could have been well aware of this when producing these objects, even if they were primarily concerned with production using premade ingots (The ore calamine was needed for brass production along with a technical process called cementation, Bayley and Butcher 2004, 12-13). The colour difference between brass (with its yellower appearance) and tin rich bronze and gunmetals, was one of the main ways craftsmen identified it from the other alloys, therefore enabling choice when it came to production decisions (Bayley and Butcher 2004, 13; also Baker 2013, 429). They would also have been aware of the quantities of lead added, or the amount of scrap metal to recycle into a certain object type. The alloy groups presented in the results section can to some extent be considered evidence of conscious decisions, taken individually or collectively within an organized craft and remaining consistent over several generations of craftsmen. In this section we attempt to form hypotheses about the organization behind the production of these items, by comparing the results against the workshop models presented in section 7.1.3. These hypotheses will allow distinctions to be made between local and non-local production, which in turn will inform the final part of the discussion, which focuses on identities and the social meaning behind these functional but deliberately styled objects.

Workshop organization and access to materials

Disc brooches

As mentioned earlier, Bos has suggested a broad date between the ninth and eleventh centuries for these items, with the earliest Carolingian brooches appearing around AD 800, if not slightly earlier. The wider compositional survey by the first author (Roxburgh) has shown that from this early phase the alloys consisted of a leaded copper-zinc mixture with an absence of tin. This mixture or tradition seems to have been maintained across what is now the Netherlands for a period of three hundred years. This tradition therefore would have needed controlling over several generations of craftsmen if other alloy choices were to be avoided, especially in the disposal of scrap bronze. This would have introduced variable levels of tin into the alloy, which is not the case. This would be the situation for Walcheren as well, except that it is as yet the only location that has produced disc brooches in deviating alloys. This has some very interesting implications for the organization of brooch production.

A hypothesis for the workshop organization of Carolingian disc brooches has been suggested in more detail elsewhere (Roxburgh et al. 2016, 125-128). The consistency of alloy choice rules out production at primitive workshops, domestic households and by travelling merchants, because of the greater freedom of choice - to work with whatever was at hand - under these conditions. No recycled material containing tin for example, in the form of gunmetal or bronze, is apparent in these results. Furthermore, the skill levels required to consistently produce these brooches, most of which are enamelled, would most likely not be present under these conditions. Therefore it can be suggested that the source of production lies within the more organised models, such as at royal estates, emporia, or monastic production at the great abbeys; either on a regional or supra-regional scale.

Whilst there is good evidence for monastic landholdings from distant monasteries on Walcheren, production appears to have been agricultural in nature rather than metalworking (Henderiks in press). If we assume therefore that the disc brooches made from the standard alloy, originated from a monastic production model - perhaps produced at a site some distance away, serving a much larger region - the fifteen disc brooches that were made from deviating alloys require a different explanation. If we consider them to be copies of the more commonly found brooches, it would be reasonable to suggest that a craftsman skilled in working with copper alloys could copy a disc brooch if required to do so. The end result would be to meet similar functional and visual standards as the original. What might be less apparent, however, is the compositional mixture. If the copying was done outside of the control of the main workshop, in this case probably a monastic one, the specific alloy, or the knowledge to replicate this alloy, may not have been available to the person replicating the brooch. This would leave him free to choose a different alloy, such as a bronze, gunmetal or pewter, as we have seen in the results above. On the assumption that these disc brooches were produced on Walcheren in the first place, an hypothesis for the deviation in alloy - subsequently produced under a different workshop organization - can then be proposed. It is clear that the island was gifted to Danish warlords in the ninth century and it is not unreasonable to suggest that one of the requirements of local craft workers on Walcheren, including metal workers, would be to meet the demands of a new non-Frankish elite. The exact timespan for Danish rule is yet unclear and it might have only lasted a few decades. But a change in workshop organisation and its metalworking traditions brought about during this time may have continued - in some form - long after its return to control by a local elite. This change could account for the break in knowledge regarding the alloy composition. That to an extent, production was taking place in isolation from the main centre, perhaps situated some distance within the Frankish heartland. The two organisational models that best fit this scenario are as follows: either Model A, involving top-down control from a royal centre, in this case associated with Danish warlords, with professional craftsmen possibly engaged as bondsmen. Or Model C, involving a permanently administered urban production site, for example associated with an emporium or trading post, with products destined for a market. If we assume that craftsmen working at a royal centre would have been more occupied with producing elite goods, then the latter model

seems the best fit, although it might still have been working under Danish administration for a time.

Ansate brooches

Unlike the disc brooches discussed above, the ansate brooches do not appear to be imbued with Christian meaning. The vast majority are made from bronze or gunmetal, which is at odds with ansate brooches found in the northern areas of Frisia, which are made from the same alloys as the disc brooches discussed above. This suggests two separate workshop traditions producing a separate range of typological styles for either the Frankish or the Frisian areas. The use of leaded bronze or gunmetal for brooch production is the norm for the Merovingian period, as zinc was not mined during this time. The dating for the ansate groups found at Domburg is quite broad, encompassing the seventh to tenth centuries One could therefore propose that the bronze or gunmetal alloying tradition started in Merovingian times but then continued unbroken into the Carolingian period, when zinc and hence brass alloys had become available again. This consistency – at a time when production in brass *could* have replaced this earlier tradition – suggests a degree of organization and control.

There are a small number of brooches whose alloy measurements deviate from this norm, as seen in the left of figure 8, graph B, which have been produced from brass (For the brass results see measurements plotted as circles in fig. 8, graph B). This production could be associated with the stirrup-strap mounts or zoomorphic mounts, as they are made from a similar alloy group and therefore could be local in origin perhaps copies of styles more commonly found on the Frankish mainland. As with the disc brooches discussed above, production at primitive workshops (model D), merchants (model E), and domestic households (model F), are the least likely options, based on the same reasoning. Production at royal estates (model A) is also less likely due to the likelihood that these would be focused on making high-quality items (Such as the craft production at the Royal Palace at Aachen, see Schutz, 2004, 386), which leaves either model B (supraregional, professional, intensive seasonal production at permanent workshops), or model C (production at permanent administered urban production sites, such as emporia or trading posts). Both of these models involve the production of items destined for a market. Therefore the majority of the ansate brooches found on Walcheren were most likely produced at a number of urban centres within the western Frankish heartlands, producing stylistically different decorations, perhaps evolving over time. Alternatively (but less likely), they may have been produced at a supra-regional production centre, possibly monastic, again in the Frankish heartlands, whose output changed stylistically over a long 400-year period. That said, one of these production sites could have been on Walcheren, giving rise to a local ansate brooch style and including a small number – mentioned earlier – that were produced from brass.

Zoomorphic mounts

The disproportionate number of zoomorphic mounts found around Domburg by comparison to other areas suggests that they perhaps were produced locally (see Webley in press). This could therefore be associated with production at the trading post (if it was still active; Deckers, this volume), or at an administered workshop, where both the required skills and a continued availability of zinc ore (to produce brass), or brass ingots - traded from elsewhere - would have produced the consistent alloy ratios seen in the results (For archaeological evidence of Brass ingots, see Bayley et al. 2014; Sindbæk 2001*).* This hypothesis matches Söderberg's model C: a permanent administered workshop site manufacturing objects for trade.

It is less likely that production took place within models A or B, i.e. casting within royal or supra-regional centres. The professional craftsmen engaged at these places may have been more concerned with higher-quality items in the first instance and then secondly, regional or supra-regional production would presumably have produced higher volumes distributed over a wider geographic area, resulting in more of them being found in other locations. Thirdly, in considering the Christian nature of the Frankish world, many copper-alloy items found within the heartlands bear Christian motifs. This is not the case for the mounts in this analysis: indeed, they appear to be influenced by animal styles, Many Scandinavian zoomorphic art styles were adopted and developed over time into local forms within the Christian Anglo-Saxon and Frankish world, and metalwork styles in particular were appropriated and integrated into local cultural traditions (Kershaw 2010; Thomas 2012). However the large-scale production of items bearing motifs that were not explicitly Christian in their design would seem at odds with production at Frankish royal estates and monastic workshops. It is more likely therefore that production took place at a more neutral workshop, such as one associated with a different power-base such as a trading site.

Production at primitive workshops (model D) seems equally unlikely, because the skills and knowledge required to apply the zoomorphic decoration would have to have been maintained over long periods of inactivity. The technological knowledge required for casting in brass would also have had to be maintained over these gaps. It would also seem likely in this model that scrap items would be poorly sorted, allowing bronze or gunmetal to enter the mixture, which does not appear to be the case in this instance.

It is also less likely that travelling merchants (model E) produced these mounts. They may well have had something to do with the production of - or trade in - brass ingots, such as those found in excavations as distant as London, Hedeby and Gotland (see Bayley et al. 2014; Sindbæk 2001). It is more likely that travelling merchants would have been primarily interested in trading finished goods, rather than overseeing their production. Finally, the least likely option of all is production in a domestic setting (model F). In contrast to simple repairs and alterations, the more advanced craft skills needed to cast in brass and to decorate in a zoomorphological style, do not fit this model.

The most likely model therefore is that of an urban production site (model C) under a Church neutral administration - possibly Scandinavian or Frisian in nature rather than Frankish.

Stirrup-strap mounts

As discussed earlier, the alloy measurements for this artefact group generally exhibit the same leaded brass composition as the zoomorphic mounts. Therefore a similar argument for the organization of their production could be made, i.e. a local permanent administered workshop (model C) making items for a market. Like the zoomorphic mounts, they are found in other areas around the North Sea as well, including England, Flanders and the modern province of Friesland, but not in numbers comparable to the zoomorphic mounts found at Domburg. For those found in England, Williams suggests a continental influence, if not a production source, possibly within the Netherlands. This is based on the fact that the distribution of the find locations was limited to the eastern coastal counties from Lincolnshire in the north to Kent in the south (Williams 1997, 23). Assuming that stirrup-strap mounts were solely reserved for equestrian equipment and not used to protect the leather strap-ends of some more heavy duty personal equipment (Huggins 1988, 145-147, for example of non-equestrian context), they would have been made in smaller numbers than if they had been produced for personal use. Hence at Domburg they would occur in more limited numbers than the zoomorphic mounts, which is the case. As mentioned earlier, the most likely organizational model is a more permanent administered workshop, possibly on Walcheren, but also possibly in the Northern Frisian areas or in England.

Dress pins

This artefact group represents a class of personal objects that is a relatively common find around the North Sea area. As mentioned earlier, Ross suggests that from the 7th century onwards these items were mass-produced through the adoption of the casting process. Like all of the artefact groups presented in this paper, they are easily transportable, and therefore their find locations could be at significant distances from their points of manufacture. Conversely, the relative simplicity of production by a metal worker means that they could also have been made locally.

The least likely organizational model is that of domestic production (model F). Perhaps repairing took place, but initial casting seems unlikely as it would have required access to moulds, crucibles, specialist tools and raw materials, unlikely to have been found in everyday households, even assuming the skills to use them were commonplace, which is unlikely. The craftsmen engaged at royal estates (model A), whilst probably preoccupied with more elite production, could have produced dress pins quickly and easily in order to satisfy a local demand. Merchants (model E) may also have cast these relatively simple objects as an alternative to ingots and weights, maybe as a way to turn scrap-metal into goods for market. The remaining models (B:

supra- regional production at permanent workshops; C: permanent administered urban production sites, such as emporia or trading posts; and D: infrequently used primitive workshops, making socially determined goods - all producing items for market) therefore remain the most likely sources of these items.

Ring pins

The debate over the production of ring pins follows similar lines to that of the dress pins. The simplicity of these objects including their alloys would allow for production to have taken place within any of the organizational models presented above. However, we can consider models D (infrequently used primitive workshops, making socially determined goods and exhibiting little experimentation) and F (domestic households, non-professional, including simple jewellery and repairs) as particularly valid sources for these items. This is because the ring pins found at Domburg offer little in the way of stylistic consistency, unlike the dress pins with their shaped heads. Functionality appears to be the main criterion and even though a number of them have hexagonally shaped heads, they could have been altered in a domestic setting to take the ring. The ring pins with rolled heads (fig x A); could also have been made by simply taking a thin fragment of scrap copper alloy and then bending one end around a ring.

Identities: Frankish, Frisian, Scandinavian or Anglo-Saxon?

Many of the items are so common and distributed across such a wide area that it is hard to establish a specific cultural sphere to which they belong or to a location to which they were manufactured. This would particularly be the case for the various pin-types. Also there is a chronological dimension as well, as some objects such as the anseat brooches and stirrup-strap mounts can be seperated in time by a century or so. Other objects, more specifically the zoomorphic mounts, seem – in terms of both decoration and distribution – connected to a particular cultural sphere along the North Sea coast, whilst the widespread disc brooches with cross-motifs in form seem to belong to a Frankish sphere. The analysis of the items from Walcheren indicate that these different items with various cultural connections were present simultaneously, like - in the wider context - the dress pins found in Frisia and Flixborough on opposite sides of the North Sea.

An analysis of the alloys in combination with typological data suggests that identities on Walcheren were constructed using objects drawn from both local and non-local sources. This was done either by producing items for various groups in a local workshop, or by using items acquired from sources elsewhere, such as the ansate brooches. A hypothesis would be that the copper-alloy assemblage on Walcheren and in particular from the trade settlement Walichrum reflects a multicultural group, perhaps drawn together by the trading post. This trading post would most likely have

been a neutral site where people from Christian and non-Christian backgrounds, from the Frankish and Frisian areas as well as from the British Isles and Scandinavia, could all come together to exchange items.

In that sense disc and ansate brooches represent a personal connection with people within the Frankish/Ottonian cultural hegemony whilst the zoomorphic mounts and stirrup-strap mounts contributed to an identity constructed from connections with people from Frisian, Anglo-Saxon, and/or Scandinavian areas. Apart from the various individual identities and affiliations that people expressed via this portable metalwork, the general 'identity' of Walcheren as we see it reflected in the archaeological material would have been constructed using a combination of both local and non-local personal items, with Christian and non-Christian decorative styles, and from various workshops. In addition, the local workshop on Walcheren would have produced a range of objects as well, such as copies in different alloys of the Frankish disc-brooches.

Historical evidence indeed suggests the presence of people from diverse backgrounds, drawn together by the opportunities the trading site had to offer. Bearing in mind that within a large coastal area there would most likely have been regional differences, as part of a greater Frisian sphere, some people related to Walcheren may have been called Frisian. In the eighth century, it had become part of the Frankish sphere and Frankish counts seem to have been connected to it. During some time in the ninth century, due to Viking attacks and the measures taken against them, Danish war-lords and their followers (probably being multi-ethnic) were present in Walcheren when it became a Danish benefice.

Despite the many items that belong to widespread continental types, the use of materials on Walcheren distinguishes some of them from their parallels. As such, the metalworking in Domburg and Middelburg stands out through the choices seen in the alloys. The choices in alloy may reflect a local identity in terms of production from a local workshop, as suggested by the zoomorphic mounts in terms of both typology and composition. Together they point to a North Sea identity at the island, which possibly was under Danish administration for some time and which, throughout time, combined Frankish, Frisian and Anglo-Scandinavian influences. This suggests that there is a metalworking tradition on Walcheren, which was able to combine items from the above-mentioned spheres and produce them locally, reflecting the multi-ethnic presence and connections on the island.

CONCLUSION

The nature of the metallurgical tradition at Walichrum is discussed further, elsewhere (see Copeland, Deckers and Weetch in press). The evidence here however suggests that for copper-alloy production at least, it was most likely organised along the lines of a permanent administered urban production site, such as an emporium or trading post, with products destined for market. This model seems the best overall fit as it

would allow for the local production of zoomorphic mounts, stirrup-strap mounts, dress pins, ring pins, and a smaller group of ansate brooches. It would also account for small number of disc brooches produced in a deviating alloy to those found in the rest of the Netherlands. The bulk of the disc brooches and the ansate brooches however, are more likely to have been produced somewhere within the Frankish heartlands. They are likely to have found their way to Walcheren as trade items, perhaps at the demand of the locals, or as personal items worn by people from the Frankish sphere who could have been involved with the trading site. This allows us to consider the existence of a multicultural group of inhabitants, perhaps drawn together by the trading post, which most likely would have been a religiously neutral and multicultural site. For future research, it will be interesting to combine compositional and typological analysis on items from other areas, to see if this can shed further light on the organization of workshops and a possible relations to different cultural spheres.

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Chapter 8

A Comparative Compositional Study of 7th- to 11th-century Copper-Alloy Pins from Sedgeford, England and Domburg, the Netherlands.

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In this paper we present the results of a compositional study of two small groups of early medieval pins. One group comes from the middle Anglo-Saxon/late-Saxon excavations at Sedgeford (Norfolk, England); and the other group was recovered from the beach near Domburg, on the former Island of Walcheren (Zeeland, the Netherlands). Both groups are contemporary in date, deriving from the 7th and 11th centuries, and derive from coastal settlement contexts.

In contrast to the pre-Christian period, copper-alloy artefacts from this time remain relatively rare, mainly due to the transition from furnished to unfurnished burial practices. As a result, knowledge regarding copper-alloy working at this time remains less well understood. The evidence so far, however, suggests a revival in metalworking activities, signalled by the large assemblages recovered from excavations in England such as at Flixborough, Lincolnshire and Hamwic, now Southampton, Hampshire (Blades 1995, 38; Rogers et al. 2009 for Flixborough and Wilthew 1996 for Hamwic). Although the numbers of pins measured in our study fall short of these larger assemblages, the pins considered here were found at similar types of site, at early medieval coastal settlements whose position within the maritime cultural landscape is of archaeological interest (e.g Callmer 2001; Deckers 2010; Hodges 2012, 8–10; Barrett and Gibbon 2015). It is unlikely that further quantities of pins will be recovered from Domburg or Sedgeford as these sites are now either eroded away, or have been systematically excavated. As a result this study compares just a limited quantity and variation in pin type, but it presents significant results useful for future large-scale comparisons with additional assemblages recovered from sites connected by the North Sea trading zone.

Frankish customs and their social and cultural influence on both England and Scandinavia have received considerable scholarly attention over recent decades, especially in the exploration of social identity and cultural affiliations within the North Sea region (e.g Loveluck and Tys 2006; Willemsen and Kik 2010; Bates and Liddiard 2015). There has been a tendency, however, within England to interpret metalwork within 'Anglo-Saxon' or 'Scandinavian' frames of reference (Thomas 2012, 487). Frankish influence on metalwork items found in England, either through inspired copies or imported goods, has received less coverage (Ibid, 488), with more emphasis given to the eastern coastal areas and in particular to the Anglo-Scandinavian nature of metal finds, especially in terms of copper-alloy personal items (Margeson 1996; Leahy and Patterson 2001; Kershaw 2009). The technology behind the production of these items can contribute to our understanding of the nature of contacts within the North Sea region if comparisons can be made between items recovered from differing locations. This is true not only in terms of the desired shape

or function of objects, but also with regards to the choice of raw materials; the characteristics of which may differ and change as a result of local or regional geographical or chronological conditions.

While detailed pin typologies now exist, and demonstrate a degree of chronological variation (Capelle 1976; Ross 1991; Haldenby and Richards 2009; Rogers et al 2009), the exact use of pins during this period is not fully understood, but it is assumed that they were used for pinning hair, clothing and veils (Ross 1991, 22), and funerary shrouds in cemetery contexts (Hinton 2005, 92). Broadly speaking they can be considered as decorative and functional personal fasteners that were likely to have been used visibly in daily life and are therefore an object category susceptible to cultural trends. The 7th century, which is the earliest date to which we attribute the pins considered in this study, witnessed a change in female costume in Anglo-Saxon England that reflected the influence of the Frankish world located just across the North Sea (Owen-Crocker 2004, 128). Written accounts from the 8th century attest to the regular travel of scholars between Anglo-Saxon England and the Carolingian Empire. The missionary Boniface, for example (originally born in Wessex, England), was appointed the Bishop of Frisia and Old Saxony in 718. Surviving correspondence between Boniface and Charlemagne describe clothing as a common gift between the two individuals. This evidence pertains to an elite, ecclesiastical context, but it attests to the exchange of clothing and fashions between English and continental courts (Ibid, 27). It is not surprising that in this world of cross-cultural contact, personal items such as the pins discussed here appear to have developed along very similar typological lines on both sides of the North Sea. It has been suggested that pins as an artefact group are a rich data source for studying continuity and change in the Anglo-Saxon world (Ross 1991, 5), and that they can offer information on cultural change and economic variation, in terms of the spatial patterning of finds and the evidence of variation in production techniques. It has also been suggested that the large numbers of pins found in the archaeological record in comparison to other copper-alloy artefact types is evidence of large-scale production, centralised in this period around *wic*s, churches and royal estates, and possibly produced by a specialist workforce (Hinton 2005, 92). Seamus Ross observed that the workmanship of the pins from the 7th century onwards is significantly reduced in terms of skill than in previous centuries, with pins roughly cast, typically in base metals, then finished by hand (Ross 1991, 148). Ross has also proposed a change to the mass production of pins starting in the late-7th century (Rogers et al. 2009, 41).

While evidence of large-scale production is suggested by the frequency and type of the decorative head-styles from known assemblages, it is unclear whether this extended to the choice of alloy. If large-scale production was centrally organised, then it is possible that the alloy mixtures used may have been controlled to a degree reflecting, perhaps, the large-scale acquisition of raw materials, or a consistent school or genre of production with craftsmen working within a well-proven alloy tradition. Furthermore, if some level of material organisation took place at production level, it should not be assumed that this was identical in Anglo-Saxon England and on the Frankish Continent, even if the pin design was similar.

A compositional approach to the study of these artefacts may thus tell us something meaningful about the way in which production was organised. We ask here if the metal composition of pins can provide information on the organisation of production at Sedgeford and Domburg? To answer this question we assess how similar or not the alloy choice was between pin forms from these settlements. This study employs the use of handheld, portable X-Ray Fluorescence Spectrometry (hhXRF). This is an analytical device commonly used in archaeology for exploring the compositional nature of ancient materials. Used in a semi-quantitative way, respecting the principles of scientific validity and reliability (Speakman and Shackley 2013), the data collected by this non-destructive technique, may tell us something about the character of craft production, within the interconnected early medieval North Sea world.

HISTORY OF RESEARCH ON ARCHAEOLOGICAL COPPER-ALLOYS

Much has already been published on a broad range of copper-alloy personal items including brooches, equestrian gear, and decorative mounts, as well as dress and ring pins. Taking the publication by Torsten Capelle as a departure point for Domburg, useful typologies now exist for the copper-alloy dress pins discussed in this paper. The artefact assemblages from York (Yorkshire, England), Flixborough, and Hamwic provide important comparisons for Anglo-Saxon Sedgeford (See Ross 1991 in particular for detailed geographical, chronological analysis, then Rogers et al. 2009 for Flixborough).

Ancient copper-alloy objects have been the subject of typological interest for well over two centuries, but the ability to study them from a compositional aspect has only really been available from the 1950s through the invention of new scientific X-ray instruments, including Optical Emission Spectrometry (OEM), Neutron Activation Analysis (NAA) and laboratory based wavelength dispersive X-ray Fluorescence Spectrometry (labXRF). The late 1950s and 1960s saw the first studies of small metal objects using labXRF (Feretti 2014, 17531), but it was only in the early 1970s through the development of Energy Dispersive XRF (EDXRF), that the technology became small enough to transport to museums and archaeological depots, while at the same time offering non-destructive analysis, an important consideration when curating a finite supply of archaeological material. The earlier generation of equipment is commonly referred to as Portable XRF (pXRF), with the latest generation of 'point and shoot' devices being referred to as Handheld XRF (hhXRF, see Frahm and Doonan 2013, 1426). The equipment used in this study is the latter, therefore we employ the term hhXRF to distinguish it from the bulkier benchtop systems.

The results of past alloy studies have already shed light on the compositional and technical choices available to ancient craftsmen. The main alloying agents to copper were tin to make bronze, and zinc for brass, with or without a quantity of lead. Alternatively, a mixture of tin and zinc (in brass form being added to bronze) could be used, a choice that is usually termed ‘gunmetal’. The deployment of inductively

coupled plasma atomic emission spectrometry (ICP-AES) in the investigation of copper-alloy use from early medieval archaeological sites in England has produced useful results (Blades 1995). Nigel Blades analysis of 151 middle Anglo-Saxon period artefacts (mainly pins) from Brandon (Suffolk, England) suggested that there were two basic choices of alloy in use at the time. A relatively pure brass composition and also bronze (with varying degrees of lead) were used for casting. No correlation was observable between artefact typology and alloy choice. For the late-Saxon period in England, Blades analysed 78 objects from Ipswich, Beverly and Lincoln (Suffolk, Yorkshire and Lincolnshire respectively), only 12 of which were small cast finds. Again no correlation between artefact type and alloy choice was observed and the alloys measured were similar to those at Brandon, mainly bronzes, then brass, with a small amount of gunmetal. This lack of gunmetal suggested that fresh metal was available and was being used in preference to the recycling of scrap (Ibid, 161). Energy dispersive X-ray fluorescence (edXRF) was also deployed in an analysis of middle Anglo-Saxon copper-alloy finds from Hamwic (Wilthew 1996). Approximately 140 pins were analysed of which 34 were produced in brass and only 15 produced in gunmetal, with or without added lead. The remainder were produced in bronze or leaded bronze. The alloy results for the polyhedral-head-types suggested that no correlation between composition and head-type, with all alloys being present in the assemblage. A different situation was observed for the biconical-head-types. The pins with simple biconical heads and those with median bands were made in brass, while the rest of the pins were produced in bronze or gunmetal. From these results Paul Wilthew suggested that different pin types may have been produced separately, either at a single or a limited number of sites and that composition may have been deliberately controlled (Ibid, 67–8). These past studies have suggested close interconnected relationships between composition and typology (Dungworth 1997, 902), including the technical limitations of different alloy combinations used in casting (as a molten liquid) for example, or in cold working such as hammering and stretching. A large-scale, non-destructive, compositional approach, especially focused on items from the early medieval period, and the Netherlands in particular, has until now been limited (e.g. Bayley 1991; Baker 2013; Pollard et al 2015; Roxburgh et al. 2014; 2016a). This is because the application of hhXRF in the study of corroded copper-alloy items is still developing (See Roxburgh et al. 2018).

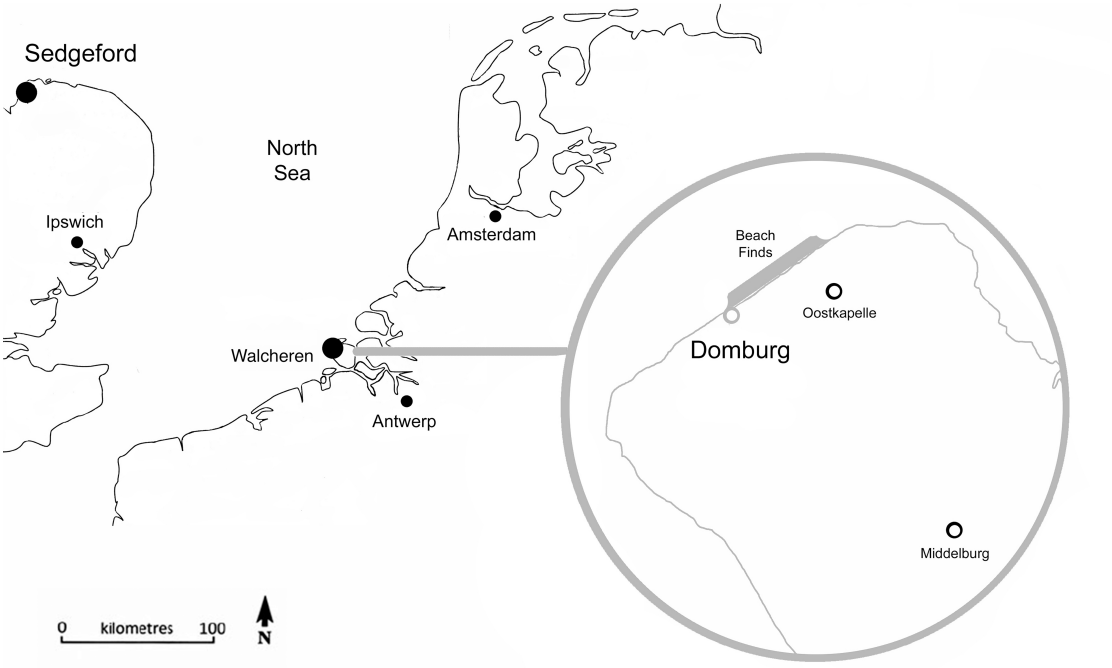


FIG 1
Locations of Domburg (Zeeland) and Sedgeford (Norfolk), as mentioned in this study.

THIS STUDY: FIND LOCATIONS AND HISTORICAL CONTEXT

Of the 33 dress pins presented in this study, 19 were recovered near to modern day Domburg (see Fig 1). These were mainly beach finds washed ashore after heavy storms and collected at low tide in the 19th and early 20th centuries (Op Den Velde and Klaassen 2004, 3). Ocasionally at very low tides the North Sea still reveals the remains of the early medieval cemetery and settlement structures. There has been much discussion about early medieval Domburg, with suggestions that the site was a trading settlement or emporium during the late-6th to 9th centuries, involved in interregional trade around the North Sea (Ibid, 2). Repeated Viking raids are said to have contributed to the gifting of Walachrium (believed to be the medieval name of the settlement at Domburg) as a fiefdom to Danish warlords by the Frankish emperor Lothar I (795-855), but during this time its role as a trading centre seems to reduce significantly as other trading sites became more influential (Ibid; Van Heeringen et al. 1995, 230; Theuws 2004). This settlement is believed to have been the centre of the royal manor of Walachrium, from which the island (Walcheren) takes its name. Its rural hinterland is believed to have consisted of numerous specialised coastal farms, many of which involved in the raising of sheep. Trade activities at Domburg (continuing with the modern name) therefore, would have included exchanges of both rural- and craftsperson-produced goods, and its position within an interconnected

North Sea trade network would have facilitated the movement of both types of produce over longer distances (Tys 2010, 172).

In 2017 the excavations at Sedgeford, a rural village on the coast of Norfolk, entered its 22nd season. The project conducted by the Sedgeford Historical and Archaeological Research Project (SHARP), has systematically revealed a middle Anglo-Saxon to late-Saxon settlement and associated burial ground (Davies 2010, 252–73). The site is located besides the River Heacham and lies just 5 km from the present coastline. The location of the settlement is also associated with two major N/S trackways, the prehistoric Icknield Way and the late Roman-period Peddars Way. Although evidence for trade remains elusive at Sedgeford itself, its location places it in close proximity to small-scale trading sites such as Burnham, Bawsey and West Walton. Their market-like assemblages and proximity to possible beach or river landing sites suggest a connection to the wider North Sea world (Deckers 2010, 165). Analysis of the artefacts recovered from this rural settlement can provide useful comparisons for the study of activity at trading posts such as Domburg (McCormick 2001, 1; Hodges 2006, 16). Mass-produced items such as pins could have been produced for either local consumption or, because their small (and very portable) size, may have been destined for trade at these interconnected markets. A comparison of pin compositions from both of these sites contributes to the debate surrounding the nature of trade and production at both emporia and lesser rural settlements alike.

EARLY MEDIEVAL COPPER-ALLOYS AND THEIR PRODUCTION

The most frequently used copper-alloy in early medieval Britain was bronze (copper alloyed with tin) and the closest tin-producing area would have been Cornwall, in south-western England (Penhallurick 1986). A significant amount of bronzes at this time were not pure, containing a mix of other alloying ingredients, whether added on purpose or not (Baker 2013, 228). The other major alloying component was zinc, to make brass, possibly favoured in ancient and early medieval times for its distinctive golden colour. Zinc is not mined in England and the closest mining area would have been at La Calamine in Belgium, well within the Frankish hinterland (Boni and Large 2003). Brass also needed a different technological process to bronze — the cementation process — where the zinc enters the copper in a gaseous form in a closed vessel (Ibid, 234). The production of items in brass appears to decline rapidly in Antiquity, and was replaced by production in gunmetal, which is a mixture of brass and bronze (in varying proportions) and would have been a suitable mechanism for recycling scrap objects of both alloys. Gunmetal could also be a preferred choice in its own right as a zinc-rich leaded alloy would have good casting properties, while the addition of 1–2% zinc to a bronze acts as a deoxidant, making the object more resistant to corrosion (Bayley and Butcher 2004, 15, also see Tylecoat 1977 and Nazeran 2013, 5). That said, the addition of 1–2% zinc to a bronze could also be the result of reusing old crucibles (Baker 2013, 90).

By the 7th century, therefore, most pure brass in the Anglo-Saxon kingdoms may be considered as either reworked Roman scrap, or freshly imported from the

Frankish world, perhaps in the form of ingots such as those found at Kingsway, London, or those found much further north in the Baltic region (Bayley et al. 2014; Sindbæk 2001). A relative scarcity of brass during this time in comparison to a wider availability of gunmetal and bronze, combined with its popularity as a more golden copper-alloy, may well have created a difference in cultural value when selecting between brass- or bronze-based objects (Baker 2013, 33). In addition, brass allows for more elaborate cold working of the object such has hammering, drawing and bending; making it the metal of choice for more high-status jewellery, perhaps including pins. Bronze on the other hand, especially leaded bronze, is easier to cast in thinner objects, and therefore easier to mass-produce. However, it is very difficult to cold work (leaded) bronze as it will break or tear more easily than brass (Cameron 1974, 217–19). A trading centre at Domburg would have been in a good geographic position to be involved in the trade of brass around the North Sea, and to Britain in particular, if in demand by Anglo-Saxon craftsmen.

The organisational characteristics of early medieval craft activities and the social standing of the artisans who produced them is still under debate, but it is clear that different organisational structures for production must have existed, Anders Söderberg, a Swedish archaeologist and craftsman, proposed several classification models for the organisation of copper-alloy crafting activities (Söderberg 2004, 116). Adriaan Verhulst, from a historical perspective, suggested that artisan production was mainly centred around royal courts, abbeys, large estates and urban centres, but with a small amount of production by travelling artisans, perhaps less controlled than that produced by those working within more sedentary environments (Verhulst 2002, 72).

Artisans would have been the main decision makers in the production techniques employed to make different types of copper-alloy artefacts. They controlled the production technology, the choice of raw materials and hence the quality of the finished item. If a pin was the product of organised large-scale production, then the level of consistency present, both in terms of shape and composition, could be higher than might be expected from more ad hoc production events. The consistency of the raw material supply such as brass or bronze would be a factor in the decision-making process, however, but if regular duplication took place then the possibility exists that the raw material supply and hence alloy choice became more standardised. Craft specialisation and standardisation have been attracting archaeological interest since the work of Gordon Childe in the 1930's (e.g. Childe 1930; 1936). In more recent times craft specialisation, standardisation and the organisation of labour have been explored using portable X-ray fluorescence, focusing analytically on chemical clusters and the concept of batch production of weaponry in ancient China (Martinón-Torres et al. 2012). Standardisation of alloy choice has also been observed in hhXRF studies of Frankish brooches from across the Netherlands. The small long brooches of the 'Domburg'-type dating to the 7th century were only produced in tin-rich gunmetal (Roxburgh et al. 2016a, 123, fig 4; Heeren and van Der Feijst 2017, 211, type 82h). Furthermore, an overwhelming majority of Carolingian- and Ottonian-period disc brooches, again from across the Netherlands, are produced in leaded brass (Roxburgh et al. 2016a, 126, fig 5). It would be of

interest therefore to see if this standardised choice of alloy extended itself to pins, which are another mass-produced and widely distributed object.

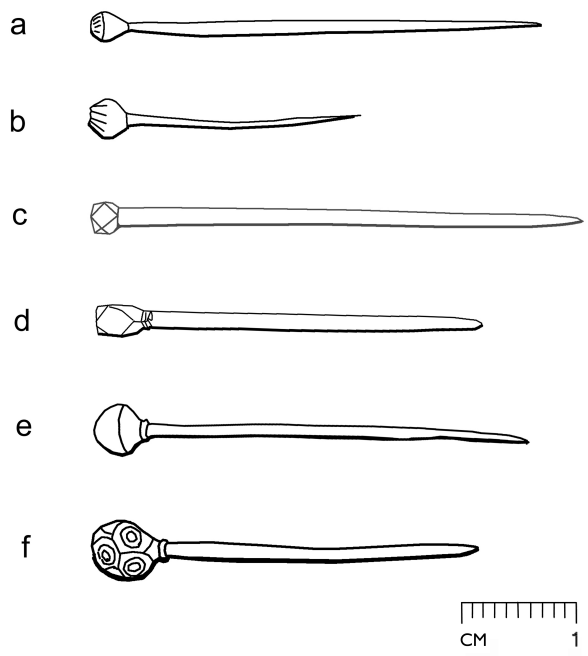


FIG 2
The pin types. Domburg: (a) Biconical (0032-122); (b) Biconical (0032-120); (c) Polyhedral (0032-109). Sedgeford: (d) Polyhedral (SH01BYDOT793); (e) Biconical (SH03BYDNT1173); (f) Biconical, ring-and-dot decoration (SH01BYDNT709). *Drawn by first author.*

MATERIALS

The pins found near to the modern seaside town of Domburg were eventually placed into the care of the Zeeuws Museum and the Cultural Heritage Agency of Zeeland's archaeological depot (SCEZ, Partly as the collection of the Koninklijk Zeeuwsch Genootschap der Wetenschappen (KZGW; the Royal Zeelandic Society of Sciences), Middelburg). The pins were first accessed for hhXRF analysis by a research masters student, with scientific support from the Dutch Cultural Heritage Agency (Van Tendeloo 2017, supervised by the second author). The compositional measurements from this study were subsequently absorbed into a larger doctoral project undertaken by the first author ('Charlemagne's Workshops' is an investigation into the social organisation of production behind Roman to early medieval period copper-alloy objects).

The pins from the archaeological excavation at Sedgeford were accessed in 2016, with measurements subsequently undertaken by the first author, using the same portable device as at Domburg, on loan from the Dutch Cultural Heritage Agency. We selected examples from two coherent groups of pins based on the shape of their heads (see Fig 2), then subsequently studied them from compositional, typological and contextual viewpoints. An extensive typological study of non-ferrous Anglo-Saxon pins was published by Seamus Ross in 1991, and subsequently a comparable study was produced by Nicola Rogers on the pins recovered from the excavations at Flixborough (Rogers et al. 2009). From these studies we were able to assign a classification to pins from both Sedgeford and Domburg (Tab 1, also see Ross 1991, 371–80; Rogers et al. 2009, 35). Archaeological dating from Flixborough suggested that both the polyhedral-head series and the biconical-head series were found in layers dating to between the late-7th century and late-10th century. The chronology proposed by Ross places the polyhedral head series between the mid-7th century to mid-9th century, with the biconical head series starting a decade or two earlier and lasting into the mid-9th century. The excavations at Cottam in Yorkshire enabled a better glimpse of these pin chronologies (Haldenby and Richards 2009, 309). The drifting nature of the site across the Anglian to Anglo-Scandinavian periods enabled chronological analysis across the two phases. This revealed evidence for the continuation of the biconical series across both phases and the disappearance of the polyhedral pin at the beginning of the Anglo-Scandinavian phase, in favour of a new disc-headed pin form (Haldenby and Richards 2009, 314).

METHODOLOGY

The principles of the hhXRF portable device are very much the same as for laboratory based XRF versions, both of which can be used to assess the quantities (and hence ratios) of metallic elements present in an object (See Shackley 2011 and Shugar and Mass 2012 for additional technical details, including examples of archaeological applications). For this study a Niton XL3t GOLDD XRF device was used. These devices are factory calibrated with several internal standards for metals and metallic alloys, allowing a suitable mode (electronic metals) to be selected with which to gather data. This mode, although developed for modern electronic equipment, was the most suitable because it recognised most of the elements found in medieval alloys, namely; copper (Cu), tin (Sn), silver (Ag), zinc (Zn), gold (Au) and the potentially hazardous lead (Pb), mercury (Hg), arsenic (As), and selenium (Se). Time trials subsequently determined that the signal was found to be stable after a reading time of 35 seconds, therefore sufficient enough to determine an elemental count of 10ppm for most elements and adequate for the level of analysis required. Two spectrum readings were taken at 35 second intervals, the first for the main range of elements at 50kV (Cu-K to Ba-K, and Au-L to Pb-L) and the second for the low range at 10kV (Al-K to Cu-K). One measurement per dress pin was taken (on the head) and after the analyses, the spectra were processed using dedicated Niton software and subsequently checked for unexpected peak overlaps.

The patina or outer corroded surfaces can be contaminated to a degree with soil residues (typically sand, clay and iron hydroxides), therefore an external normalisation of the completed dataset was undertaken using Microsoft Excel.™ The concentrations of the alloying elements were subsequently normalised on a light elements (Si-Fe) free basis. For the purpose of this study we only focused on the main alloying elements (Sn, Zn, Pb). The addition of these elements can be considered a conscious act by medieval craftsmen, the ratios of which, when added to copper (which is always present) give different alloying properties. The factory calibration of the device was also checked against the CHARM –certified, heritage copper-alloy – reference set (See Fig 3, left, and Heginbotham et al. 2014) and the bias introduced due to corrosion was also evaluated by comparison to recent studies on corroded Roman finds (Roxburgh et al. 2018). This revealed that copper and zinc are the principle elements lost during the corrosion process, creating the patina and permanently altering the original metal surface layer (Fernandes et al. 2013; and also Roxburgh et al. 2016). The deviation in alloy ratio between corroded and non-corroded measurements is visualised in the following ternary diagram (Fig 3, right). The trend in zinc loss is clear and had it been possible to destructively clean all the pins measured for this paper, it could be expected that the results displayed in Figure 4 would deviate in a similar way. The pins from Domburg, probably by nature of being found on a beach, showed little patina, allowing the measurements to take place directly on the altered outer metallic surface. The pins from Sedgeford conversely had an even patina as commonly seen on most artefacts recovered from buried contexts. This difference would be expected to increase any deviation between the two datasets, but not to the extent that the alloy interpretation could be affected.

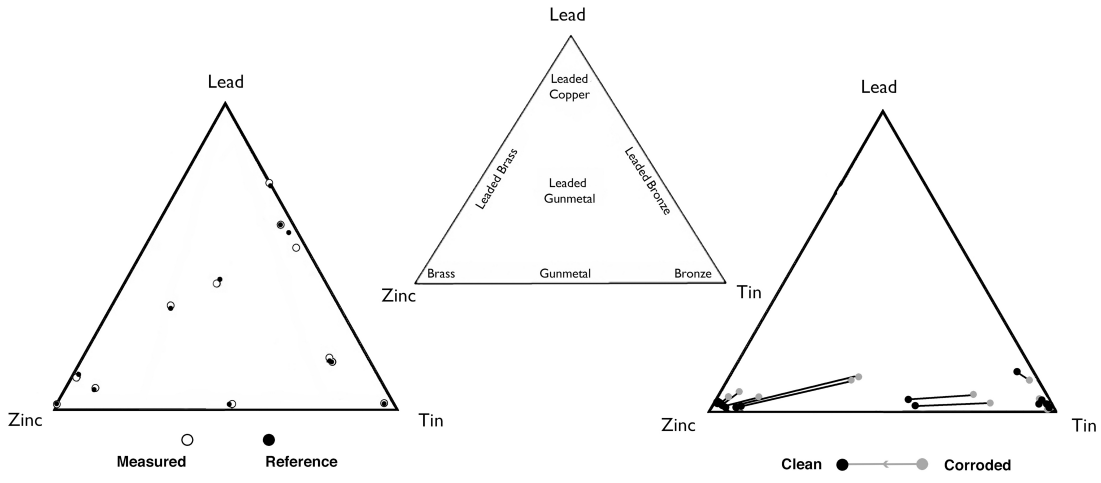


FIG 3

Ternary diagrams. Compositional classifications (after Bayley and Butcher, 2004, fig 7) in centre, measurement bias versus the CHARM heritage standard (left) and deviation in measurement due to corrosion (right). *Drawn by first author.*

These results are based on two groups of corroded objects, necessarily so to avoid destructive surface removal. The normalised results are presented in Table 2, their relative alloy groups are presented as ternary diagrams in Figure 4, and the interpretative classification (adjusted for the corrosion bias discussed earlier) is presented in Table 1.

TABLE 1
Results classified by alloy type.

Head Type	Alloy	Domburg	Sedgeford
Polyhedral	Brass	3	2
	Gunmetal	0	1
	Gunmetal (+Lead)	2	0
	Bronze (+Lead)	7	3
Biconical	Brass	1	1
	Brass (+Lead)	0	1
	Gunmetal	0	1
	Gunmetal (+Lead)	2	0
	Bronze (+Lead)	4	5
		Total 19	Total 14

TABLE 2
Finds ID, typological classification and normalised results. Description based on Rogers et al 2009.

Finds ID	Description	Cu %	Sn %	Pb %	Zn %
Domburg					
0032-107	Polyhedral	82.0	1.5	1.5	15.0
0032-108	Polyhedral	79.0	7.5	10.0	3.5
0032-109	Polyhedral	85.0	7.5	5.0	2.0
0032-110	Polyhedral	63.5	15.0	19.0	2.5
0032-111	Polyhedral	86.5	10.5	2.5	0.5
0032-112	Polyhedral	55.5	30.0	14.0	1.0
0032-114	Polyhedral	82.5	5.0	4.0	8.5
0032-115	Polyhedral	67.5	27.0	4.5	1.0
0032-117	Polyhedral	85.0	10.0	4.0	1.0
0032-94	Polyhedral	84.5	0.5	0.5	14.5
GA0112	Polyhedral	69.0	20.0	9.5	1.0
0032-119	Polyhedral	54.5	24.0	19.0	2.5
GA0115	Biconical	84.5	12.0	2.5	1.0
GA0111	Biconical	79.0	10.5	8.0	2.0
0032-84	Biconical	83.0	8.5	6.0	2.0
0032-120	Biconical	83.0	2.0	5.5	9.5
0032-123	Biconical	83.0	11.0	5.0	1.0
0032-118	Biconical	67.0	20.5	10.5	2.0
0032-122	Biconical	87.5	9.0	3.0	0.5
Sedgeford					
SH98 104	Polyhedral	82.0	9.0	3.5	6.5
SH99 1399	Polyhedral	90.0	0.0	1.5	8.5
SH02 933	Polyhedral	83.5	1.0	5.5	10.0
SH97 60	Polyhedral	49.0	30.0	21.0	0.0
SH97 14	Polyhedral	58.5	20.0	21.0	0.5
SH01 793	Polyhedral	52.5	32	15.0	0.5
SH97 6	Biconical	76.5	3.0	7.5	13.5
SH96 8	Biconical	71.0	1.5	15.5	12.0
SH99 347	Biconical	65.0	30.0	5.0	0.5
SH01 709	Biconical	45.0	16.0	38.0	1.5
SH09 3064	Biconical	53.5	17.0	29.5	0.0
SH97 4	Biconical	81.0	10.5	8.5	0.0
SH03 1173	Biconical	54.0	33.5	7.0	5.5
SH09 3042	Biconical	46.0	9.0	44.5	0.0

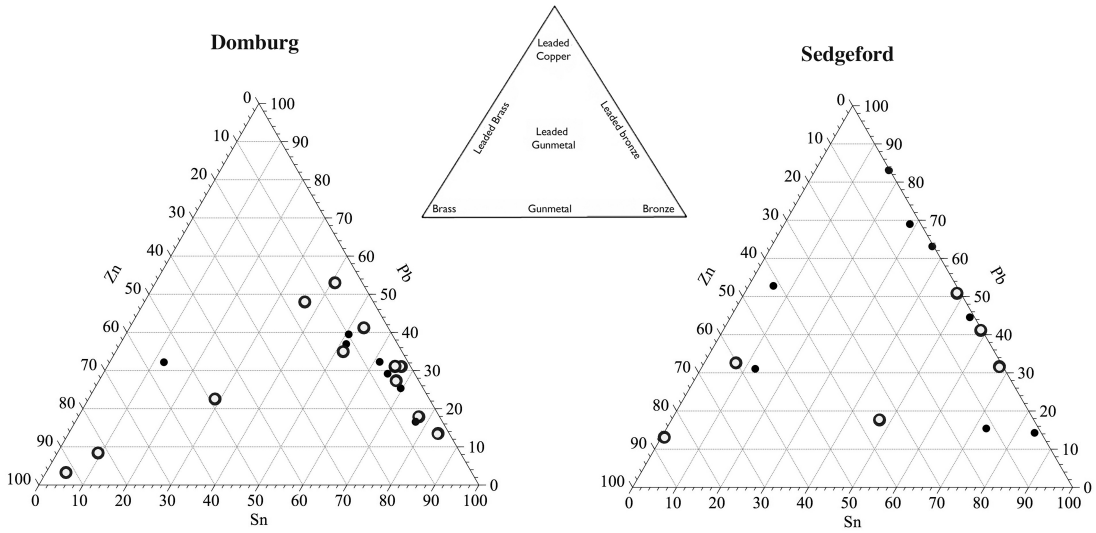


FIG 4
Ternary diagrams. Showing ratios of tin (Sn) to zinc (Zn) to lead (Pb) circles = polyhedral heads; dots = biconical heads.

DISCUSSION

The pins from the settlement at Sedgeford provide a closer geographic comparison for the previous alloy studies by Nigel Blades and Paul Wilthew, so we start the discussion here. All three alloy groups are present in this assemblage, with bronze being the most frequent choice, then brass, then gunmetal. Blades' analyses of the middle and late-Anglo-Saxon pin alloys found at Brandon, Ipswich, Lincoln and Beverley suggest that craftsmen had a preference for production in bronze, then brass, and lastly gunmetal. This preference in alloy choice matches, to some extent, the results for the pins from Sedgeford. The results published by Wilthew for Anglo-Saxon Hamwic are also comparable. Production in bronze was the most frequent choice, then brass, then gunmetal.

A comparison of alloy to head types on the Sedgeford pins failed to identify any correlation between the two. This is in line with Blades' observations, and to some extent those of Wilthew, whose results suggest that the production of some sub-types of polyhedral pins were restricted to brass. Unfortunately an inspection of the two polyhedral-head-types, produced in brass, from Sedgeford was inconclusive. The suggestion by David Haldenby and Julian Richards from the excavations at Cottam that polyhedral-head-types go out of fashion during the 9th century provide an opportunity to observe a chronological change in alloy use. Blades, however, found that there was little difference in alloy choice between the middle Anglo-Saxon and

late-Saxon periods, suggesting that the typological changes observed at Cottam, if comparable to other areas, are more likely to be independent of alloy choice.

A further suggestion made by Blades was that the lack of pins produced in gunmetal could be due to an availability of fresh metal supply being on hand for production, with the craftsmen selecting it in preference to recycled material. This could therefore be the case for the pins found at Sedgeford as bronze and brass are also the dominant alloys in the assemblage. Wilthew also suggested that there may have been a degree of deliberate compositional control, perhaps with manufacture being organised through a limited number of production centres that specialised in different pin forms. It could be argued that an avoidance of production in gunmetal, perhaps as a result of avoiding recycled material, is evidence of deliberate compositional control. To avoid this choice, craftsmen would have to have had regular access to a supply of fresh bronze or fresh brass, perhaps in the form of trade ingots. We assume that bronze ingots would have been made closer to the tin-mining areas in south-western England and then widely distributed. If we exclude recycled Roman brass due to a probable inconsistency of supply, making it unsuitable for mass production, then fresh brass would have entered England from the Continent, in ingot form via the North Sea trade network, perhaps through routine long-distance exchange similar to that suggested by Soren Sindbæk for Viking-Age bars/ingots (mentioned above). The main entry points for regular supplies of brass would most likely have been ports such as Ipswich and Hamwic, perhaps destined, along with bronze, for consumption at these growing craft centres. Verhulst's suggestion that craft production was concentrated around urban centres, abbeys and royal courts matches the view held by David Hinton, who also suggested that the large-scale production of pins, by a specialist workforce, was most likely centralised around markets, churches and other similar centres. If this model is applied to the results from Sedgeford, the pins found there were most likely produced at a larger centre, such as at Ipswich, and then distributed in quantity via smaller-scale markets, such as at Burnham on the northern Norfolk coast. The alternative hypothesis is that pin production was still quite localised, perhaps operating at small-scale markets, such as Burnham. Localised production may have been able to take better advantage of scrap metal recycling techniques in preference to sourcing fresh metal stock, especially overseas brass. As pins produced using scrap metal, in the form of gunmetal, is the most infrequent alloy choice observed here, it can be suggested that this is the least likely scenario.

The results from Domburg are similar in that the majority of the pins were produced in a bronze alloy with a much smaller group being made in brass. Unlike the bronze results from Sedgeford, the bronze measurements from Domburg in Figure 4 demonstrate the presence of a small amount of zinc. As outlined in the methodology section earlier, dezincification is a main contributor to the formation of the patina on a corroding copper-alloy surface. Therefore, it is very likely that the proportion of zinc in the Domburg pin group was originally higher, possibly in line with the corrosion diagram in Figure 3. This observation suggests that the craftspeople making the pins used a less pure bronze than that found at Sedgeford. Depending on how strict the

definition is applied in classifying the group, it could also be described as a tin-dominant gunmetal. If we assume that craft production, including the making of pins, took place at Domburg then its geographic position within the North Sea coastal area would have meant that it was in a strong position to engage in the trade or exchange of brass and bronze ingots. This slightly higher ratio of zinc could have entered at the ingot casting stage of the process, perhaps introduced through the recycling of a small amount of scrap into the mixture. Or it could have been through the deliberate addition of a small amount zinc-rich copper-alloy just prior to pin production itself. The deliberate addition of just a few percent of zinc to a bronze acts as a corrosion inhibitor, especially useful in saline coastal or maritime conditions such as those experienced at Domburg. However a low percentage of zinc could also be picked up from the residues left behind in crucibles in a busy production centre. The latter would imply a by-product of the process, rather than a conscious act however.

As at Sedgeford there is no indication that the craftsmen producing polyhedral or biconical-headed pins reserved a particular alloy for either head form. This result contrasts with the results for the small long 'Domburg'-type and Carolingian-period disc brooches mentioned earlier, whose alloys remained constant for a considerable time. That said, the 'Domburg'-type brooch was produced in a tin-rich gunmetal not dissimilar to the most common alloy choice for the pins. This could be because this alloy was a common local choice, reflecting metal availability in the region. If so, the presence of some pins in brass infers a different kind of organisation for production. The latter could well have been produced at Domburg, in brass, rather than the local alloy, but equally being small and highly portable they could be evidence of non-local production, perhaps at a site some distance away where production in brass was the norm. The richer, more gold-like colour of brass pins, perhaps imported from elsewhere, may have provided competition for locally produced pins made in duller bronzes and gunmetals.

CONCLUSION

Two similar groups of pins from both sides of the North Sea were analysed non-destructively by hhXRF. The aim was to qualitatively assess how closely craftsmen controlled the alloys in view of the argument for large-scale production starting in the 7th century. One group of pins came from the site of a suggested coastal emporia, at Domburg, the Netherlands and the other from a rural site on the Norfolk coast, England. The evidence for both groups was comparable to previous alloy research at other locations. Although a relatively smaller amount, the pin alloys from Sedgeford generally matched those measured at a number of other English sites. Bronze was the most common alloy, followed by brass, then by a smaller number produced in gunmetal. For Domburg the results were similar, but the bronze-alloy exhibited a small proportion of zinc within it that, whether added deliberately or not, would have had anticorrosion properties, especially useful in a coastal maritime setting. Unlike some types of Frankish brooches from the period, a single standard

alloy choice was not present. Ross' suggestion for mass production centralising around *wics*, churches and royal estates may well hold true as fresh metals were favoured over recycled material, implying a closer connection to the supply than that of a small rural settlement at Sedgeford, where more local metalworkers may have favoured using up scrap material first over more valuable fresh alloys. The results for Domburg also suggest that some pins may have been produced in a common local alloy, implying that pins made in brass were from a different production event, perhaps organised separately if produced at Domburg itself. Alternatively due to their small and highly portable nature, pins made in brass could easily have been made a considerable distance away, perhaps at a site where production in brass was the norm.

The study of medieval copper-alloys using hhXRF is still developing and its non-destructive process and fast throughput of objects allows for analysis of greater numbers of objects from more locations than ever before. It was in this context that the analysis took place and we view it as a basis for future, large-scale comparisons of copper-alloy artefacts recovered from the interconnected regions around the North Sea.

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Chapter 9

Conclusion

The purpose of the research presented in this thesis was firstly to explore the limits of HHpXRF use on corroded copper alloys, then secondly to develop a methodological approach using research questions that are relevant to archaeology. This was addressed in the methodology section presented in chapter 2. This methodology was then tested on a large number of Roman and early medieval personal objects dating between the 1st century BC and the 12th century AD. Subsequently a number of published case studies are presented (chapters 3 to 8) as examples of its effectiveness.

The aim of the project was to contribute to our understanding of Roman and early medieval craft organisation, through gaining a better understanding of the choices made in the production of copper-alloy personal items. More specifically the aim was to investigate variability in the control of copper-alloy composition, in particular the variation between bronze, brass or gunmetal, and to identify regional or chronological differences between groups of artefacts. Subsequently the intention was to gain new insights into the way production was organised, including the supply of raw materials, and to identify differing cultural associations through the choice of alloy.

This was achieved through the application of HHpXRF, deployed in the reconnaisance method described in chapter 2. The method was found to be able to sort objects into basic copper-alloy groups (bronzes, brasses, gunmetals, then also identifying high or low levels of lead). It also had some success in identifying objects that had been surface coated such as the disc brooches presented in chapter 4. This qualitative, semiquantitative method, enabled a better understanding of the choices being made in the production of copper-alloy personal items and therefore contributes to our understanding of Roman and early medieval craft organisation. Now that objects could be sorted by both typology and composition, over a given region and time, the level of variation, both within and across typological groups could be assessed. This assessment was central to the case studies presented in chapters 3 to 8. The results of these case studies demonstrated that a level of compositional control could be established for typological groups, allowing for an exploration of regional or chronological differences. Subsequently new insights into the way production was organised were uncovered. The investigation of the Roman period bow brooches presented in chapter 3 demonstrated that the transition from bronze to brass during the 1st century BC could be identified using the method, but importantly after this transition a number of brooch types were found to continue in bronze, in parallel with the new brass working tradition. This allowed new hypotheses to be formulated, exploring for example, differences between Roman military and local civilian production. Because brass and bronze have differing raw material sources, the direction in which fresh copper-alloy travelled allows discussion about contact

between the people of different regions. It is particularly useful in establishing what is common for an area in terms of alloy use at a given time. When this is established any variation in objects with a differing alloy choice can be explored. If both the typology and the alloy of an uncommonly found object is seen to match those more commonly found in a distant region, then it adds something to discussions regarding mobility. In this case the evidence supports the notion that the objects were made in that distant region and had travelled. Conversely if the alloy choice for this uncommon object was found to match that of locally produced objects, then local copying could be considered. This is kind of difference is particularly evident in the composition of the disc brooches discussed in chapters 5 and 7. The standard for the region was established as being zinc based, and it was only on the small island of Walcheren that deviation in this alloy choice was observed. This suggested that if disc brooches were made on the island, and not imported from elsewhere (possibly from a region outside the current research area), the production output, in particular the raw material exchange and technological knowledge, was different to that for the rest of the region. This difference could then be compared with other data (such as historical sources) to provide new hypotheses for why the difference is present. This included the formulation of different cultural associations, such as those presented for the Roman period disc brooches in chapter 4 and the Viking age mounts in chapter 6.

The answers to the research questions:

a) Was it possible to construct an interpretative framework for the use of HHpXRF on copper-alloy, particularly regarding the issues concerning its use on corroded artefacts?

The scientific objection to HHpXRF centred around the inability to produce highly accurate quantitative data on corroded copper-alloy surfaces. Furthermore objections were raised about the potential for misuse, by archaeologists lacking appropriate scientific training. Supporters of HHpXRF countered that it could be effectively used in a qualitative or semi quantitative way. That it was capable of basic alloy classification and therefore useful in answering certain archaeological questions. To address the objections of inapropriate use, a scientific methodology was called for that established reliability and validity. Importantly the nature of the analysis needed to be understood; be it qualitative or quantitative.

The method presented in chapter 2 addresses this problem. Its departure point argues for a qualititative and semi quantitative approach, but in doing so investigates the extent to which a non-destructive analysis of the corrosion layer can be used to classify copper-alloy artefacts. A reliable level of accuracy and precision for XRF had already been established elsewhere, but the degradation of copper-alloys and the subsequent formation of a corrosion layer, needed better understanding. To achieve this a group of early Roman brooch fragments were measured in a corroded then cleaned state. This tested the deviation in results between the two states, which was

neccessary if interpretations regarding alloy choice were to be made on large numbers of corroded objects. This test was critical if the aims of the project were to be achieved. Steps were also taken to address the objections surrounding inapropriate use.

The methodology adresses the issues regarding lack of 'scientific' approach, by demonstrating an understanding of the instruments parameters and settings. It also provides a basis for experimental reproduction by other machines and also allows comparison with other published datasets. To achieve this the method recommends the inclusion of a detailed account of the HHpXRF device being used when publishing results. Including details of its internal callibration standards and specific operating geometry. Furthermore the performance of the device would ideally be tested against the CHARM reference set and the results also reported, to further aid comparison to other machines and datasets. The tests on the Roman brooch fragments showed satisfactory levels of accuracy and precision albeit under more ideal analytical conditions. The lack of sample preparation and non-ideal measurement conditions on corroded brooches did not prevent a broad recognition of different alloy groups. An intermachine comparison was also conducted in chapter 4. A Bruker machine was used for the analysis and deployed in a 'off the shelf' capacity. Comparison between the Bruker and Niton devices was undertaken using a set of locally made standards. This linked the two machines together even though only one had been linked to the CHARM standard. In addition, measurements took place on objects from three quite different regions (The Netherlands, the east coast of England and the cremation cemeteries of Estonia and Northern Latvia) to investigate if different preservation conditions would significantly alter the measurements. It was established that the measurements taken by the Bruker device could be compared to data published elsewhere, as well as that gathered in The Netherlands and England using the Niton device. It was found that the overall error for the elements of interest, for both machines, was well within the limits needed to achieve the projects research aims.

b) What compositional variation is there in large numbers of similar copper-alloy objects?

Variation in composition could be seen when analysing large numbers of corroded items. But the data produced this way requires an interpretive step to be of use, due to the bias introduced by corrosion. The normalised data, especially when visualised in ternary diagrams frequently showed a strong correlation to artefact type. This allowed for classifications to be made along the lines of brass, bronze, gunmetal, with high or low levels of additional lead. To attempt to interpret the data coming straight from a corroded surface is highly misleading. This is because the bias introduced by the leeching of zinc from corroded outer surfaces has the effect of artificially enriching the tin values. Specifically, the tin levels are magnified in the resulting data. This means for example that a group of very similar objects may have all been made in brass, but the results show a more randomised pattern due to the variability casued by

zinc loss. This means that some of the results could inadvertantly be misinterpreted as gunmetal because of the tin enrichment. An amount of correction needs to be applied therefore, in line with the results of the corrosion tests presented in chapter 2. Generally the measurements from these objects can still be interpreted as being produced from a bronze, brass or gunmetal alloy. There are some object types however that do not demonstrate controlled composition, such as the disc brooches found in Estonia and Northern Latvia. One interpretation is that these objects were surface treated, e.g. coated in tin to change the colour. These thin surface treatments would be the first to decay during the corrosion process, possibly creating a patchy, inhomogeneous result. The presence of a decayed surface treatment in this case prevents the deeper exploration of the main alloy composition. That said, identifying deliberate surface treatments, is as worthwhile as identifying controlled alloy groups in terms of producton choices, especially when considering the highly visual nature of personal costume accessories.

c) Is there evidence for deliberate control of copper-alloy composition (perhaps between different types of objects)?

The assumption from the outset was that groups of closely related objects might have been made in the same or very similar alloy. That is to say that a choice was made to make an object either in brass, bronze, or gunmetal. Deliberate control was observed from the outset, starting with the introduction of brass in the production of early Roman period brooches. Certain brooches, which have been traditionally associated with the Roman military, were consistently produced in brass. Other brooch types conversely were made in bronze. Both brass and bronze existed as a readily available choice in the early Roman world, at least until the widespread change to production in bronze and gunmetal towards the end of the 1st century AD. For some brooch types however, such as the Gallic bow on Spring-tube type presented in chapter 3 and the later Roman period disc brooches presented in chapter 4, the opposite appeared to be true. The highly variable results suggested that the craftsmen did not care about the alloy choice for these items, or that they were solely produced using highly variable recycled scrap, which if the case was a different form of deliberate control, avoiding fresh raw material. The other hypothesis was that a tin based surface treatment had broken down within the corrosion layer masking the underlying copper-alloy. The identification of a surface treatment however could also arguably be evidence for deliberate control as it is a deliberate technical choice, reserved for these brooch types, possibly intended to change or enhance their colour.

The reduced use of gunmetal (probably made by recycling scrap objects) in the pins found at Sedgeford and Domburg, can also be seen as evidence for deliberate compositional control. This is because the craftsmen would have needed regular access to fresh bronze and fresh brass to avoid widespread use of recycled material. This fresh material probably took the form of trade ingots, and as zinc (for brass) was not mined in England, yet tin (for bronze) was, ideas could be formulated regarding

their movement within a North sea trade network and the organisation behind their production.

d) Is there evidence for chronological change in alloy use from the early Roman period to the beginning of the Middle Ages (1st century BC - 12th century AD)?

A relationship between alloy choice and typology was established using the methodology presented in chapter 2. Typology forms an important dating tool in archaeology and subsequently allowed the assemblages to be studied for chronological variation. The clearest variation was the widespread introduction and subsequent control of brass in the early Roman period. But brass use was seen to exist in parallel with bronze use for a number of centuries, until a general change to gunmetal took place during the later Roman period. There is a widespread revival in brass use during the Carolingian period, at a time when gunmetal and bronze was also available. These long-term chronological changes were identified by the HHpXRF methodology.

e) Can regional differences in composition be seen (perhaps eluding to the availability or otherwise of raw materials)?

Typology is an equally useful tool for studying regional differences as well, especially when linked to alloy choice. This study identified different alloy choices between the brooches found on the island of Walcheren, Frisia and the rest of The Netherlands. The Carolingian/Ottonian period disc brooches found on Walcheren showed a significantly wider range of alloy choice than that for those found in the rest of The Netherlands. A difference was also apparent when the equal-arm brooches were analysed. Those found in Frisia are typically of a leaded brass, but those found on Walcheren were typically produced in gunmetal and bronze. This last example could have had a chronological aspect as well as regional one, but the current dates for the typologies suggest that some of the equal-arm forms existed alongside each other, but were consistently produced in differering alloys. HHpXRF was also involved in revealing regional differences in Estonian and Northern Latvian disc brooches, supporting the identification of different surface treatments.

f) What are the potential supply lines for the sources of raw materials?

The results for the early Roman brooches (chapter 3) identified two parallel production traditions existing at the same time. Some brooch types were produced in bronze and other types were produced in brass. This allowed an hypothesis to be formed regarding two different supply lines. One being a local civilian one, using bronze, perhaps following pre-Roman alloy traditions, where the tin (possibly in the form of bronze ingots) was imported from England. The second was a new tradition using brass (with the zinc possibly coming from La Calamine in the Ardennes, Belgium), possibly being reserved initially to Roman military centres.

For the early medieval period, the regional differences between the equal-arm brooches found at Walcheren and the northern Frisian areas, also allows discussion regarding raw material supply. The equal-arm types found on Walcheren have a find distribution pattern that places them well within the Frankish realm. But the research identified that some were made in bronze, not in brass, which presumably would have been available locally at the same time. In contrast, the equal-arm brooches from the Frisian north are made in brass. As in Roman times, the closest source of zinc at this time is thought to be the Ardennes region of Belgium. But if correct this means that Frankish production of the Walcheren brooches (if they were indeed made locally) ignored the local brass, raw material supply, in favour of bronze (using tin presumably imported from England). Conversely the production of the brass made brooches found in the Frisian north, suggests a different raw material source, perhaps one more closely connected to the Viking world. Alternatively, Frankish brass production could have solely been reserved for export to the north. Brass was also linked to the Viking north through the analysis of the zoomorphic mounts found on Walcheren (chapter 6). Apart from the zoomorphic decoration having strong cultural associations with the Viking age North Sea world, they were made in brass. The same goes for the equestrian stirrup-strap mounts from the same period (chapter 7), also bearing similar decoration. Two supply lines are visible therefore. Tin, possibly in the form of bronze ingots would have come from England and zinc in the form of brass ingots could either have come from the Ardennes region, or much further afield through the Viking sphere of influence. The discussion regarding the raw material supply for the pins found in Britain (chapter 8) demonstrate the usefullness of knowing which alloy an object is made of. No zinc is mined in Britain, therefore all brass in the form of fresh raw material would have to have been imported. These small personal costume items, when made in brass, must have been made from imported raw material, or possibly imported as ready-made objects in their own right.

g) To what extent can compositional variation, across geographical and temporal distributions, allow new insights into the social organisation of production, or the identity of those wearing the finished objects?

Many hundreds of costume accessories analysed in this project may have frequently travelled on the clothes of their owners. When an individual object, or a type of accessory is found some distance from it's believed place of origin, then discussions surrounding mobility or migration frequently take place. The prime purpose of the method proposed here is not to identify unusual objects from a typological perspective. It identifies them from an alloy perspective. This was the case for a number of early medieval disc brooches found on the island of Walcheren (chapter 7), where the typology of the objects matched the rest of the region, but the alloy did not. But costume accessories could well have been involved in more complicated expressions of identity as well. Pilgrims or other travellers, when returning to their homelands, might have brought souvenirs back with them, perhaps as "returning gifts" for friends and family, which when worn could change a persons status. This

idea is expanded upon in chapter 5, where these early medieval disc brooches are discussed against the hypothesis of monastic production and ecclesiastic distribution. This discussion was made possible because of the consistant use of the same alloy (as identified by the HHpXRF), for several centuries, could well have been made possible through control based on long term monastic tradition. Linking these brooches to monastic production subsequently allowed for discussions regarding exchange between the church and the peasantry, one where these brooches may have been imbued with 'cosmological authentication' in a similar way that pilgrim badges did a few centuries later.

The method also enabled identity discussions surrounding local versus regional production. The high concentration of unusual zoomorphic mounts found on the island of Walcheren (chapter 6), suggested local production. The decoration on the mounts and the alloy used, allowed an expression of identity to be formulated, for a cultural group, based on intensive relations between Franks, Frisians, Vikings and Anglo-Saxons, in an interconnected North Sea world.

It was possible therefore to construct an interpretative framework for HHpXRF use on copper-alloy, taking into account surface interaction and corrosion. The relationship between form and bulk alloy composition could be explored and the results applied to the archaeological questions formulated for the project. The conclusion is that this interpretive framework enables basic alloy classifications to be formulated for typological groups and is therefore useful in answering certain archaeological questions.

Limitations of the study

From the outset there were two key objections to this line of investigation. Firstly that the approach was not quantitative therefore should not be undertaken in the first place. Secondly that the ease of access that HHpXRF provided to the archaeological community would lead to misinterpretation and misuse by poorly trained and or inexperienced users. Addressing these issues formed an important part of this thesis. Firstly if we accept the argument regarding quantitative analysis, that it is the only acceptable scientific route for data gathering, then the methodology presented above fails. The critical stumbling block to fully quantitative analysis (excluding differences in costs) is the need to take destructive samples, which is usually only possible from a very limited number of archaeological objects. The departure point for the qualitative, semi quantitative method presented above is that non-destructive analysis is prefered if we are to conserve this stock of objects for future generations. The key issue is how or indeed if we should infer any useful archaeological meaning from the corroded outer surfaces of these objects. The methodology presented here limits itself to data recovered from these corroded outer surfaces and will always be substantially

different to data recovered by sampling an objects core. Therefore the corroded data as its stands is not suitable for answering traditional archaeological questions. The study found no meaningful correlations for trace elements for example (other than the presence or absence of mercury, used with gold as part of a deliberate surface treatment) and has to limit itself to the study of the bulk metals used in production. The methodology only works because an interpretive jump is required to classify the alloys from corroded data to original choice. This interpretation is possible thanks to the deviation study conducted between clean and corroded surfaces, identifying a systematic trend in copper and zinc loss during the corrosion process. It is therefore at risk of subjective observer error and therefore as it stands cannot satisfy the scientific objections posed earlier. This issue also applies to the second objection, that operators can easily misuse or misinterpret the data. The biggest risk in the application of HHpXRF by untrained or inexperienced archaeologists is the mistaken belief that the measurements obtained are quantitative, i.e. that they are a 'true' measurement of the items original composition. This is particularly true if a mesurement is taken on one single object with the notion of gaining a "correct"value of its composition. The methodology has been shown to work in identifying trends for groups of objects, not for gaining reliable single alloy measurements in isolation. Therefore a misinterpretation of the alloy composition is a very real risk in this circumstance. The risk is doubled in this scenario by the mistaken belief that whole objects, or patches on the objects (lacking a corroded outer patina, perhaps where it has been chemically removed in the conservation process), can yield a similar result to a measurement taken from a clean core sample. This is not the case as this "shiny" outer surface deviates further from this 'true' measurement than the corroded patina. This is because the outer surface has also been significantly altered, by the leeching of copper and zinc. A related objection regarding misinterpretation was that inexperienced operators would take the internal data being produced by a single machine and consider it to be comparable (and therefore replicable) to other studies, without the need for referencing against external standards. The methodology developed in this thesis and published in the article presented in chapter 2 goes someway to address these issues. The methodology provides a basic guide, or protocol for other HHpXRF users. It warns of the issues just mentioned and also provides a useful callibration reference through its link to the CHARM standards. Even though this methodology is published however, there is no guarrantee that all users of HHpXRF will adopt it in their research. Ultimately therefore Speakman and Shackley's call for the peer reviewers of all HHpXRF based manuscripts, to seriously scrutinise them for invalid and unreliable data, holds true.

The range of artefact types presented in this thesis is quite limited, in comparison to the much larger number of copper-alloy object types known from these periods. This was primarily due to the need to gather large number of measurements on objects from the same typological groups. It was not intended to provide an exaustive typological/chronological survey of the Roman and Medieval periods, so brooches in particular were good candidates to study. This is because they are found in large quantities and are supported by pre-published typological and chronological

reference data.

The limited case studies, presented in this thesis serve to highlight the effectiveness of the methodology, but in doing so leave large typological and chronological gaps. Some of these gaps have been addressed in publications elsewhere, (See Roxburgh *et al.* 2014, Roxburgh *et al*. 2017). Brooches have been extensively published for the Roman period, but other important artefact types are missing and also need analysing (e.g. coins, bracelets, finger rings, neck rings, items of miliary gear). It is not enough to use the alloy choices identified in Roman brooches as a proxy for raw material availability for other personal dress items. For example it is not yet clear if all objects relating to the military or military centres were made in brass, or conversely those from outlying civilian centres relied more heavily on older bronze making traditions or the recycling of mixed scrap items into gunmetal. Coins in particular have been left out. This was primarily due to the frequent use of surface enrichment or coating employed in their production. Also coins are not often used in identity construction, therefore they are a less useful than brooches for example. A useful HHpXRF survey of Carolingian coins using die chain analysis has recently been undertaken elsewhere however (Buis 2016). The subject of surface enrichment or treatment is quite an important one and is touched on briefly in the disc brooch article in chapter 4. The surfaces of corroded objects that have had a treatment, such as tinning, silvering or guilding, are much more variable in their composition, due to the fragmentary remains of these external treatments being trapped so to speak in the corrosion layer. The presence of tin from a coating for example is especially problematic because it would cause the results of an HHpXRF measurement to be tin rich, suggesting that the alloy of the object itself was a bronze or a gunmetal, when in fact the underlying alloy could easily be a brass. The presence of silver or gold could equally lead to misleading surface measurements. This becomes problematical when attempting to analyse some important object types from the Merovingian period for example (The main reason why Merovingian period artefacts, and especially brooches are under-represented in this thesis). Visual inspection revealed that from the late Roman period onwards many brooch types showed traces of surface treatment. Several Merovingian types in particular appear to have been consistently surface treated, including radiate head, square head, bird, garnet inlaid disc and S-shaped brooches (see Heeren and van der Feijst 2017, types 81, 82, 83, 84, 85 respectively). These types frequently occur in furnished burials from this period. Whilst these brooch types are available in large enough numbers to be included in the project, the variation introduced by corroded surface treatments put them beyond the methodological limit for establishing alloy choice and therefore engaging with the debate surrounding workshop organisation, changes in raw material supply and cultural association. That said, establishing regional or chronological patterns in external colouring, as discovered for the disc brooches in chapter 4, is also of archaeological interest but is a line of enquiry that is not continued here.

If the quantitative objection is firstly ignored in favour of the development of a non-destructive qualitative method, the limits outlined above still highlight the risks posed by the misuse or misunderstanding of HHpXRF by inexperienced

archaeologists. That said the method is effective in answering some very relevant archaeological questions.

A course of action and useful areas of further research

All of these limitations would initially seem to support the objections posed earlier. However like any emerging technology further steps are neccessary to improve its effectiveness. These steps include the development of better machine performance in relation to more readily available external callibration standards. This study would not have been possible without the destructive testing of the fragments of early Roman brooches to establish the deviation between corroded and clean measurements. Knowing how the results deviate is critical in making the interpretive step that assigns an alloy classification to a group of objects. A larger data set, including objects taken from a wider timespan (late Roman for example), especially including items with higher lead content, would further strengthen the interpretive step. But what would be much more effective would be to develop a statistical regression model or similar that removed the interpretive step completely. A return to the Nijmegen assemblage from which the original fragments were selected would be the first course of action, to establish if more objects could be released for destructive testing. Then other large assemblages might be sought from which fragments could be gathered. But whichever the source, the destructive cleaning of artefacts, even fragments cannot be casually undertaken, the end use of the data would have to be clear and permission would need to be granted from the owners and/or curators.

A further avenue of investigation would be to gain a better understanding of the corroded remains of surface treatments. A visual inspection of an item, especially of an artefact type known to have been tinned, silvered or gilded, can frequently identify patches of this outer colouring amongst the corroded patina. But many artefacts do not offer up this secret so readily. But there are most likely chemical clues left behind in the patina that HHpXRF can unlock. Unusually high levels of tin, silver, gold and mercury for example, measured on what would usually be considered a featureless (corroded) surface, may indicate a surface treatment that had worn off, or that has become lost in the corrosion phenomena. The development of HHpXRF in this direction would allow further exploration of metalic colour choices, used in past identity constructions.

The systematic "fingerprinting" of assemblages from both settlement and cemetery sites can now also be considered. That is the amount of objects produced in varying alloy types, perhaps expressed as a percentage of the overall assemblage, may be of great archaeological use. This additional way of exploring the material culture would allow for inter site comparisons to be made, similar perhaps to that made between the assemblage on Walcheren and the rest of The Netherlands, but on a much more intensive scale. Cemetery sites could be "fingerprinted" in the same way, so that geographical and chronological variation in alloy choice can be explored, adding a

useful tool in understanding how cemeteries were organised if distinctly different alloy groups are found to be present amongst the grave goods. Furthermore, the organisation of the alloys in a cemetery, are closely related to the deceased individuals buried there. As we have seen in the previous chapters, a link between typology, alloy choice and surface colour can infer something about the lives of the people buried there, especially if used in conjunction with other avenues of investigation such as those within the field of Osteology. Does HHpXRF have a future then? Yes it does. It is very much an emerging tool for the study of a range of artefacts, including corroded copper-alloys. The methodology needs refining and developing further but the potential for answering important archaeological questions is high, as has hopefully been demonstrated in this thesis.

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Summary

This thesis, presents six peer reviewed articles and an editor reviewed book chapter that discus the relationship between the composition and typology of a large number of brooches and other personal items, dating between the end of the Iron-Age and the end of the early middle ages. The main study area is The Netherlands, but for comparative purposes, objects are also drawn from the Baltic states of Estonia and Latvia, and also from the east coast of England. The compositional focus explores the use of portable X-ray fluorescence spectrometry (HHpXRF) as a surface measurement tool, on corroded objects. This socially embedded approach explores the relationship through the intentional actions of the crafts people who made them. This approach is more meaningful than traditional provenance studies because it explores the socio-technological context of production. As well as identifying indicators for social complexity and economic change, personal artefacts from this period also play a role in the study of human mobility and identity construction.

The research engages with the important debate surrounding the transformation of the western Roman world into the modern nation states we know today. The processes that led to the medieval 'recovery' in the west cannot be fully understood without a better understanding of the role of craft production during this time. The more specific aim is to investigate variability in the control of composition and to identify regional or chronological differences. Subsequently the intention is to gain new insights into the way production was organised, including the supply of raw materials, then to identify differing cultural associations through these differing choices of alloy. The primary research goal is to analyse the degree of variability (or standardisation) of the ratios of base metals used in production, which will shed light on both technical and raw material choices. The social organisation of production and the various (exchange) mechanisms that resulted in the artefact distribution patterns we see today are also explored.

Subsequently a number of research questions were formulated, starting by addressing the traditional problems associated with the use of HHpXRF in the study of corroded objects, to establish a valid methodological approach. Then questions could be asked concerning the nature of compositional and chronological variation, seen in the measurement of large numbers of artefacts. Questions surrounding the evidence for deliberate compositional control, pertaining to regional differences and the sourcing of raw materials, are then posed. Lastly where compositional variation across geographical and temporal distributions exists, questions are formulated regarding the social organisation of production, and the identity of those wearing the finished objects.

Brooches (also known as fibulae) are the main artefact type analysed in this study. They were used extensively by ancient communities during the Roman and early medieval periods with their forms and types changing significantly over time and geographic region. Roman period bow brooches are included from The Netherlands, dating between the last half of the first century BC to the late second century AD. Then an assemblage of middle to late Roman period disc brooches from

the eastern Baltic, dating between the 2nd and 5th centuries is also included. For the early bow brooches, the main question is whether regional, or civilian production could be identified versus production at military centres. A 'Roman' alloy if it existed could be compared to alloys more confined to local or 'tribal' typologies. The questions asked of the later Roman disc brooches relate to the organisation of production and variation in regional culture, engaging in particular with the debate over the nature of long distance contact with Lithuania and the distant Roman provinces. The next group of brooches are early medieval in date, returning once again to The Netherlands. A great many Carolingian/Ottonian period disc brooches bear what are thought to be Christian motifs and were mostly popular during the late 8th to 10th centuries, but with a few types staying in use as late as the 11th to 12th centuries. The earliest type of brooch included in the study is the Saints brooch, popular during the 9th century. But the bulk of the brooches are of the enamelled cross type dating between the 9th and 10th centuries. The organisation of production is considered once more then the exchange system in which they circulated is explored with particular emphasis on the Christian nature of their motifs. Both disc and equal-arm brooches (dating between the 7th to 10th centuries) from the island of Walcheren are then explored regionally, in comparison to those found from other areas of The Netherlands. Hypotheses regarding the organisation of production are then proposed against Walcheren's historical past. This in turn leads to discussions surrounding cultural identity within an interconnected North Sea world. For the equal-arm brooches an earlier hypothesis is tested; that the more northerly Fresian brooches are regionally different to those from those found at Walcheren.

The next type of artefact to be included is a group of zoomorphic mounts tentatively dated between the 9th and 11th centuries. The origin, their original function and their relationship in terms of expressions of identity are subsequently discussed in detail. A number of Stirrup-strap mounts were also found on Walcheren and are considered to have an equestrian function. The subsequent analysis enables a discussion to take place regarding local versus non-local origins. The choice of alloy could also be compared with the other find types in the study. Ring and dress pins are presented last, but additionally with a more detailed comparison to a similar assemblage from 2009. The Walcheren examples above are thought to date from the 7th to 11th centuries. A discussion takes place regarding mercantile contact between the two coastlines as well as local or centralised production in an interconnected North Sea world.

The approach selected for the compositional analysis is a very important part of this thesis and is discussed in some detail. There is a particular focus on the published debate surrounding the reliability and validity of HHpXRF use in archaeology, as it is still causing objection from some parts of the scientific community. The main objection is that highly accurate quantitative data is not obtainable from the measurement of corroded copper-alloy surfaces. Furthermore that gaining a 'true' measurement (by the destructive removal of the patina) of an objects composition is key to solving archaeological questions. The second objection was that the technology was being misused, that it was not appropriate for archaeologists to

just simply purchase an HHpXRF machine and go out and measure anything they wanted, without having adequate training or years of experience behind them. This debate has subsequently led to a divided community with one side believing that it is an unnaceptable side of science, and the other calling for a break away from limited laboratory based paradigms so that appropriate methodologies can be applied to archaeological use. Past studies (elsewhere) have demonstrated that it is not possible to achieve highly accurate quantitative data on corroded copper-alloy surfaces, but an alternative qualitative route has been proposed, that these devices are suitable analytical tools to sort objects into classifications, therefore able to answer questions regarding the basic choices made in terms of copper-alloy production (e.g. brass or bronze).

To address the second issue that inexperienced archaeologists can just pick up these devices and misinterpret the data (e.g by mistakenly interpreting qualitative corroded measurements as quantitative 'true' measurements), a protocol is called for, one that includes experimental reproduceabilty based on appropriate scientific standards. This call for a protocol is subsequently addressed in the methodology article presented in chapter 2. This article argues that HHpXRF is a suitable measurement technique to study the production of ancient copper-alloy artefacts. Rather than try to match techniques developed within laboratory paradigms, it suggests that it is more beneficial to deploy it in a survey role, one that attempts to model chronological and geographical changes within large quantities of artefacts. To achieve this, it investigates to what extent corrosion and the issues surrounding surface measurements affect the potential of this approach. A combined typological/compositional analysis of early Roman period brooches from the Nijmegen region of the Netherlands was compared with published data.

Following on, chapters 3 to 8 present the results of a series of case studies employing the approach developed in chapter 2. These articles not only engage with the debate, but also demonstrate appropriate lines of archaeological questioning and offer some intriguing new insights into the organisation behind ancient copper-alloy craft production. Chapters 3 and 4 present research on early and late Roman brooches respectively. For comparative reasons they take their measurements from brooches found in two seperate geographic regions (The Netherlands and Estonia/Latvia), from two HHpXRF machines, and from two different manufacturers (Niton and Bruker). Chapter 3 identifies a shift away from bronze to brass between pre-Roman and early Roman bow brooch types. This allows for discussions to take place regarding the appearance and use of brass in military camps and civilian centres. The hypothesis of Roman military production fits well with notions of Roman industrialisation, but bronze also continues to be used for some brooch types as well. Various hypotheses are put forward, firstly that the craftsmen had a high degree of control over the alloy choice, secondly that the choice of alloy relates to the mode of production, i.e. that if choice was not just determined by the production method, it could be that civilian workshops maintained their production in bronze, whilst brass was reserved for production in the military centres. Chapter 4 moves location to the eastern Baltic to explore the typological and compositional relationships between middle to late

Roman period disc brooches. Regionality was explored together with the nature of contact and influence from other areas. The alloy composition was also compared with published results from other countries leading to the conclusion that the choice for these brooches was not as strictly controlled as that for the bow brooches of the previous chapter. Alternatively the HHpXRF analysis combined with visual inspection revealed evidence for tinning, a sivery coloured surface treatment, which may also have influenced the compositional results. The combined analysis contributed to the identification of two regionally distinctive groups. The brooches from one area were found to be silvery in appearance (created by a surface treatment). The brooches from the other area were golden coloured (by leaving them untreated).

Chapter 5 then returns to The Netherlands to explore the typological and compositional relationship of Carolingian/Ottonian period disc brooches. Several aspects of production and exchange are examined. The compositional results show a marked change in alloy use from the end of the Merovingian period. They also revealed a high degree of alloy consistency allowing hypotheses to be formed that production may have been organised on a regional or super-regional scale. The most likely source for these items was the great monastic estates, perhaps creating long lasting production traditions capable of applying a high degree of control over several centuries. This hypothesis when supported by the Christian nature of the motifs on these brooches also enabled discussions surrounding an exchange system imbued with Christian meaning, one where the brooches served to reinforce the social heirarchy between the ecclesiastical elite and the ordinary individual.

The next three chapters concentrate in detail on one particular assemblage, the early medieval artefacts found on Walcheren, The Netherlands. The artefact types include disc fibulae, equal arm fibulae, dress pins, ring pins, stirrup-strap mounts, and zoomorphic mounts. A detailed study of zoomorphic mounts is considered first in chapter 6. The results shed light on the character of the technology of the time and also allow a new hypothesis to be formulated regarding their purpose and cultural associations within a Viking-Age, North Sea world. Although exact dating remains elusive, the styles suggest that close ties existed between the Frisian, Viking and Anglo-Scandinavian worlds between the 9th and 11th centuries. Chapter 7 considers the wider assemblage found in Walcheren and is published as an editor reviewed book chapter. The results suggested that copper-alloy crafting on Walcheren was probably organised along the lines of a permanently administered urban production site, with items being made for market. Differences in local versus traded items are also discussed, followed by a hypothesis being put forward proposing the existence of a multicultural group of inhabitants drawn together by the presence of an inter-regional trading site. Lastly, Chapter 8 draws a comparison between the dress pins found in proximity to the coastal town of Domburg on Walcheren and those found at a comparable coastal site in England. Pins such as these are found in large quantities on both sides of the North Sea, therefore the nature of cross-cultural contact is explored in terms of style, composition and manufacture. Our results suggest that pin production may have been focused around major mercantile, ecclesiastical or royal centres, but also that it was also localised in terms of production methods and material

supply, the latter favouring more accessible scrap metal for production than the former more centralised locations where access to fresh metals would be easier.

Samenvatting

Over de Fabricae van Augustus en de Ateliers van Karel de Grote
Een compositionele studie van gecorrodeerde artefacten van koperlegering aan de hand van hand-held portable XRF

Dit proefschrift onderzoekt Romeinse en Vroeg-Middeleeuwse productie van koperen kledingaccessoires aan de hand van een gecombineerde typologische en chemische analyse van deze objecten. Het bestudeerde materiaal beslaat met name uit vondsten uit Nederland, ter vergelijking worden er ook objecten uit Estland, Letland en Oost Engeland bij betrokken. Het chemische onderzoek naar de objecten maakt gebruik van de draagbare X-ray Fluorescence Spectrometry (HHpXRF) methode met oppervlakte metingen van objecten van de gecorrodeerde koperlegeringen.

Dit proefschrift bestaat uit 6 peer-reviewed artikelen en een artikel uit een samengesteld boek. Hierin wordt de relatie tussen chemische samenstelling van een groot aantal objecten en hun typologie bediscussieerd. De bestudeerde objecten dateren van de late IJzertijd tot het einde van de vroege Middeleeuwen. In alle artikelen staat de socio-technologische context van de productie van deze objecten centraal. Deze kledingaccessoires worden gezien als indicatoren van sociale complexiteit en economische ontwikkelingen aan de hand waarvan een overkoepelend beeld wordt gevormd van menselijke mobiliteit in identiteitsvorming.

Het onderzoek is binnen de discussie over de transformatie van de Romeinse wereld te plaatsen. Dit proces van verandering kan niet volledig worden begrepen zonder de rol van productie daarin in detail te onderzoeken. De specifieke doelstelling van dit proefschrift is het achterhalen van variabiliteit in de chemische en stilistische samenstelling van objecten waarbij regionale en chronologische verschillen worden vastgesteld. De organisatie van productie is bestudeerd aan de hand van de context specifieke keuze van koperlegering, waarbij ook rekening is gehouden met rol van de aanvoer van grondstoffen. Het voornaamste doel van dit onderzoek is de analyse van de variabiliteit (of standaardisatie) in de ratio's van de gebruikelijke basis metalen. Dit zal inzichten creëren over de keuzes binnen het technische proces en de keuze van grondstoffen. Ook zal objectverspreiding, welke het resultaat is van de sociale organisatie van productie en de verschillende uitwisselingsmechanismen, worden geanalyseerd.

De onderzoeksvragen van dit onderzoek hebben ook betrekking op het methodologisch vlak. Een verantwoording voor het gebruik van de HHpXRF methode voor het bestuderen van gecorrodeerde koperen objecten en een discussie van de problemen die daarmee geassocieerd worden is opgenomen in dit proefschrift.

Daarnaast beslaan de vragen de variatie in samenstelling van de objecten, de chronologische en regionale ontwikkelingen hierin en ten slotte de sociale organisatie van productie en de identiteit van degenen die gebruik maakten van de objecten.

Fibulae vormen het grootste deel van de objecten die in deze studie zijn geanalyseerd. Deze objecten zijn massaal gebruikt in Romeinse en vroegmiddeleeuwse perioden waarbij de vorm en types veel verschillen per tijdsperiode en regio. De objecten uit de Romeinse tijd zijn fibulae welke dateren van het tweede deel van de eerste eeuw voor Christus, tot de tweede eeuw na Christus. Daarbij wordt een assemblage van laat Romeinse, tweede- tot vijfde-eeuwse, schijffibulae uit het Oost Baltische gebied gevoegd. Voor deze vroege groep fibulae is de vraag of deze in regionale, lokale productie zijn gemaakt of in militaire centra. Interesse ging uit naar het vergelijken van een eventueel 'Romeinse' legering met die van lokale, tribale typologieën. Bij de late groep schijffibulae staan de vragen over productie organisatie en variatie in lokale cultuur in het licht van het grotere debat over de organisatie van het contact tussen de Oost Baltische gebieden en de Romeinse provincies.

De volgende groep van fibulae is een vroegmiddeleeuwse verzameling uit Nederland. Veel van de Karolingische en Ottoonse fibulae laten Christelijke motieven zien welke populair waren tussen de late achtste en de tiende eeuw. Een enkele fibulae dateert echter ook tot in de elfde en twaalfde eeuw. De vroegst daterende fibulae uit deze selectie is 9e-eeuws, de Heiligen fibula. De meeste fibulae zijn echter kruisvormige geëmailleerde exemplaren daterende tussen de negende en tiende eeuw. De organisatie van de productie is ook hier van interesse waarbij de rol van de Christelijke motieven voor de uitwisselingsmechanismen extra aandacht krijgt. Zowel schijf- als gelijkarmige fibulae van het eiland Walcheren, daterende van de zevende tot de tiende eeuw, worden regionaal vergeleken met gelijktijdige fibulae uit de rest van Nederland. Een hypothese over de organisatie van productie van deze fibulae zal vervolgens geopperd worden, gestoeld op het historische verleden van Walcheren. Daaruit zal een discussie over culturele identiteit in het onderling verbonden Noordzeegebied voortkomen. Voor de iets vroeger daterende gelijkarmige fibulae wordt een andere hypothese getest. Namelijk dat de meer noordelijke Friese fibulae regionaal te onderscheiden zijn van die van Walcheren.

Het volgende type object wat is opgenomen in deze studie is een groep dierbeslag daterende van de negende tot de elfde eeuw. De herkomst, originele functie en de rol van deze objecten voor het uiten van identiteit worden in detail besproken. Een aantal onderdelen van stijgbeugelbeslag uit Walcheren zijn onderzocht en worden eveneens onderzocht op lokale versus niet lokale herkomst. Daarbij werd het metaal van deze vondsten vergeleken met objecten van een ander type. Ringnaalden en kostuumnaalden worden als laatste gepresenteerd, samen met een eerder geanalyseerd assemblage uit 2009. De objecten uit Walcheren dateren van de zevende tot de elfde eeuw. Een discussie over de rol van handelaren in het contact tussen de twee kustlijnen en de lokale of gecentraliseerde productie van dit soort objecten binnen een verbonden Noordzee wereld zal worden aangesproken.

De in deze studie gebruikte methode voor het analyseren van samengestelde objecten is een belangrijk onderdeel van dit proefschrift en wordt in detail bediscussieerd. Er is een focus op het al gepubliceerde debat rondom de validiteit van het gebruik van de HHpXRF methode binnen de archeologie. Het grootste punt van discussie betreft het feit dat het verkrijgen van hoge resolutie data van het gecorrodeerde oppervlak van koperen objecten niet mogelijk is. Daarnaast wordt vaak beweerd dat een 'echte' meting (door het verwijderen van patina) nodig is voor het beantwoorden van archeologische vraagstellingen. Het tweede punt van discussie betreft het gebruiksgemak van de HHpXRF. Zo werd eraan getwijfeld of het wel gepast was dat de vrij gemakkelijke en gebruiksvriendelijke HHpXRF methode door relatief onervaren gebruikers effectief ingezet kon worden. Dit debat heeft de wetenschappers die zich met dit onderwerp bezig houden verdeeld. De ene kant accepteert de methode niet als valide methode binnen de wetenschap, de andere kant argumenteert voor het gebruik van de HHpXRF methode waarbij het toepassen van geschikte methodologieën voor het gebruik van de methode centraal staan. Eerdere studies hebben aangetoond dat deze methode niet geschikt is voor gedetailleerde kwantitatieve data analyse op gecorrodeerde koperen oppervlakten. Hier wordt echter een alternatieve, kwalitatieve, applicatie voorgesteld. Namelijk dat deze methode een goed analytisch middel vormt om objecten in een classificatiesysteem te plaatsen waarbij het beantwoorden van vragen over de voornaamste keuzes voor de samenstelling van koper legeringen mogelijk is (messing/brons).

Het tweede punt van discussie over het gemakkelijke gebruik van de methode, en de angst voor een verkeerde interpretatie van de verkregen data door onervaren archeologen wordt opgevangen door het instellen van een protocol. Dit protocol bevat experimentele herhaalbaarheid van metingen gebaseerd op de toepassende wetenschappelijke standaard. De behoefte aan zo'n protocol wordt besproken in het methodologie artikel, hier hoofdstuk twee. Dit artikel argumenteert dat de HHpXRF methode geschikt is voor het bestuderen van oude objecten gemaakt van koperen legeringen. In plaats van de standaarden van lab-gebaseerde technieken te evenaren, is de HHpXRF methode eerder geschikt voor een survey waarbij er een poging kan worden gedaan om chronologische en geografische veranderingen te modelleren voor een groot aantal objecten. Om dit voor elkaar te krijgen, bespreekt het artikel in hoeverre de gecorrodeerde oppervlakte metingen het potentieel van deze aanpak beïnvloedt. Een gecombineerde typologische en chemische analyse van vroeg Romeinse fibulae uit Nijmegen werd samen met dit artikel gepubliceerd.

In hoofdstuk drie tot en met acht wordt vervolgens een serie aan voorbeeldstudies gepresenteerd welke gebruik maken van de methodologie die ontwikkeld is in hoofdstuk twee. Deze artikelen bespreken niet alleen het eerder geïntroduceerde debat maar geven ook inzichten in wat voor vragen beantwoord kunnen worden met deze methode en laten een intrigerend kijkje binnen de organisatie van de productie van oude koperen legering zien. Hoofstuk drie en vier presenteren onderzoek over respectievelijk vroeg- en laat Romeinse fibulae. Ter bevordering van de vergelijkbaarheid worden de metingen op objecten uit

verschillende regio's gedaan (Nederland en Letland/Estland), met twee verschillende HHpXRF machines en van verschillende maakwijze (Niton en Brucker).

Hoofdstuk drie identificeert een verschuiving van het gebruik van brons naar messing tussen de voor- Romeinse en vroege Romeinse fibulae typen. Dit maakt een discussie over het opkomend gebruik van messing in militaire kampen en burgerlijke centra mogelijk. De hypothese van Romeinse militaire productie past goed bij het idee van Romeinse 'industrialisatie', ook al blijft brons toch in gebruik wat de fibulae betreft. Verschillende hypotheses worden geopperd. Allereerst dat de ambachtsmannen veel controle over de keuze van het metaal hadden. Ten tweede, dat de keuze van metaal productie gerelateerd is. Oftewel, het zou kunnen dat non-militaire werkplaatsen de productie met brons bleven doorzetten terwijl het gebruik van messing uitsluitend in militaire werkplaatsen voorkwam.

Hoofstuk vier bespreekt het verband tussen de typologische gegevens en de resultaten van het onderzoek naar de chemische samenstelling van de laat Romeinse schijffibulae uit de Oostelijke Baltische staten. Regionaliteit wordt besproken net als de aard van het contact met andere gebieden. De samenstelling van de legering wordt ook gecontrasteerd met al gepubliceerde resultaten uit andere landen. Dit leidt tot de conclusie dat de keuzes in fibulae niet zo gecontroleerd waren als de fibulae uit het vorige hoofdstuk. De HHpXRF methode liet echter ook bewijs zien voor het vertinnen van de objecten, hetgeen de resultaten van de metingen beïnvloed zou kunnen hebben. Zo konden twee regionaal onderscheidbare groepen worden geïdentificeerd. De ene groep had een zilverkleurig uiterlijk (door het vertinningsproces), de andere groep had een goudkleurig uiterlijk (door het niet vertinnen van de objecten).

Hoofdstuk vijf keert weer terug naar Nederlandse objecten uit de Karolingische en Ottoonse tijd. Aspecten van productie en uitwisseling worden geanalyseerd. De resultaten van de chemische analyse laten een duidelijke verandering zien in vergelijking met het gebruik van legeringen in de Merovingische tijd. Ook laten de samengestelde legeringen een hoge mate aan consistente waarden zien. Dit onderbouwt de hypothese dat productie in de Karolingische en Ottoonse periode regionaal of supra-regionaal georganiseerd was. De meest voor de hand liggende bron van deze objecten zullen kloosters zijn geweest. Deze kloosters vormden wellicht langdurige productie centra met tradities welke de ambachtslieden in staat stelden een hoge graad aan consistentie te behouden gedurende een aantal eeuwen. Deze hypothese wordt ondersteund door de Christelijke symboliek op vele van deze geëmailleerde fibulae. Dit maakte het mogelijk een discussie te voeren over de aard van de uitwisselingssystemen welke gekenmerkt werden door Christelijke symboliek en waarin de fibulae de sociale hiërarchie tussen de geestelijke elite en de normale mens versterkte.

De volgende drie hoofdstukken gaan in detail in op de vroegmiddeleeuwse artefacten van Walcheren. Deze artefacten beslaan schijffibulae, gelijkarmige fibulae, Ringnaalden en kostuumnaalden, stijgbeugel beslag, en diervormig beslag. Een gedetailleerde studie van het diervormig beslag wordt in hoofdstuk zes gepresenteerd. De resultaten geven inzichten in de technologie van die tijd en laat de formulering van

een nieuwe hypothese toe over hun functie en culturele associaties binnen de Noordzee wereld in de Vikingtijd. Al blijft het exact dateren van de vondsten lastig, de gebruikte stijlen doen vermoeden dat er een hechte band bestond tussen de Friese, Viking- en Anglo-Scandinavische wereld van de negende tot de elfde eeuw.

Hoofdstuk zeven bespreekt de grotere assemblages vondsten gevonden te Walcheren en is als hoofdstuk in een boek verschenen. De resultaten suggereren dat de productie van objecten uit koper legeringen in permanente, administratieve stedelijke productiesites plaatsvond, waarin objecten speciaal werden gemaakt voor de markt. De verschillen tussen lokaal gemaakte en geïmporteerde objecten worden ook besproken, waarbij de hypothese wordt geopperd dat er een multiculturele groep van inwoners samen werd gebracht door de aanwezigheid van een interregionale handelsplaats.

Ten slotte is in hoofdstuk 8 een vergelijking getrokken tussen de naald van Domburg op Walcheren en de naald van een vergelijkbare kustplaats in Engeland. Dit soort objecten worden in grote aantallen gevonden aan beide kanten van de Noordzee. De aard van dit interculturele contact wordt verdiept op het gebied van stijl, samenstelling en maakwijze. De resultaten suggereren dat de productie georganiseerd werd rondom grote handelsplaatsen, kerkelijke centra of koninklijke centra. Echter was er ook een zekere lokale factor in de productie wat betreft de aanvoer van grondstoffen. Met name de koninklijke centra schijnen meer te hebben gerecycled, terwijl de handelsplaatsen en kerkelijke centra toegang hadden tot nieuw metaal.

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Curriculum Vitae

I was born in Chorley, Lancashire, The United Kingdom in 1966 and have been interested in archaeology and history for a long as I can remember. But it was only in my late 30s that I actively got involved in digging. Initially through volunteering, then through part-time commercial work. In 2010 I undertook a master degree at the University of York, England, specialising in field and medieval archaeology. It was here that I developed an interest in early medieval copper-alloy artefacts initially from Viking age England. This developed into a thesis topic where I attempted to better understand the geographical spread of early medieval personal items, recovered along the east coast of England.

In 2011, instigated in part by the poor state of the UK economy (the credit crunch of 2008 was still stifling commercial archaeology), I undertook a second master degree at Leiden University, where my interest turned to the composition of early medieval metal finds from the terps of Frisia. This ongoing interest opened up a larger research project as a PhD candidate at the faculty of archaeology at Leiden University. When I am not writing I like nothing more than to take off on my motorcycle or to chat with friends over a beer or two.