Reconstructing Past Craft Networks:
A Case Study using 3D scans of Late Bronze Age Swords to reconstruct Specialized Craft Networks

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Kristina Golubiewski-Davis

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Dedication

This dissertation is dedicated to my husband, Earl Davis. You followed me across the country and never bat an eye when I travel abroad. For every sleepless night, for every meal you've made to make sure I eat, for sticking by through thick and thin, and especially for every edit you've made: Thank you. I couldn't have done it without you.

Abstract

As the collection of 3d data proliferates in the archaeological community, new methods integrating analysis of those data must also be developed. This dissertation project approaches the problem of observing social networks by examining decisions made by specialized craft workers: specifically, Late Bronze Age smiths (~1200-800BC). The data examined include shape data collected from 3D scans of bronze swords. These data were used to group the blades using cluster analysis based on different aspects of the swords including blade profile, hilt profile, and various decorative shape data. Those clusters create links between the swords which were then used to examine the network of bronze smiths. This project is a case study of how one might go about studying the way individuals with specialized knowledge were connected in the past by studying the results of that knowledge expressed through tangible differences between artifacts.

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LIST OF ABBREVIATIONS

3D – Three dimensional

ACECLUS – approximate covariance estimation for clustering

ANOVA - analysis of variance

As – Arsenic

Bi – Bismuth

Bz – Bronzezeit

CAT scan – Computerized axial tomography scan

CCC – cubic clustering criterion

CT – Computerized Tomography

Cu – Copper

CVA - canonical variates analysis

DRUM – Digital Repository for the University of Minnesota

FBA – Final Bronze Age

Fe – Iron

GM – Geometric Morphometrics

Ha – Hallstatt

LBA – Late Bronze Age

MANOVA – multivariate analysis of variance

Ni – Nickel

NRC – National Research Council of Canada

NRCA – Neutron Resonance Capture Analysis

NURB – non-uniform rational B-spline

PBF – *Prähistorische Bronzefunde*

PCA - principal components analysis

PFS – Pseudo F

PST2 – Pseudo T squared value

RBA – Recent Bronze Age

Sb – Antimony

SLS2 – structured light scanner 2

Sn – Tin

XRF – X-ray fluorescence Spectroscopy

Zn – Zinc

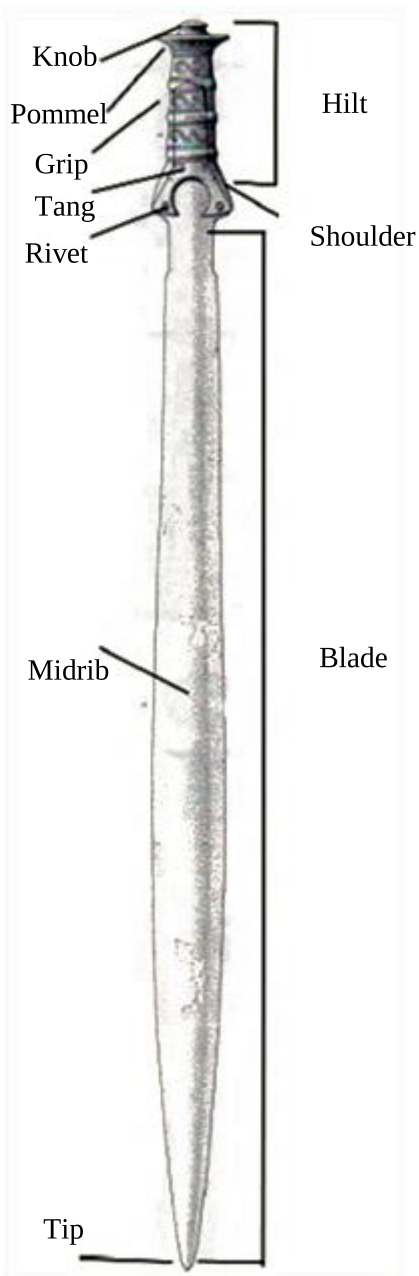


Figure 0.1: Sword terminology. Figure altered from Wüstemann, 2004.

INTRODUCTION

The key to understanding people is understanding the ties between them.

(Christakis and Fowler, 2011: XV)

The manufacture choices observable in bronze swords reflect the trade and communication networks of the smiths who made them. Throughout this dissertation, I combine network theory, high dimensional statistics, morphology, and artifact design theory to examine these networks. The combination of theoretical frameworks has allowed me to bridge the gap from artifacts to individual or small group decisions and finally to networks of communication in a prehistoric context. While I use a very specific case study, the methodology can be expanded to examine other groups of artifacts in other times. Furthermore, for this dissertation I examined both traditionally collected data in the form of linear measurements, drawings, typologies, and find information alongside 3D scans. The collection of these additional data has allowed me to examine the shape of objects in a more detailed manner than previously possible. I approached this dissertation project with the following research questions in mind:

- How can manufacture choices be used to recreate networks based on specialized craft knowledge?
    - *Can 3d data provide meaningful links based on manufacture differences between swords?*
- What types of networks existed between Late Bronze Age sword smiths?
    - *Were there multiple networks?*
    - *Are the networks consistent with style?*
- Can networks reconstructed based on manufacture choices help understand the question of itinerant smiths vs. sedentary smiths?
- Can individual smiths be recognized based on differences in manufacture shape?

I have chosen to examine the swords of Late Bronze Age (LBA) Central Europe as a case study to establish these connections. This body of artifacts is large enough in size that I was able to collect a reasonable 3D sample of 145 blades to compare. Beyond those collected for 3D scanning, the *Prähistorische Bronzefunde* (PBF) series of publications is a collection of measurements, metallic compositions, find circumstances and locations, descriptions, drawings, and typological designations published between 1971 and present. These data have been included in my study. Bronze swords are an ideal artifact type to examine during this time period as they represent a prestige good which traveled throughout the area, have stylistic distinctions, and would have required specialized craft to knowledge to produce. Thus, by examining the decisions made by the crafts workers I can piece together similarities based on that specialized knowledge and compare swords. These traits can be used to posit the likelihood of certain blades coming from workshops with similar knowledge and how similar that knowledge may be. By comparing links based on similarities across the landscape, I recreate a possible network along which that knowledge may have traveled.

The dissertation is separated into three parts. The first part builds up the theoretical framework within which I operate. I begin by looking at the wider realm of network theory and then narrow in to how that can be applied to the archaeological record and prehistoric groups. From there, I explore how we can use ideas of making to examine the decisions of individuals or small groups through the artifacts they have created, and finally how modern technology aids in that endeavor. Part II introduces the reader to the Bronze Age in general and then narrows down to describe the bronze swords and how they were made. Finally, Part III provides the information, experimentation, methodology, data, analysis, and conclusions of my sample.

Throughout the paper, terms that are bolded can be found in the glossary. This dissertation is aimed at a number of audiences who many not be familiar with the different terms, particularly technical terms related to statistical analysis or 3D scanning. Many of these terms are defined within the body of the text as well.

This dissertation has resulted in a variety of data. Numerical data, images, network matrices, Fourier transforms, and cluster analysis data have been uploaded to the Digital Repository for the University of Minnesota (DRUM) at http://hdl.handle.net/11299/180367 for public access and long term storage. Copyright for the 3D files is held by the museums that own the individual blades. If you are interested in obtaining those files, please contact the museums directly.

Part I: Theoretical Framework

Part I of the dissertation consists of four chapters which present the theoretical framework of the project. These four chapters are based in the concept that communication links people through certain connections. Those links can then be mapped to illustrate the networks that join people. The section starts out in the broad realm of network theory. Each subsequent chapter narrows in to create a means through which defined sets of data can be used as evidence for connections between groups of craft workers, such as bronze smiths, represented in the archaeological record.

Chapter One introduces the concept of network theory, which is rooted in studies of modern peoples and networks. Many of the examples in this chapter come from current events. Many of the connections in network studies are based on known relationships between specific and identifiable people or entities.

The ability to identify individuals or distinct entities is not a luxury afforded to those studying the archaeological past. Chapter Two covers the ways in which objects relate to human activities. Since the individuals or groups of the past are not clearly defined, it is essential to create a link between the evidence that is left behind to those who populated the past. The second chapter explores these links and provides examples of how objects can be used to approximate groups of people in the past. In these examples, the networks represent how groups of people, and not individuals, are connected.

Chapter Three provides a means by which the scale of the network can be used to look at smaller groups in terms of craft workshops. These workshops likely included only a handful of people at most. The focus of this chapter is on linking the final form of an object to the craft worker who created it, in my case the bronze sword smith. The concept of the workshop skirts around the problem of identifying a specific smith in the archaeological record, and its use acknowledges the likelihood that smiths may have worked in groups instead of as lone individuals.

Finally, Chapter Four provides examples of how three dimensional scanning and statistics have been used to quantify morphological traits of artifacts and translate those into evidence of meaningful manufacturing decisions. This chapter is intended to provide a means through which connections between workshops can be defined. These connections thus represent the links of communication between workshops.

Part II: Bronze Age Contextualization

The second section of the dissertation focuses on the Late Bronze Age in Central Europe. This section provides background knowledge of the time and place which the case study examines. While it is by no means a comprehensive overview, it does provide the context within which the swords were made.

Chapter Five is an overview of the Late Bronze Age in general. Covered in this chapter are the topics of subsistence, settlement types, craft and technology, religion, hoarding, and social organization. Each section is covered in brief, but is necessary to understand the world in which the smiths existed. It is through these lenses that the craft workers would have obtained both the materials and knowledge for their craft. It is also within this larger social network that they existed, and through this network that their craft was given importance and therefore the support to reinforce its use.

Chapter Six describes the production sequence of a sword. This chapter begins by examining the role of the smith within the community. It then follows the life cycle of a sword from extraction to creation. It is notable that bronze can be recycled, and this phenomenon is discussed in this section alongside possible repercussions to this life cycle.

Chapter Seven focuses on the use of the blades during the LBA. This is approached from the aspect of find context, various use wear analyses, and stylistic importance. The focus of this dissertation is on *Vollgriffschwerter,* or swords with a metal hilt, many of which are decorated. It is interesting to note that where decoration occurs, no two blades are exactly alike. Despite these differences, there are similarities between different styles that have led to an extensive typology discussed in this section alongside other previous works surrounding the blades.

PART III: CASE STUDY - LATE BRONZE AGE SWORD SMITHS

The case study is the crux of the project. In this section, the data gathering, analysis, and discussion of the archaeological record is presented. These final chapters present the types of data collected, the analyses performed on them, and a series of network graphs to aid in the interpretation of past networks.

Chapter Eight is the beginning of the case study. The data collected for the case study is presented here. My sampling strategies and the collection of data are discussed. The 3D scanning process is discussed in brief: a more detailed protocol can be found in Appendix A. For each type of data, I explain how it was collected as well as the reason for collecting that particular information.

Chapter Nine is an in-depth description of how I arrived at the network graphs. In this chapter, I begin by explaining how I arrived at different manufacture clusters of the swords. The cluster analysis separates out blades using manufacture choices, specifically those related to shape. Location data and rivet placement were also considered for clustering purposes. These clusters become my unit of analysis for hypothesis testing in Chapter 11. For the rest of the chapter, a set of 12 blade clusters is used as an example to show how each type of analysis is performed. The chapter concludes by explaining how the network graphs were created.

Chapter 10 is a series of hypotheses that are tested using the data. These hypotheses examine how style, find type, and manufacture decisions (interpreted through shape data) interact. Each interaction is presented as a null hypothesis, suggesting that there is no interaction between manufacture and the category being interpreted. Places where there are notable differences between groups are presented and discussed. The chapter concludes by presenting the network graphs of categories determined to be representative of potential networks based on the hypothesis testing using the clusters as nodes. The chapter concludes by examining possibilities for using the blades as nodes instead of clusters, which would provide a greater resolution of interaction than using the clusters as nodes.

Chapter 11 presents my conclusions and interpretations of the network graphs. The graphs are considered in two ways. First, the clusters based on different shape data are used as nodes in the network graphs. These are used to reconstruct large scale networks in LBA Central Europe. Second, the individual blades are used as nodes. The links between these nodes is defined by shared clusters between the blades. These networks are used to infer smaller scale networks and suggest blades that are more closely related than others.

Chapter 12 resituates the connections between Bronze Age smiths into the overall networks of the Late Bronze Age. The chapter specifically focuses on how LBA bronze smith networks help bridge the gap between small local interactions and large scale trade networks.

PART I:
THEORETICAL FRAMEWORK

Chapter 1: Networks and Communication

As we learn more about ourselves and the world around us, it is increasingly apparent that our connections and networks are an important part of our everyday lives and society at large. The term "social network" has become commonplace with the advent of Facebook, Twitter, and other online tools which allow us to connect with people everywhere from our backyard to halfway around the world. While it may seem like these phenomena emerged overnight, the human networks they are built upon have been forming for millennia in particular historical and prehistorical circumstances. Only by parsing out the variables that lead to where we are can we begin to untangle the complexities, and implications, of our current social networks.

In order to do this, I first explain what a network is, how it is formed, and how it affects us both as individuals and as part of a greater whole. The aim of this chapter is to examine network theory and to provide a framework which will, in the following chapters, be used to examine past networks.

The Building Blocks of Networks

In its most basic form, a **network** is comprised of points which are connected. These points are known as **nodes**. The network is the entire composition of how the nodes are connected. In the context of human networks, the nodes are often people and the **connections** consist of familial ties, work ties, friendships, or any number of ways in which we define our relationships with others. Nodes can have multiple types of connections to other nodes. In networks where the nodes are individuals or groups of people, these connections are not always stable. This ability to be a part of various networks is known as **multiplexity** (Christakis and Fowler, 2009:92). The nodes can be individuals, groups of peoples such as towns, or other entities all together, such as websites.

Networks are more than just the lines along which communication occurs. They influence our lives in ways that we might not expect. In addition to information, diseases, resources, and even emotions can travel along network connections (Christakis and Fowler 2009:35). The extent to which individuals can influence each other along network connections demonstrates the strength of networks. These influences can be inconspicuous, such as when a parent comes home in a poor mood because their boss mistreated them and then in turn yells at their child for a minor mishap, or easily apparent, such as the so called laughing epidemics of Bukaboa. This epidemic started with three classmates in January, 1962 who began laughing uncontrollably. The laughter spread to their classmates, forcing the school to close as each new student was unable to stop laughing, and eventually spread to surrounding villages. This epidemic of uncontrollable laughter spreading from person to person lasted till as late as June of that year and affected over 217 individuals (Christakis and Fowler 2009:34). In this case, the spread of laughter from one person to another was visibly apparent and could be traced along the route it took.

Communication structures the way communities interact and provides a framework for networks of trade and information to build upon. Through constant communication in the form of speech, visual cues, and other daily interactions, individuals learn the socially appropriate way to interact with others and their environment. The networks to which people belong are complex, and thus their decisions are informed and influenced by a variety of sources. The decisions they make often preference the obligations of smaller, familial networks over larger societal ones (Gudeman 2001:9). By examining the decisions people make, researchers can begin to understand what networks may have influenced those decisions and through this examination, reconstruct the complex networks which connected past societies.

Networks are constructed in multiple ways using connections with a variety of properties. The most basic of these is a **non-directional connection**. This is simply a connection that goes two ways. For example, Susie and Mary are friends. They are both connected by friendship. See Figure 1.1 for an example of the ways in which Susie and Mary can participate in various networks. **Directional connections** only go in one direction. Academic papers are a good example of these types of connections. When written, the author of the paper cites the author of another paper. However, since the cited paper has already been published, there is no connection back to the paper which cited it (Barabási 2014:48). As the connection only goes from the most recent paper to the previous paper and not vise-versa, it is a directional connection.

Connections have a tendency to **cluster**. Often, when two individuals are connected, they are likely to have similar connections. For example, Susie and Mary, whom we have already established are friends, are also both friends with Ben (Figure 1.1.2). These three individuals are connected with each other in a cluster. This example can be extended to other networks. Coworkers and family members are likely to cluster in this matter. In the network of academic papers, authors who read a paper are likely to read, and therefore cite, the articles that are cited within the original paper, thus creating a cluster.

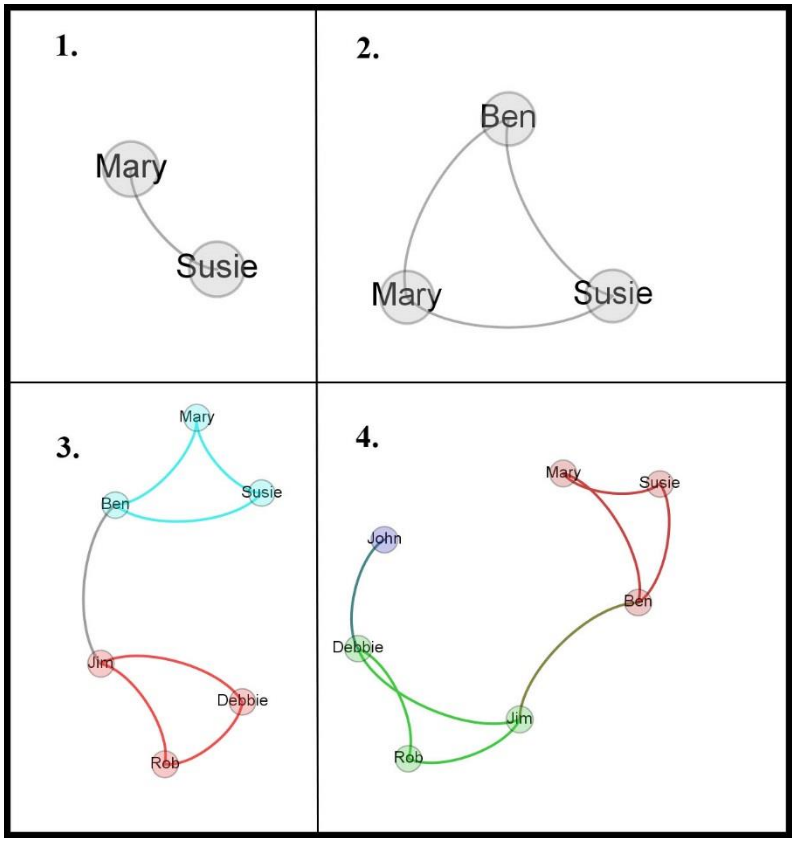


Figure 1.1: The Networks of Susie and Mary

The connections that make up a cluster are considered **strong ties**. They are reinforced by other similar connections within the group. **Weak ties** expand out of the cluster. In this way, they create connections between clusters. In our running example of Susie and Mary, the two of them are part of a cluster with Ben. Since all three individuals are friends, the ties between them are strong ties. Ben has an acquaintance from work, Jim, who does not know Susie or Mary and has his own cluster of friends

(Figure 1.1.3). As Ben's tie to Jim is not reinforced by his other ties, this constitutes a weak tie. Despite their name, these connections play a very important role in the larger structure of networks. Because of their ability to connect clusters, they create the lines along which information moves from one cluster to another. This concept is known as the "strength of weak ties" (Granovetter 1983). The explanation of how weak ties strengthen the network is exemplified in Granovetter's study, wherein he asked how people learned of the job they currently held. In most cases, it was not through a friend, but rather an acquaintance, or the "friend of a friend". These acquaintances were weak ties rather than those with whom they shared strong ties (Granovetter 1994).

Strong and weak ties are often present concurrently in networks. Each group of individuals represents a highly connected cluster. However, a few individuals have connections to other clusters. These single connections to another cluster are the weak connections, but the only way in which information moves from one cluster to another. Returning to Susie and Mary, imagine that Mary is interested in attending a concert, but is unable to find a ticket. It turns out that John happens to have a ticket which he doesn't want. Given the network depicted in Figure 1.1.4, there are no strong ties which connect Susie and John; however, the information that John has the ticket can still reach Susie by following a series of strong and weak ties (from John to Debbie to Jim to Ben and finally to Mary). The weak ties provide a way for information to jump from group to group. This path of information flow does not necessitate the creation of new links, though it may create a new weak tie between Susie and John by the end of the exchange.

The minimum number of connections required to maintain the network is one (Barabasi 2004:8). This is important, as it means that so long as there is a single connection, the network is maintained. Most networks have a built in redundancy. This redundancy creates a stability to the network such that the removal of a single connection (though not necessarily a single node) prevents the entire network from collapsing. In nature, networks tend to have multiple redundancies strengthening the stability of the network.

TYPES OF NETWORKS

RANDOM NETWORKS

The simplest form of network construction is that of a **random network**. A random network is created when the connections between nodes are randomly created and the likelihood that any two nodes is connected is equal and independent of any other connection. This type of network was developed by Erdős and Réyni (1959) and is credited as the basis for the underlying mathematics of network theory (Barabási 2014:36). Their work created the basis upon which all modern network theory is built. It was assumed for a long time that all networks had an underlying random base. This would mean that it was just as likely for a barber in Minneapolis to be friends with the Queen of England as it would for him to be friends with a taxi driver in Australia. Despite the obvious problems with this mechanism on certain scales, a large enough network does appear to be random unless you know the rules that govern the connections, such as social status and geographic placement.

A random network typically exhibits a **normal distribution**, where the majority of the measurements are similar and the graph of points typically resembles a bell, as shown in Figure 1.2. In this type of distribution, most nodes will have a similar number of connections and a few nodes will be outliers. These outliers are rarely extreme. Human height is a typical example of a bell curve distribution.

HUB AND SPOKE NETWORKS

In a **hub and spoke network**, certain nodes are significantly more connected than others. Naturally occurring networks, including human social networks, tend to cluster by following certain rules. For one, people who are connected tend to forge new connections based on their existing connections, thus strengthening their ties within a group. Other individuals become highly connected with people from various different clusters and act as weak ties for those clusters. These individuals then become highly connected hubs. Networks that have hubs of connections follow a **power law distribution** (Figure 1.2). In this type of distribution, most points cluster in one spot with a few extreme outliers. If human height were distributed along a power curve, we would not be surprised to see an individual who was one hundred feet tall or taller (Barábasi 2004:70).

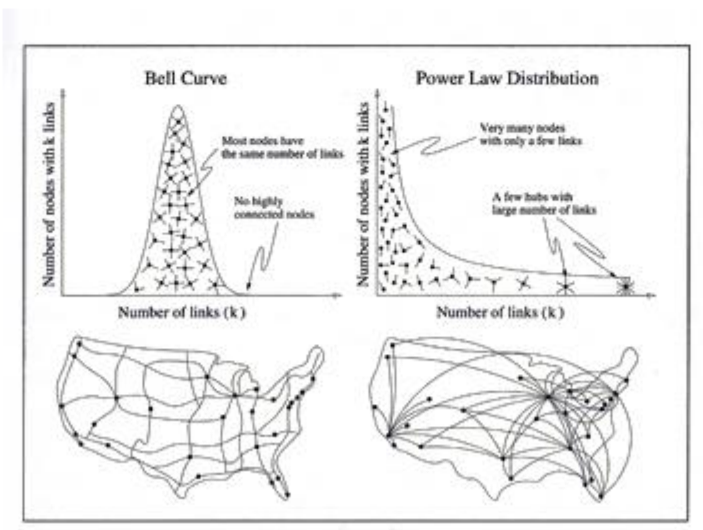


Figure 1.2: The bell curve of a random network compared to a power law distribution of a hub and spoke network. (Barabasi 2004:71)

A network with a power law distribution contains nodes that are highly connected. These connections can be non-directional or directional. Airports, such as Chicago O'Hare, which have many different connecting flights act as a non-directional hub. Flights are both incoming and outgoing to the airports connected to it. An example of a directional hub would be Amazon.com (Barábasi 2004). In the case of the internet, many websites link to Amazon.com, but Amazon.com does not necessarily link back to the sites with incoming links. In both of these cases, there is one node that has a larger number of links in the network, it is simply the structure of those links that changes.

HIERARCHICAL NETWORKS

Finally, there are **hierarchical networks** (Figure 1.3). These structures are set up so that there is a cascading set of nodes. Each node in the network has the same number of connections as other points, but they are to different points in the nodes. An example of this type of structure would be a telephone tree. One person calls two people, who call two more, so on and so forth (Barábasi 2004). In the case of a phone tree, the connections are directional; however, a hierarchical structure need not be directional.

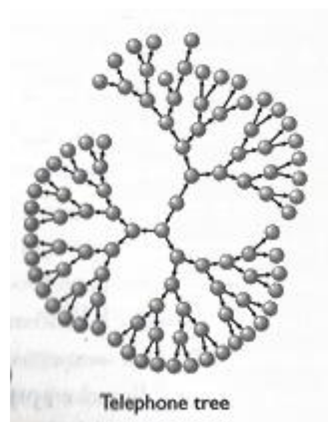


Figure 1.3: A simple hierarchical network. (Christakis and fowler 2009:12)

COMMUNICATION ALONG NETWORKS

C**ommunication** consists of the methods in which information passes from one individual (or group) to another. It is along network structures that information travels.

Information comes in many forms. The most obvious of these is the spoken or written word, but the more interesting forms of information are those that are encoded into sounds, images, and other vessels which transport the information across space and time. Encoded information requires that there is an agreed upon meaning for that encoding. This agreement is in constant flux and changes dependent upon the technologies available. As writing was introduced and eventually used by more and more people, the importance of spelling became increasingly important.

One such example of nontraditional communication is the Kele drums (Gleick 2011:13). The Kele use drums to transmit information via sound, but they are limited to a small number of sounds that the drum can make. The small number of units would be akin to the Hawaiian alphabet, which only contains 13 letters. In order to communicate complex ideas, many of their messages are long and contain extra bits of information.

> "No one spoke simply on the drums. Drummers would not say, "Come back home," but rather,
>
> Make your feet come back the way they went,
> make your legs come back the way they went,
> plant your feet and your legs below,
> in the village which belongs to us." (Gleick 2011:13)

Gleick was interested in understanding why the message was so complex instead of a simple request. What he found was that the elongated messages allowed for redundancy which provided context. This context cleared up any confusion on what the message might have been.

Redundancy, it turns out, is an important part of encoding messages. The fewer characters available for representation, the more redundancy is needed to create a clear message. This holds true across all different types of encoding: from alphabets, to the Kele drums, to Morse code. Much as redundancy in networks strengthens their connections, so redundancy in communication strengthens its meaning.

Six Degrees of Separation and Three Degrees of Influence

The interconnectedness of people on a global scale plays an important role in today's society. The sections above discuss the different ways which networks form. This section examines the extent to which these connections impact us. These are the theories of six degrees of separation and three degrees of influence.

Six degrees of separation is the general rule that each node on a network can be connected within six links. That is to say, that a farmer from Wisconsin is linked through six people to a banker in China that he has never heard of. These people have never met, and yet there is a connection between them. This connection is possible due in large part to the global connectedness of today's society. There are certain people who are highly connected, and thus act as hubs in a global hub and spoke network. It is not difficult to imagine that the farmer from Wisconsin has a friend (link 1) who has met their state representative (link 2). The State representative would know the President of the United States (link 3) who has likely met the current President of China (link 4). Following this line of thought, there is a Chinese governmental employee (link 5) who knows both the president and the Chinese banker (link 6). In this example, both presidents have a large number of connections making them effective hubs in the social network. Note that is not important for those links to be strong ties in the terms of six degrees of separation. In fact, it is the large number of weak ties (spokes) that a few individuals maintain which enhances this effect.

The idea of six degrees of separation has been examined in multiple scenarios, the most famous of which is the experiment conducted by Milgram (1967). Milgram designed a setup wherein he contacted random individuals from Wichita KS and asked that they attempt to pass a letter on to one of two chosen individuals in either Boston or Cambridge, MA. If the individual did not know the person in question, they were instructed to pass the letter onto someone who was more likely to know the intended recipient than themselves. Each letter was forwarded with the names of those who had previously forwarded the letter. In the end, all of the letters made it to the designated recipient within the necessary six steps (Milgram 1967:65). This experiment is, of course, not without its problems. Barabási notes that the study was limited since each of these individuals were within the confines of the United States (Barabási 2014:38). Nonetheless, it is a useful demonstration of the ways in which people are connected without the need to understand those connections.

Three Degrees of Influence expands on the idea that we're all connected and brings in a second, arguably more important aspect of networks: we affect others within our networks whether or not we are aware of it. Experiments by Christakis and Fowler have shown that that influence extends only to three degrees (Christakis and Fowler 2009:108). This means that while our farmer from Wisconsin may be connected to the Chinese banker, the actions of the banker and the farmer rarely effect the other in any meaningful way.   This sphere of influence is a critical part of understanding spheres of communication, as they help define the extent to which an individual's actions can influence the spread of ideas.

The structure of networks is an integral part of this equation. In cases where an island network exists with no outside connections, the influence can never extend outside of that island. A hub and spoke network can either display high or low influence dependent on whether the influence reaches a hub of the network quickly. By combining an understanding of network configurations with the exhibited connections, one can attempt to reconstruct the structure of a network without knowing the full extent of the network.

Conclusions

As individuals and societies, our connections are defined by the interactions we have with others. These interactions create the networks to which we belong. A new contact changes the portion of the global network to which we have access. The human network is not stable throughout all time and space. The connections that comprise our network today change in small portions as individuals gain and lose connections. Just as the small scale effects are ever changing, there are large scale changes that occur as cultural norms change and societies interact in various manners from new trade agreements to wars. As these structures change, the paths through which information flows is affected in different ways. In this way, today's network is defined by the changes which occurred in the past.

In this chapter, I have focused on what comprises a network and how information moves along the networks that surround us. As it is the past that defines a large portion of how today's global network is constructed, the focus shifts to applying network theory to the past in an attempt to disentangle the web of what came before. While this dissertation is in no way attempting to recreate the entirety of how today's network has developed over all time and space, it is with the intent to examine a portion of this history that I now turn.

Chapter 2: Applying Network Theory to Archaeological Contexts

The previous chapter discussed how networks are structured. Many of those examples were based on modern day situations where the relationships between individual people could be defined. Shifting from the present to the past, these individual relationships are often lost to time. This loss of distinction is even more apparent when examining the archaeological record. The further from present that time is, the more obscured those connections become. Furthermore, the prospect of simply asking people what connections they have and maintain is no longer an option.

This is where archaeologists turn to the material evidence left behind. I posit that this evidence can be used to recreate network structures. However, these structures are limited in their nature. As the actions of individual people are often obscured, the nodes in these structures must be redefined to an entity that makes sense based on the evidence at hand. Archaeological evidence provides clues to what people have done in the past, both on a societal and individual level. However, it is often difficult to determine if a particular individual performed actions that are discernable. Were these two bones butchered by the same individual? Or did one person butcher a sheep on Friday, and another butcher a sheep on Sunday? This issue is often addressed by examining the **agency** of people. Agency is when an individual or group must have had some connection to the evidence which reflects their actions or beliefs. There are many types of evidence that can be found in the archaeological record that fit this criteria including, but not limited to, pollen profiles, stratigraphic deposits, the treatment of both living and dead as seen in bodies, settlement plans, and artifacts. Each type of evidence provides additional information to how past networks were structured.

The purpose of this chapter is to first establish the ways in which artifacts are affected by human agency, followed by a discussion on how these objects and their relation to people can be used to reconstruct the connections between nodes in past networks.

EXPRESSION THROUGH OBJECTS

PATTERN OF USE

The types and frequency of objects can show change over space and time. Certain suites of objects found together consistently indicate a similar use pattern of objects. To a certain extent, people are informed of the proper way to use objects and what they should be doing by the culture in which they live. For example, in modern day America most people live in permanent structures which have rectangular walls (houses). Houses have a roof, a floor made of wood which is sometimes carpeted, glass windows that let light in but keep animals out, a door that closes and locks, and separate rooms for distinct purposes (bedrooms, bathrooms, kitchens). Pots and pans belong in the kitchen and are used for cooking while blankets belong in the bedroom and are used for warmth at night. Brushes in the bathroom range in size from a tiny brush on a long stick meant for brushing one's teeth, to a hard bristled brush about the size of a hand meant for untangling one's hair, to a rounded soft bristled brush meant for curling one's hair, so on and so forth. The example can be extrapolated all the way down to the individual items in the house with each item serving a different purpose. These items are found with relative consistency in a house. This pattern informs the observer of the mode of living employed by people who are part of the American culture. People who share this distribution of material culture have a similar idea on what is considered appropriate. While it is true that individuals may vary, the pattern itself holds true the majority of the time.

The American mode of living is distinctly different from that of the Eveny people of Northeastern Siberia, who were forced to become sedentary at the beginning of the 20th century. There, the majority of the society remains sedentary in a small village. The sedentary nature of the village is mostly due to recent intervention by the Russian government. A group of men from the group routinely leave the sedentary village to follow the reindeer, at which time a completely different material culture pattern can be observed (Vitebsky 2005). While traveling, their homes are temporary tents built with reindeer hides and poles. Each tent is taken down and travels with them as they move with the herd. The home here consists of a single room, where individuals either own their own tent or share with each other. The objects they carry with them are relegated to those needed for survival only, such as pots and pans as well as multiple hides for warmth. The hunters routinely follow the herd and know the routes taken. The men are able to anticipate the route and have set up specific spots where they often stop. The areas where they stop are agreed upon by different groups of reindeer herders. While today this seems much like a few people camping, it is also a holdover of how the entire group once functioned. The material patterning is distinctly different than those of a sedentary group of people.

While the two examples above are from modern contexts, they can be used to illustrate the idea that different patterns of archaeological finds can be indicative of different accepted ways of living and interacting with material cultures, and thus extrapolated to the idea that they may indicate different identities. The type of identity indicated (culture, gender, individual, occupation) depends on the scale of the differences in the material patterning. When examining archaeological patterns, the focus is often on the artifacts and how their distribution changes.

The Early Formative Period (~1500BC-150AD) in Mesoamerica provides an archaeological example. This time period represents a change in substance from mobile to sedentary agriculture, however the archaeology in the area supports a more gradual change instead of an abrupt one. Many sites during the Early Formative Period, such as La Joya, shown in Figure 2.1, include structures indicated by a few post holes in an oval shape without evidence of walls (Arnold 1999:160). These activity areas include a hearth, chipped stone, ground stone, and a ceramic assemblage dominated by globular jars known as tecomates (see Figure 2.2). Notably

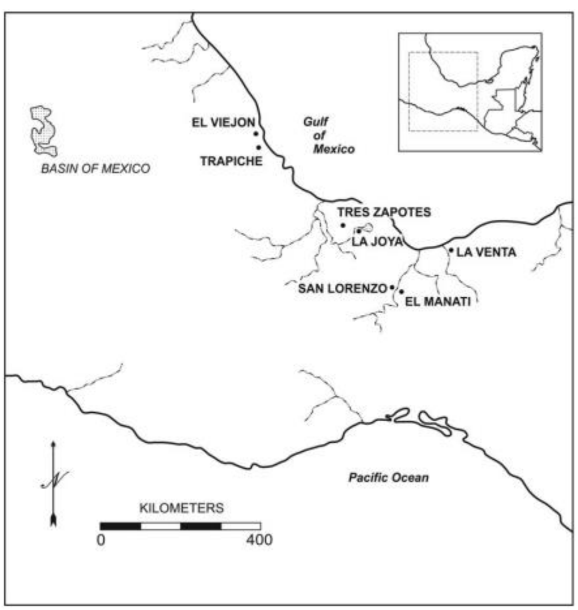


Figure 2.1: Map of La Joya (Arnold and Follensbee 2015:15)

missing from the sites is evidence of domesticated maize. Arnold argues that the tecomates, along with the rest of the assembly, are indicative of residential mobility. For Arnold, the lack of tecomates after the Late Formative Period is evidence of a change in cultural activities. Arnold suggests tecomates are a useful shape for nomadic pottery which are easy to carry, easy to make, and useful for a variety of purposes. Once the people became more sedentary, the variety of ceramics increased and tecomates became less essential to the sedentary group.

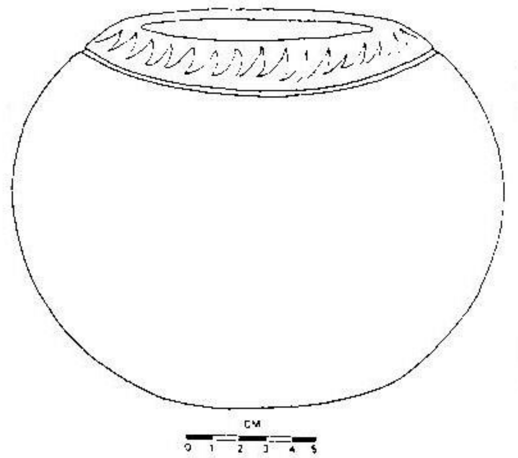


Figure 2.2: An example of a tecomate, a type of spherical jar without a neck. (Arnold 1999:158)

GRAVE GOODS

Grave goods are another way to study how objects are associated with people. These are objects that are buried with a particular individual. Because they are associated with an individual, they can be used to infer something about the individual buried or at least about those people who buried them. Large graveyards with many individuals can be examined to indicate differences in class, gender, or ethnicity. The ways in which grave types individually or as a group change through space can be used to infer ethnic diversity. Finally, since burial is by nature a social interaction (you must at least have the individual being interred and someone to bury them), grave goods and cemeteries can be used to examine social interactions of the past (Brück 2004: 309);

Branč cemetery in Slovakia (Figure 2.3) is an example of where a large number of burials exhibit gender differences in the Early Bronze Age. Shennan found that 69% of men were on their right side and 81% of women were on their left side (Shennan 1975:282). Likewise, women were more often oriented east to west. His findings unfortunately do not mention how the other individuals were found. Artifacts associated with women included rings and beads from bones, while men were buried with boar tusks, knives, and projectile points, though the quality of the grave goods themselves varied (Shennan 1975:285). Shennan interprets these differences to show a strong cultural difference in how men and women were treated. The fact that this distinction was based in gender as opposed to age suggests that gender was the more important identity. Finally, the variation in grave goods can be used to infer a complex social system. The inclusion of so called elite grave goods with children might be an indication that status was inherited at birth as opposed to achieved.

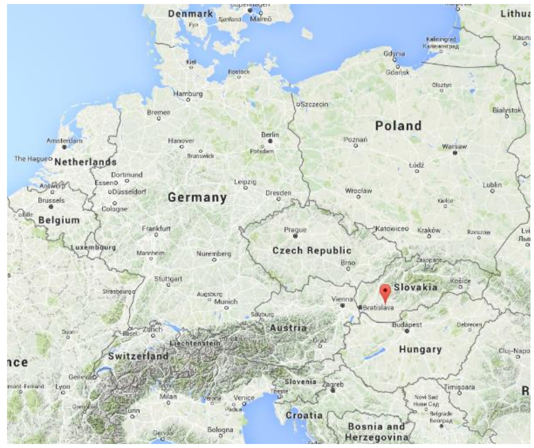


Figure 2.2: Branč , Slovakia. Map data ©2016 Google

STYLE

Archaeologists use stylistic and manufacture choices to approach identity in objects. Style can be broken down into several types of variation: **isochrestic variation**, **active style**, and **passive style** (Figure 2.4). Active style is used knowingly by the individual employing it for the purpose of informing someone else about some part of their identity. This can be for individual preferences or social strategies (Bird and Smith

2005: 222). The important aspect about active style is that it is consciously being used for a specific purpose by the individual employing it. If style is active, it must therefore "speak" to someone. Wobst (1977) argues that in most instances, socially distant individuals are the target group for active style. One's immediate household, close friends, and relatives are likely to already know the message that would be relayed through style. Individuals who are very distant are likely too far distant to be able to see the stylistic message or to have the cultural know how to decode the message. Therefore, those to whom the message is being sent are likely people with whom the individual has contact with but does not interact with on an intimate social level (Wobst 1977:325).

Passive style is used unconsciously and reflects the process of **enculturation**. Instead of thinking about the appropriate style, people often make style choices based on what unconsciously feels right (Wiessner 1983:269). Stylistic elements do not always fit neatly into one category or the other, but rather different levels of consciousness are afforded to them during creation and use (Wobst 1977:324). Wiessner's study of the

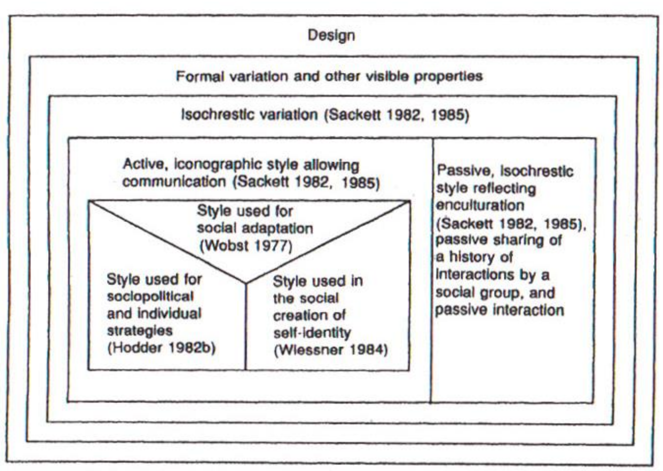


Figure 2.3:Uses of style by author as depicted by Carr (1995:158)

Kalahari San exemplifies how active style through **emblematic style**, something that is representative of something else, can be used to identify different social groups. She studied the differences in projectile points between different known language groups. Of relevance here is her findings on the length and width dimensions, which correlated to the language groups that were using them. While the points within the !Kung bands were relatively homogenous, they were approximately half the size of the G/wi and !Xo projectile points. Additionally, differences in style between the G/wi and the !Xo resulted in the !Xo community coveting G/wi arrow heads but not having the requisite knowledge to make them because "they were !Xo and did not know how" (Wiessner 1983:268). This stylistic difference between groups is an example of how habitus, or socialized behaviors (Bourdieu 1990), can be used to identify different groups through stylistic variation.

Isochrestic variation was introduced by Sackett (1982). Essentially, isochrestic variation includes all variation which is equivalent in function. Thus, the choice of temper in a pot could be considered isochrestic if it does not change the function of the pot. In addition, all stylistic variation would be considered isochrestic first, and then active or passive thereafter. The importance of recognizing isochrestic variation is that it differentiates between choices that the craft worker has based on technological and functional constraints as compared to all other choices in the production sequence. Since these choices do not affect the function of the object (at least with the exception of signaling functions) the options are then equivalent, or isochrestic.

INFERRING NETWORKS

Style, choice of technology, and patterns of particular objects are all linked to human agency. While this agency is not always intentional, it is the thread which connects the objects archaeologists study to the individuals and groups that came before us. Keeping with the theme of network studies, the next step is to combine the idea of network theory alongside artifact studies for purposes of reconstructing meaningful nodes and links to examine potential networks of the past. In these cases, the resolution of the node must be carefully considered. Where no individual can be observed, the level of the node may be higher – such as a settlement. The significance of the link is also important to determine early on. Where local specific styles appear, it is more sound to discuss the possibility of a trade network. This type of analysis, using objects to determine trade networks, has a long history in archaeological study. The introduction of network analysis provides a different angle by which to view these data. The interpretation of what consists of a link between nodes is determined by the archaeologist or researcher. The goal of network analysis in archaeology is to reveal networks that previously existed using meaningful links. Thus, revealing networks that were prehistoric in nature rather than those created by the modern researcher.

Blake's 2014 study of Bronze Age Italy demonstrates how this is done using settlements as the nodes and shared artifact types as the links (Blake 2014). The types of artifacts used for the study included Aegean style pottery, amber, ivory and antler, glass, bronzes, knives, daggers, razors, fibulae, swords, dress pins, socketed shovels, and pick ingots.

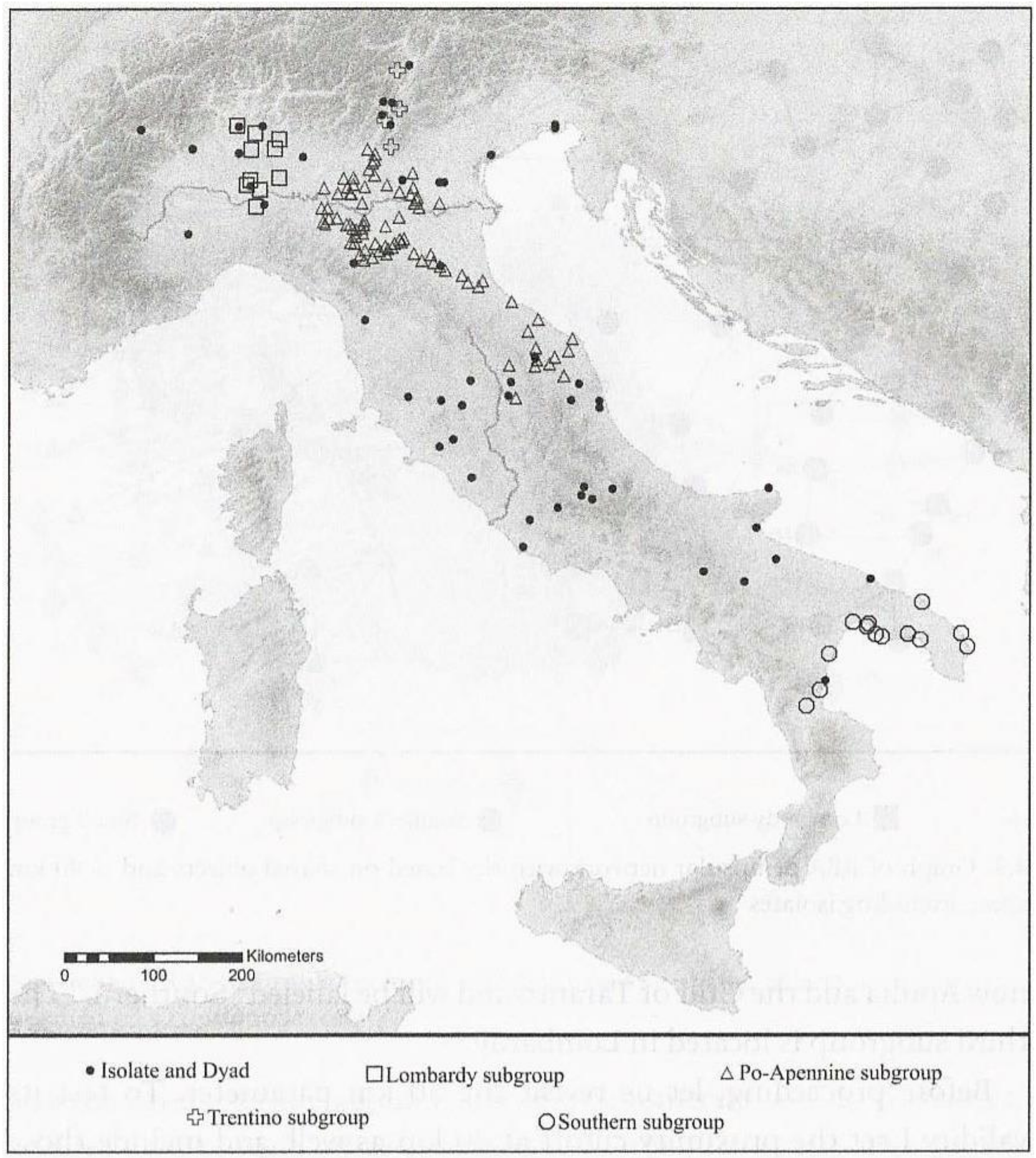


Figure 2.4: RBA distribution of sites by network (Blake 2014:93)

The work looks at various areas, types of trade, and changes over time during this period. Here, I will present some of her findings on the change in network shape between the Recent Bronze Age (RBA, 1350-1200 BC) and the Final Bronze Age (FBA, 1200-950 BC). Figures 2.5 and 2.8 provide a map of the sites she used and their network affiliations. Figures 2.6 and 2.7 are graphs of the network analysis of the sites. A link represents at least one artifact type or style being present at both sites.

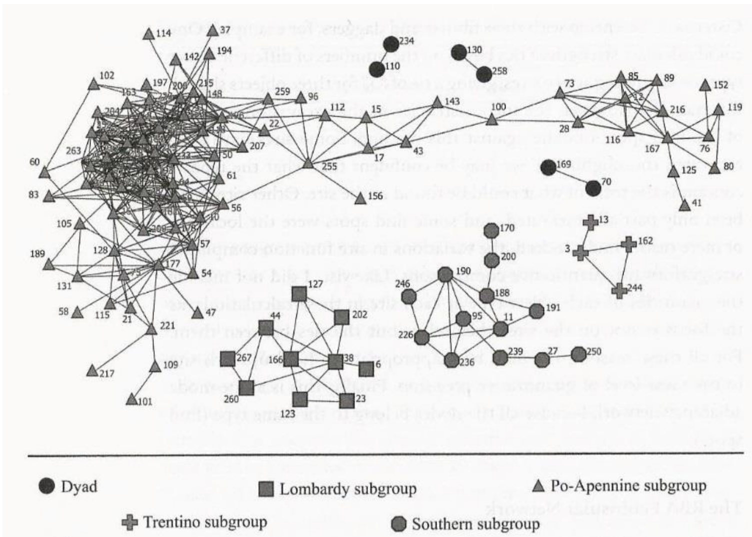


Figure 2.6: Network analysis of RBA sites in Italy. (Blake 2014:92)

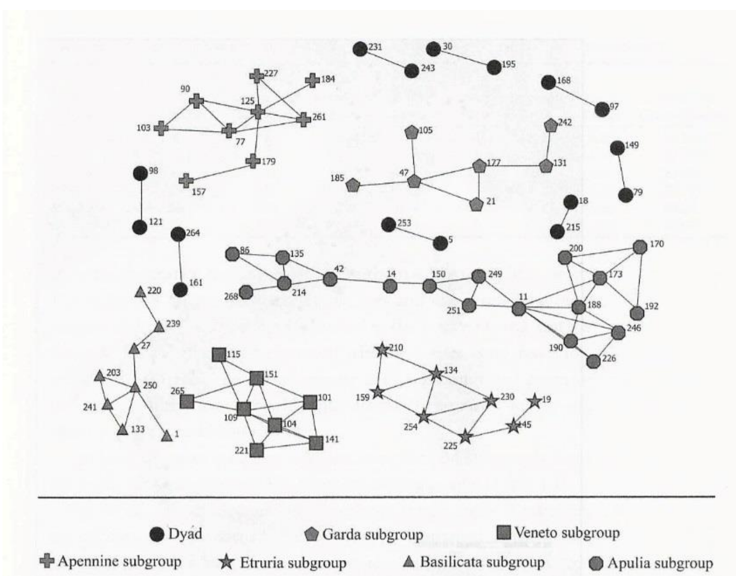


Figure 2.7: Network analysis of FBA sites in Italy (Blake 2014:103)

The RBA network was examined by Blake at two levels: sites that had a shared artifact type and were within 50km of each other, and sites that were linked within 40km of each other. The RBA map reflects the 50km network. The change in special qualifiers drastically changes the shape of the network. At 50km, there is a series of sites that links the Po-Apennine subgroup across two groups that are more closely related within those clusters. Once the distance between sites is decreased to within 40km, these groups separate into smaller subgroups. There are also subgroups that do not connect to other groups, which may suggest pockets of trade. Overall, the author determined that 50km was a better distance to base her analysis on for regional networks. Blake interprets the RBA network thusly:

> "Framing the networks historically, the Po-Apenines is the network of the Terramare culture, showing its economic reach into Marche and the Apenines. The Lombardy network corresponds to the group known as the Canegrate culture, thought to have migrated into the territory from the north and west, bringing with them the burial practice of cremation. … The southern Italian network differs from the other two in its coastal character, and it is difficult not to interpret it as a product of long-distance (in particular, Aegean) contacts rather than local ones. The three RBA subgroups do not map in any clear way onto the territories of the names groups of the first millennium BC." (Blake 2014:102)

Blake's FBA network analysis shows a very different picture of what may have been going on at the time. Gone is the overarching group that reaches along both sides of the Apennine mountains. Instead, there are a larger number of groups made up of a smaller number of sites with their own networks between them. This is coupled with the emergence of new sites. Blake's interpretation is that this difference may reflect newly emerging smaller networks or greater access to objects which would reveal the existence of smaller network groups as a type of regionalism. The intensification of regionalism is evident both in her network analysis as well as in regionalized styles of local ceramics that appear during this time, some of those correlating with the network groups seen here. Blake suggests that these networks are a continuation of the earlier RBA networks, particularly where cohesion between the two times periods can be seen. This is important, as the existence of continued networks would indicate the maintenance of those networks. Determining that a network was maintained would have implications on cultural continuity in the region, importance of trade, how far that trade would have been able to be sustained, and the paths through which information and ideas would have been able to spread.

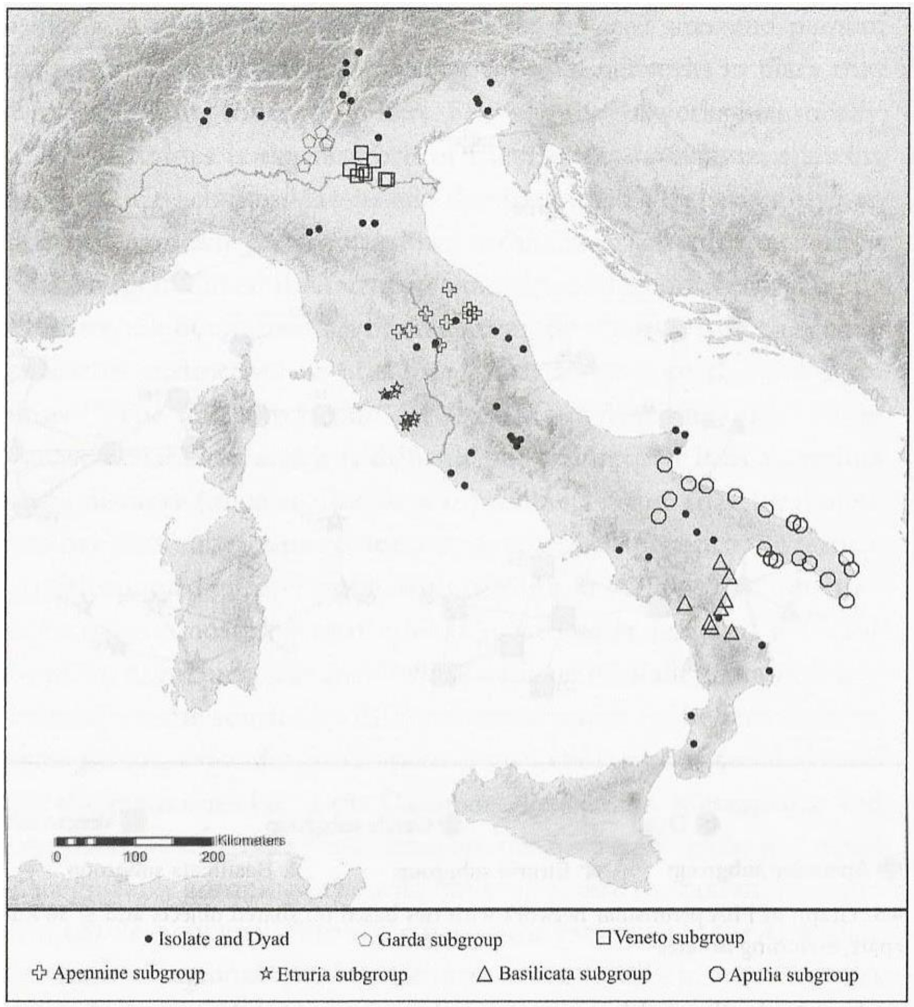


Figure 2.8: FBA distribution of sites by network (Blake 2014:104)

CHAPTER CONCLUSIONS

Making the jump between cultural inferences based on archaeological evidence to network analysis requires a careful and cautious reading of the evidence. The resolution of the node and the content of the link must be meaningfully established before the network is created. This is not unique to archaeological data, in fact it is true of all networks, but it provides a particular challenge to archaeologists as the importance and meaning of archaeological evidence is often obscured through time. In this chapter, I have built up an argument on how artifacts can be used as a form of expression, the importance of style, and how those artifacts can therefore be used to infer trade. Finally, this chapter has culminated in presenting a portion of Blake's treatment of Italian Bronze Age regional identity which uses these concepts in a network analysis framework. For my study, I am more interested in examining how networks of specialized craft knowledge are expressed. The next chapter will provide a framework for connecting final objects to decisions made by craft workers. It is these types of data that my project uses to create the links between nodes.

CHAPTER 3: OBJECTS, MAKING, AND THE MIDDLE GROUND

The previous two chapters have focused on the construction of networks first from people and then from the objects that people use. The example given in the last chapter focused primarily on using the presence or absence of specific types of artifacts in order to define the connections between archaeological sites. This chapter presents the framework for how decisions made during the process of making an object reflect the choice of the craft worker, both intentional and subconscious. This approach narrows down the size of the node in the network. Instead of using the population of a settlement, the node is now confined to the individual or individuals who created an item.

THE IMPORTANCE OF MAKING

Archaeologists studying theory of artifact design have demonstrated that the technical choices of craft workers are meaningful and can inform anthropologists about past communication networks (Farbstein 2011:403). The choices the craft worker makes are informed by their culture and training. As they make these choices, they reinforce the cultural knowledge about the craft. Deviations from the norm can change that norm (Lemonnier 1992:75, Basalla 1998:34, Deitler and Herbich 1998, Stark 1998:10).

Making something is the embodiment of an individual's knowledge about that thing. Wrapped up in the object are stylistic preferences, cultural meanings, and manufacture knowledge that have been learned; some of which are cognizant choices while others have been embedded through enculturation, behaviors learned through interactions over a lifetime (Carr 1995:182). Artifact style, those choices which appear to be based on preference for the final form of an object independent of its use, has often been used as an indication of communication between areas where similar styles are found (Stark 1998:9). Style choices are influenced by a number of factors which include age, gender, occupation, and local tradition. These influences make style a good indication of some unit of cultural affinity as styles vary between groups (Diaz-Andreu *et al.*. 2005). However, objects can be manufactured by people who do not identify with the group to whom the style belongs, particularly when the manufacture requires a specialized skill. If an item is being made for another person, as is most likely the case for bronze swords, a number of factors and individuals can influence the style of the final product.

The decisions craft workers make are based on technological and social restraints (Sackett 1982:104, 1986:269; Carr 1995:215; Miller 2007:239). These decisions are based, in part, on how the craft worker originally obtained their knowledge of the craft (Lemonnier 1992:17,80) which can occur actively through teaching or passively through observation (Carr 1995:131). Technical decisions that are not visible enough to be used for social signaling purposes are more likely to be based on behaviors ingrained through repetitive use and habit (Carr 1995:223, Carr and Maslowski 1995:268). The mechanisms through which learning occurs are one way in which manufacture related decisions reflect real lines of socially meaningful communication (Conkey 1993:113; Farbstein 2011:403). I am focusing on technical decisions to examine how networks of craft knowledge compare to the distribution of established typologies. While style can and does have an effect on manufacture, that effect can be measured by looking at the variety of technical choices which produce the same stylistic outcome. This focus on technical decisions removes the necessity of establishing (with a high degree of uncertainty) who determines the style (the craft worker or the recipient) but does provide a means to examine actions that can be assigned with confidence to a particular set of individuals, in this case, the smiths.

Manufacture knowledge can be obtained through communication between craft workers by teaching, sharing of ideas, and inspection of existing objects. This process creates a network of people who share the same craft knowledge but may have differing enculturated opinions on appropriate use of object or technique. Similarities and differences of manufacture across space can indicate the appropriation of technique by different groups. Comparing the geographic and temporal spread of technique with stylistic typologies should reflect the different levels of complexity in social interactions during this time.

Specialized craft workers are valuable in understanding how groups communicate with each other as they provide goods that are limited (Kuijpers 2008: 51, Neipert 2006), and thus they provide a form of material support for existing power structures (Helms 1993:165; Earle 2000:45). This sociotechnical material based approach is not new to archaeological inquiry (Conkey 1993, 1995; Carr and Maslowski 1995; DeMarrais *et al.* 2004; Miller 2005; Farbstein 2011) and provides a method with which to explore how objects reflect the infrastructures which allow for exchange between communities (Larkin 2013:338; Cook 2004:107; Smith *et al.* 2010:30). Since social identification, messaging, and interaction occur through material objects, the technological production of material objects therefore reflects and informs the production of those social identities (Dobres 2010:165). The methods that one employs to make an object are informed to a large degree by the social constraints on what is known about its construction (Stark 1998:6, Deitler and Herbich 1998). When trade knowledge is taught from one individual to the next, their method of making is usually passed down relatively intact. There are multiple ways that certain processes can be done to reach the same conclusion (Lemonnier 1992:51). In some cases, the deviation does not leave a sign on the final object. For example, whether a smith uses a stone or a clay mold to cast a bronze object will not be visible on the final product (Wang and Ottaway 2004:58) unless some of the clay is left behind. However, certain choices, such as whether to cast on or rivet the hilt of a sword, will be shown on the final object. By mapping all of the options available to a craft worker and noting which deviations will leave a remainder, archaeologists can begin to get a glimpse into the decision making process of the craft worker.

HABITUS

While Pierre Bourdieu was a sociologist, his ideas of *habitus* and practice theory have become integrated into archaeological study by many archaeologists. *Habitus* is the idea that there are certain aspects of society that are ingrained into our being and we follow those aspects without stopping to think about why. It is part of the self-replication of society. Bourdieu defines habitus as:

> "Systems of durable, transposable dispositions, structured structures predisposed to function as structuring structures, that is, as principles of the generation and structuring of practices and representations which can be objectively "regulated" and "regular" without in anyway being the product of obedience to rules, objectively adapted to their goals without presupposing a conscious aiming at ends, or an express mastery of the operations necessary to attain them, and being all this, collectively orchestrated without being the product of the orchestrating action of a conductor" (Bourdieu 1977:72).

If one accepts that there are certain ingrained actions that people of the same culture employ, then there should be archaeological evidence of such actions. Since these actions are unconscious acts, this provides an **etic** view of how groups may have differentiated themselves (Harris 1988).

Deitler and Herbich expand this to look at production of objects and *chaînes opératoires* (or operational sequences) (Deitler and Herbich, 1998). They argue that unlike style itself, which has various levels of possible explanation, the *chaîne opératoire* which a craft worker follows is essentially habitus. There are rules and order to the production, but they are ingrained in the craft worker's understanding of how to create the object (which is in turn informed by the individual who instructed him). Thus, material culture reproduces itself in a particular way depending on the culture, which can then in turn be observed in the archaeological record.

STRUCTURATION

Structuration is one way to separate out cultural pressures from individual choices. The framework of structuration addresses the duality of human choices based on individualistic decisions (freedom) within a societal structure (constraint) (Giddens 1984:281). The choices that individuals make are reflective of the rules and restraints which society places on them. However, these choices also reinforce those same rules and restraints. This cyclical nature of choice and agency is important because it creates a context in which choice can be both actively maintained to reinforce society or identity as well as passively, through subconscious decisions. The mere act of doing anything reflects both the individual's agency on the structure of society as well as society's restraints on the individual. Gardner seats his theoretical framework in structuration, elegantly stating it thusly:

> "Families, ethnic or religious groups, wealth classes, genders, and age grades are based upon – and shaped by – the ways in which people behave: how they dress, how they eat, and how they build and use spaces. Similarities and difference in these activities are the building blocks of social life, and as such they are both controlled by institutions and enacted by individuals. They are therefore likely to be a major factor behind the patterning in archaeological material." (Gardner 2007:197)

Gardner incorporates structuration into examining evidence for every day actions in the archaeological record. Routine activities are those which are normally not under scrutiny by the individuals employing them. Under the theory of structuration, this makes them useful for looking for identity formation. Since routine actions are not necessarily conscious actions, they ought to reflect the relationships between people and objects which are unconsciously dictated by the social structure with which the individual identifies (Giddens 1984:60). Gardner posits that by comparing archaeological deposits, such as coins, and relating them to routine actions across multiple sites and time periods, one can gain an understanding of how those social structures and identity formations are different both chronologically and geospatially (Gardner 2007: 243).

Gardner separates human behavior into three different types of awareness of behavior: **habitual**, **reflective**, and **affective** (Gardner 2007: 19). Structuration theory reflects the importance of habitual behavior. Liminal boundaries have the ability turn a habitual behavior into a reflective behavior. Noticing that a nearby group does something different would likely cause individuals of a society to reflect on that difference and possibly add an affective dimension. Pronounced differences in material remains hold the possibility of a reflective and affective way of doing things which reinforces identities.

CARR'S MIDDLE RANGE THEORY

Christopher Carr incorporated both active and passive identity theories into a unified, hierarchical, organization which allows archaeologists to link stylistic elements to theories of identity. Carr separates style into three major dimensions which are linked: visibility, manufacture decision, and production sequence. Geographic distribution and process constraints are also incorporated (Carr 1995: 182). By examining style from such a broad base and breaking down the aspects of each of his "hierarchies," Carr attempts to create an understanding of style which includes as many variables as possible. From here, he hopes that archaeologists can work with the aspects which are most useful to them for understanding archaeological style.

Carr's unified theory allows the archaeologist to approach style in a way that addresses multiple types of identity formation through archaeologically observable attributes. These considerations include technological, social, and individual constraints, verse the visibility, manufacture decision, and production sequence (Carr 1995: 185)

Carr puts his theory to practice in his analysis of cordage collected by Maslowski from the middle and upper Ohio drainage area dating to 100-1750 AD (Carr and Maslowski 1995). One of the most important factors he observes is that of cordage twist. Carr makes the assumption that direction of the twist is primarily a reflection of passive enculturation due to its relatively low visibility and lack of effect on functionality. This determination comes directly from his middle range theory outlined above. Spatial distributions of direction of spin can identify groups (that learn together), regional boundaries, and interaction between groups. In the Meadowcroft rock shelter area, both Z- and S-twist cordage are found. The Fairchance group to the south is characterized by S-twist cordage and the Wheeling group to the north is characterized by Z-twist cordage (Carr and Maslowski 1995:327). The authors interpret the Meadowcroft site as an area which was used intermittently by both groups.

Following the argument further, the authors examine the attributes of fabrics in the area. By attributing more visible aspects to more active signaling, social motivations are ascribed to the attributes. For example, the authors observed a distinct patterning of spacing in weave variations which correlated to differences in major earthworks and minor sites. This difference was attributed to an active sociopolitical motivation that separated groups by status across the entire Ohio area (Figure 3.1). A distinctly different pattern of textural coarseness correlated to geographic area, suggesting a distinction between groups that could be either active or passive. Carr and Maslowski apply this logic to several other aspects of the fabrics. This approach is useful in that it considers multiple influences for stylistic attributes while still considering how the interaction of those attributes composes the object.

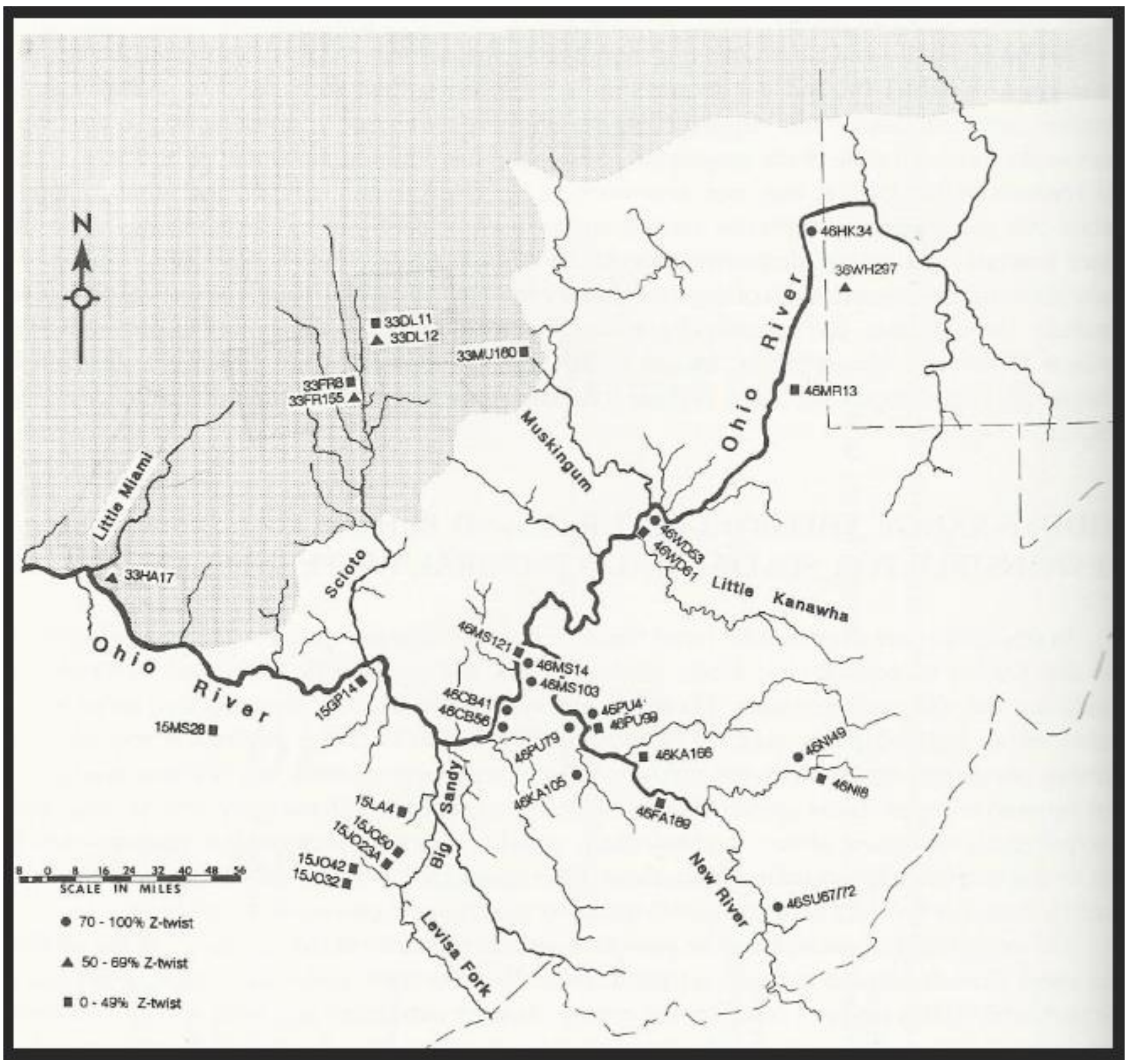


Figure 3.1: Distribution of Z and S twist cordage during the Middle/Late Woodland period of Ohio. (Carr and Maslowski 1995:316)

Conclusions

Every human made object contains clues to its construction in its materials, shape, and structure. Each of these aspects reflects a decision that was made by a craft worker at some point during its creation. The decisions available, such as whether to use a Z- or S-twist when weaving, and the types of evidence preserved vary depending on the object. Some of these choices are dictated by cultural norms or technological constraints of the craft worker. Those choices which are left up to the craft worker are based on the item's function, styles determined by society, and habits formed over the time in which the maker has been learning his or her craft.

In terms of network creation, the node is shifted from settlements to individuals or groups of individuals. Instead of focusing on the presence or absence of a particular type of object as defining where connections existed, we can use decisions of those craft workers for which there is evidence on the object. The inherent problem here is that one individual or group of individuals likely made multiple objects. This problem can be tackled in part by looking at large amounts of data concerning the manufacture of objects and using the interpretive framework presented above concerning the importance of learned behavior in making. Since each object has numerous decisions that go into its creation and those decisions are, to a certain extent, maintained in the shape of the object, comparing the morphology alongside other manufacture choices should provide a baseline of similarity between objects. This similarity can then be used to determine a relationship between the objects, with the potential to suggest that certain objects may have come from the same workshop. I am choosing specifically to look at the workshop level rather than the individual level, as my experience has shown me that craft workers often work in a group environment. This approach provides the opportunity for individuals to share their knowledge.

CHAPTER 4: TECHNOLOGY AS A TOOL

Thus far, I have described network configurations, examined how objects reflect the people that use them, described the importance of decision making during object creation, and discussed how these concepts could be used to create a network of past cultures. In this chapter, I look at how modern technology can be used as a tool to determine what data points for analysis can be collected beyond ordinary observation. In particular, I am interested in how 3D scanning of objects can be used to quantify the shape of an object. Since each object has numerous decisions that go into its creation and those decisions are, to a certain extent, maintained in the shape of the object, comparing the morphology alongside other manufacture choices provides a series of data that can be used to compare objects.

Three dimensional scanning of objects for archaeological research shows potential to enhance understanding of artifact shape. Measuring shape for the purpose of classification is not a new idea; however, the additional information provided by scanning opens up new avenues of comparison. This section will give an overview of the history of 3D scanning, discuss the details of scanning processes, and provide case studies of different types of analyses than can be performed on 3D objects. The focus of these examples is to show case studies where the authors have gone beyond scanning the object and provided interesting insights that are unique to the information that 3D data provide.

3D Scanning

The underlying framework of 3D scanning is that data points can be collected from the real world as a **point cloud** and combined to create an object made up of polygons, NURB (non-uniform rational B-spline) surfaces, or parametric curves (as discussed later in this section). The earliest automated method of collecting data was through the use of CT scanning (computerized tomography), where data are collected from multiple x-rays. The first CT scan was successfully taken in 1971 (Beckmann 2006:6) creating an environment which favored biological studies in 3D analysis early on. Figure 4.1 is an image that was published by Herman and Liu in 1979 using this method (Herman and Liu 1979:12). Light based scanning, through lasers and white light, shortly followed. One of the earliest laser scanners was produced in 1978 by the National Research Council of Canada (NRC). It was based on measuring the triangulated distance of a single laser point with multiple cameras. Other methods of acquisition include **slit scanning** (using a laser line instead of a point), **structured white light scanning**, and **time of flight** (the measurement of time a laser light takes to reflect back) (Blais 2004:66).

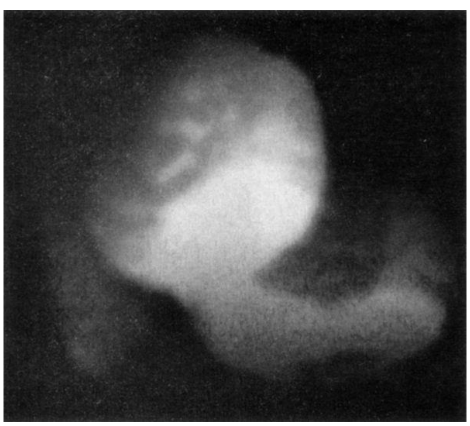


Figure 4.1: Knee joint as published by Herman. The fuzzy quality of the patella is indicative of the quality of scans at the time. (Herman & Liu 1979:12)

All of these methods were being developed simultaneously throughout the late 1970s and early 1980s (Lanman and Taubin 2009:5, Blais 2004). Two key products which have been integrated into the archaeological realm of study are the NextEngine Scanner, a small, inexpensive laser scanner, and MeshLab, a shareware product produced by archaeologists for the purpose of manipulating point cloud data and outputting the data into a format which is legible by analytical software packages such as AutoCAD (Cignoni *et al.* 2008). Today, the use of .obj. and. stl files, neutral 3D file types, allows for the sharing of original quality data with users who have 3D editing software. These types of files are non-proprietary files that contain the information needed to display the 3D model, similarly to how a .txt file can be used to share text without the need for a specific program. Alternatively, the Adobe reader platform began supporting 3D objects in January 2010 (Buchgraber *et al.* 2010:64), providing a method for the dissemination of .pdf files containing the objects. Other freeware platforms, such as RapidForm Basis and QuickTime VR, are also available for the sharing of 3D data without the need for expensive 3D software.

Geometric Morphometrics

Where 3D scanning is the method of capture for large data sets, Geometric Morphometrics (GM) is the way in which these data are analyzed. GM is a method of shape analysis that relies on measuring the difference between multiple homologous points on two or more objects. This type of analysis uses a multivariate statistical approach to determine how similar multiple shapes are and where they differ. GM is rooted in Kendall's early work on two dimensional shape analysis in the late (Kendall 1977; Kendall and Kendall 1980). For a comparison of different approaches, the reader is referred to Rohlf and Bookstein (2003) or Small (1988).

The first step for comparison is to choose landmarks on the shape of the object for analysis. Dryden and Mardia define shape thusly based on Kendall's observations

(Kendall 1977) as “all the geometrical information that remains when location, scale and rotational effects are filtered out from an object,” (Dryden and Mardia 1988:1) A **landmark** is “a point of correspondence on each object that matches between and within populations,” (Dryden and Mardia 1988:3). Given the above definitions, landmarks for 2D analysis must be chosen carefully.

> “Ideally, landmarks are (1) homologous anatomical loci that (2) do not alter their topological positions relative to other landmarks, (3) provide adequate coverage of the morphology, (4) can be found repeatedly and reliably, and (5) lie within the same plane.” (Zelditch *et al.* 2004:24)

Geometric morphometrics lends itself well to biological specimens due to the presence of homologous points found in anatomical specimen. However, so long as the above conditions are fulfilled, landmarks can be chosen on any type of object. Thus, geometric morphometrics can be applied to artifacts. Due to the varying degrees with which the above conditions can be fulfilled, there is a distinction in the type of landmark that is being used in the analysis. There are three types of landmarks (Bookstein 1992:63). Type I landmarks are defined locally, usually by the intersection of particular structures. Type II are defined by local minimum or maximum of a curve. Type III, or semi-landmarks, are

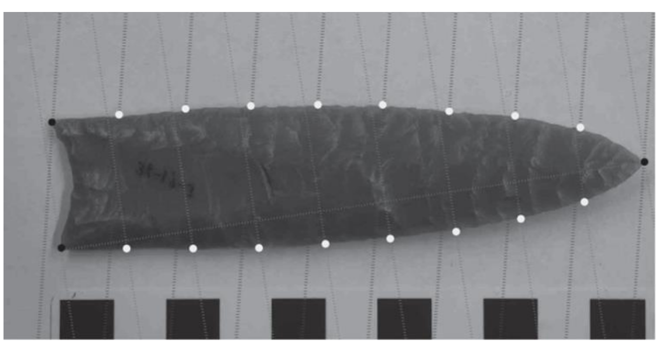


Figure 4.2: Landmark points placed on the lithic image (Buchannan and Collard 2010)

defined in reference to type I or type II landmarks by distance. In figure 23, the black points are type II landmarks and the white points are type III landmarks.

Once landmarks are chosen, a variety of analyses can be applied to determine the significance of shape changes. The data can first be simplified by using **principal component analysis** (PCA) for variation among individuals or by using **canonical variates analysis** (CVA) for variation between groups. A **t-test** will show if the means of the different data sets (either for different individuals or different groups) are the same or different. An **analysis of variance** (ANOVA) can then be carried out using an ***F*-test**, which tests the difference between the two groups by dividing the variance in the overall sample by the variance within the group. "If the means [of two groups] are far apart, a large proportion of individuals will be closer to their respective group means than to the grand mean, the value of F will be high, and the classes will be judged significantly different" (Zelditch *et al.* 2004:213).

The incorporation of morphometric analysis as a means to study how objects are interrelated comes from paleoanthropological inquiries often dealing with speciation (Rohlf and Marcus 1993). These methods of analysis have begun to be used in archaeology (Guidi *et al.* 2004), particularly in the field of lithic analysis (Monnier & McNulty 2009; Saragusti *et al.* 2005; Grosman *et al.* 2008, 2011). For example, one way of examining shape in stone tool assemblages is through Fourier curves (Ioviţă 2009:1450; Ioviţă and McPherron 2011:63). Ioviţă (2009) uses a regression of size to shape (represented by Fourier curve co-efficients) to understand the relationship between technological, functional, and stylistic choices in European Middle Paleolithic bifacial and unifacial assemblages. This framework of comparison is the basis of the types of analyses that I will use on LBA blades. Other studies in lithic analysis have modeled the interaction between exchange networks and population fissioning using both cladistics and trait based analyses (Collard *et al.* 2006). In this dissertation, I use these statistical techniques to examine shape and technical craft decisions visible in bronze blades in comparison to geographic and temporal data. The results of these analyses will provide information on how similar blades are among and between different typological designations, which can then be used to interpret the communication networks smiths were engaging in.

Through this study I am mainly examining shape as a technical choice. While shape is tied to style as well as intended use, there is still allowance for variation within that shape (Wiessner 1983:271; Sackett 1985:155; Wobst 1977:317; Carr 1995:158). It is this smaller level of variation which I am equating to technical choice, whereas the larger patterns of shape will be considered as stylistic signaling. In the case of blade profiles, there are fewer blade types than there are hilt types. Thus, the relationship of shape in comparison to style will be used to investigate how communication occurs within style groups. For the purposes of this study, style groups will consist of those typologies previously established through the *Prähistorische Bronzefunde* (1970-2009), discussed in Chapter Seven. This consideration of style allows for the null hypothesis that visual signaling influences the shape so severely that there is no room for individual differences in technical choices.

3D ANALYSIS OF ARCHAEOLOGICAL MATERIALS

Archaeologists have used 3D scans of ceramics for analytical studies as well as with methodological studies. Of note are the *Forma Urbis Romae* Project and the use of 3D scanning to automatically assign ceramic vessel classifications. The Forma Urbis Romae Project, beginning in 1999, utilized automated boundary incision matching and feature matching to reassemble approximately 1,186 pieces of the broken map of the Severan Marble Plan of Rome (The Forma Urbis Romae), a marble map of the city created during the Severan Period circa 193-235AD (Koller *et al.* 2005:237) (Figure 4.4). The Computerized Archaeology laboratory at the Archaeological Institute of the Hebrew University has likewise turned to computer algorithms for a streamlined approach towards ceramics. In 2010, Karasik implemented an automatic classification system. Once the object is scanned in, profiles are taken from several angles to increase the accuracy of the algorithm. Finally, the principal components are compared and the algorithm creates a branching classification such as that in Figure 4.3. This process is described in more detail further on in this paper. Once classified, discriminate analysis

Figure 4.3: Part of the Forma Urbis Romae (Koller *et al.* 2005:252)

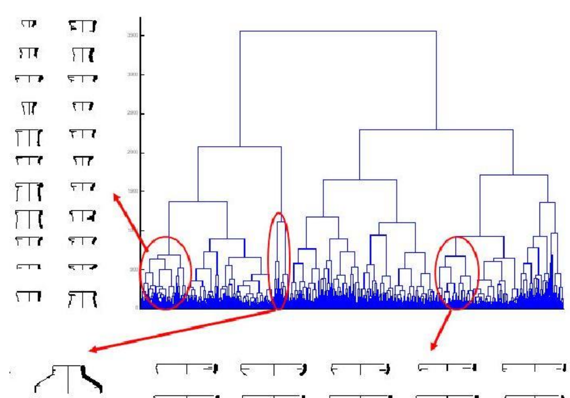


Figure 4.4: Automated Classification Groups (Karasik 2010:33)

tests were run to test the significance of the created classification (Karasik 2010:32).

SHAPE ANALYSIS

Shape analysis is at the core of all 3D modeling analysis. Without it, the data captured during the scanning phase would never be aligned, merged into a whole object, or **decimated** to remove iterative points. Shape analysis can also be used to learn something about the object being studied. The chart shown in Figure 4.5 from van Kaick *et al.* provides a general overview of the different types of shape analysis (van Kaick *et al.* 2011:1700). Of these types, topology change is the most interesting from an archaeological perspective. This type of analysis quantifies the measurement of difference and determines significance between two or more objects.

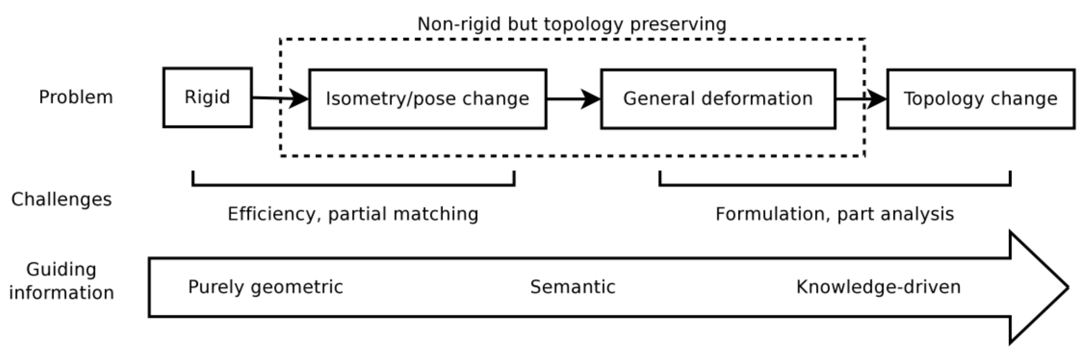


Figure 4.5: Types of shape analysis (van Kaick *et al.* 2011:1700)

Masuda *et al.* (2003) use typological comparisons to examine how bronze mirrors made from the same mold cycle change over time. The archaeological assemblage consists of three sibling mirrors (mirrors of the same pattern, likely from the same mold cycle). The mirrors are interpreted to be Chinese propaganda imports to Japan during the

Yayoi period (AD 234) based on the Chinese symbol on the back. A mold cycle begins with the original mold and casting. From that point, a new mold can be made from the cast object or the pattern that the original mold was made from. Figure 4.6 depicts the proposed mold cycle of the mirrors by Masuda *et al.* As the mold is re-used or remade, the pattern wears, providing a potential indication of casting sequence for the mirrors.

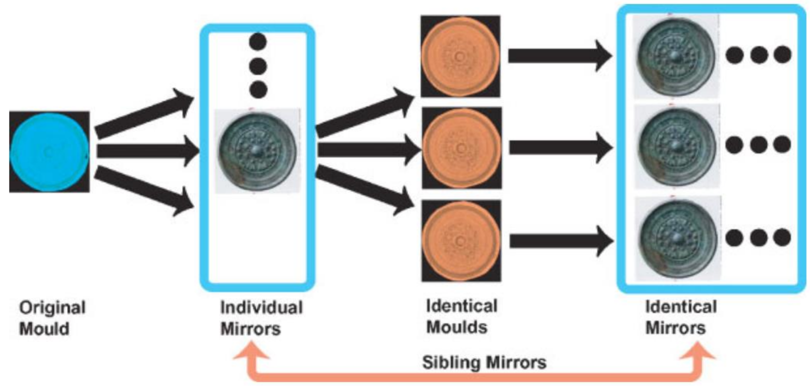


Figure 4.6: Mold cycle of sibling mirrors (Masuda et al. 2003:184)

The mirrors were scanned and aligned to compare the shape differences for signs of individual wear and deformations that may have been created during the casting process. Each model was then aligned to a single model and the distanced between the nearest neighbor is calculated and visually represented. The distinction between global difference and local difference is made based on the extremity of the difference. In Figure 4.7, the image on the left shows the bending of the upper left section and the sinking of the center. These are global changes that appear only on the Kurozuka

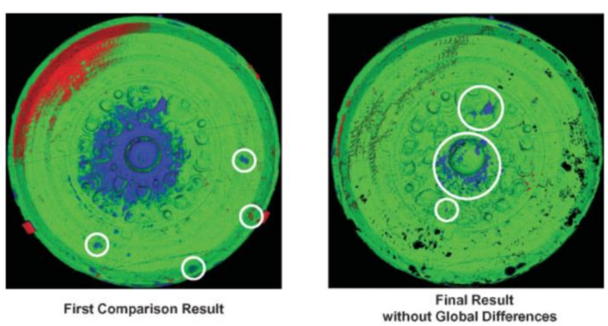


Figure 4.7: Global and local differences between two mirrors. (Masuda *et al.* 2003: 187)

mirror, and thus would have appeared after the casting of the mirror. Local differences, depicted by the right image in figure 4.7, are more likely to have occurred during the casting of the mirror, but may also be caused by factors such as corrosion.

A second set of mirrors from Chohoji-Minamihara were used to test manufacture order. These mirrors were already accepted to come from the same mold cycle making them good candidates for the test. By studying local difference (shown in figure 4.8), Masuda *et al.* observed that the original convex shape on the mirror became more convex as multiple casts were made, likely due to wear on the mold. By measuring the distance between four such local differences, the mirrors were placed in a manufacturing order (Dsamida08, Dchoh02, Dchoh1, Dhebo02-63, Dnisik-75).

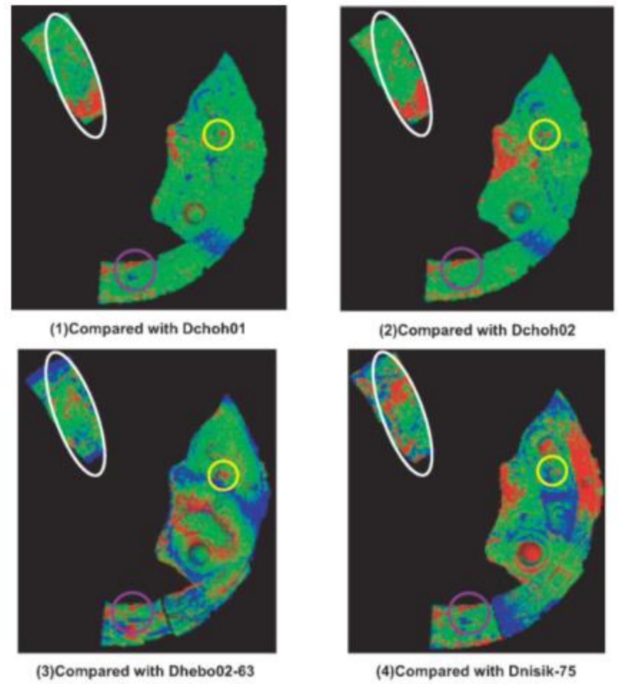


Figure 4.8: Comparisons of local differences between Chohoji-Minamihara mirrors. (Masuda *et al.* 2003:190).

CLASSIFICATION

The classification of artifacts allows archaeologists to determine the significance of similarities between multiple assemblages. Collecting three dimensional data and classifying it by means of an algorithm creates the possibility to compare and classify large assemblages of similar artifacts, most notably ceramics and lithics. Often, the measurement of these objects manually is more subjective than the observer would like due to the inherent difficulty of consistently aligning and measuring the materials. In addition to automating this process and enhancing consistency, 3D scans aid in the comparison of ceramic body sherds and in the comparison of large numbers of sherds. This paper focuses on two particular examples. The first is a series of papers published by Karasik and Smilansky. (2008, 2010, 2011) detailing the automatic classification methods used by the Archaeological Institute at the Hebrew University in Jerusalem. The second study is that of Grosman *et al.* (2008), which focuses on lithic analysis. The use of these two procedures in tandem is meant to point out the methodological similarities between different artifact classes. The procedure as a whole is broken into the categories of alignment, measurements, and comparison for classification.

The first step in automated classification is to find the proper alignment of the object. Karasik and Smilansky note the importance of this step by demonstrating that improper alignment of a ceramic sherd can result in drastically different interpretations of the vessel as shown in Figure 4.9 (Karasik and Smilansky 2008:1152). Described here are two different means of aligning artifacts: that used by Karasik and Smilansky for ceramic analyses and one used by Grosman *et al.* for lithic analysis.

Karasik and Smilansky define "optimal positioning" where all points at a given height are equidistant from the axis (Karasik and Smilansky 2008: 1152). First, the individual scanning the object places the sherd in an approximation of the correct position. Once scanned, all broken edges and pieces which would not have been part of the outer surface are removed and all remaining faces of the scan are represented by normals (each normal is vector which is perpendicular to the center of the surface). From the normals, a line which runs through the intersection of concentric circles created by the walls can be found along with a best fitting plane tangent to the rim. The tangent plane approximates the exercise of placing a rim on a table. The intersection of the circles may appear as a single point, or may appear as a cluster of points. This is dependent on the true symmetry of the vessel, as deformations in the shape will cause clustering to appear. With these two pieces of information, the sherd can then be aligned to an optimal position.

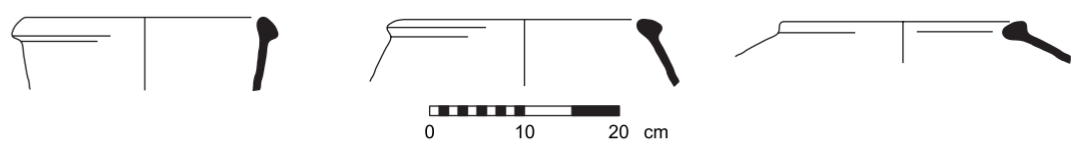


Figure 4.9: Multiple alignment options for a single sherd. (Karasik and Smilansky 2008:1152).

Grosman *et al.* also use the principle of normal vectors for the purpose of alignment. Figure 4.10 depicts the direction of normals on an Acheulian hand axe. The majority of normals point in either a perpendicular or parallel direction to an unseen plane which represents a plane of symmetry, traditionally the plane in which a lithic is drawn. An algorithm can then be applied to determine the vector which is parallel to most of the surface normals (Grosman *et al.* 2008:3105). This vector is then used to align the object.

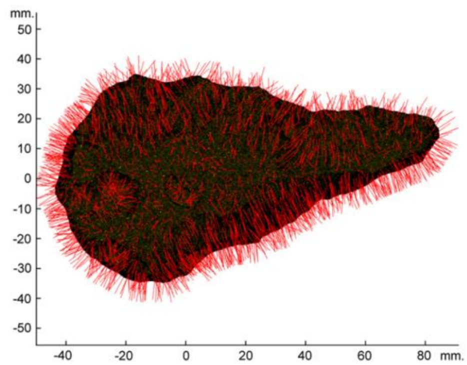


Figure 4.10: Depiction of normals (Grosman *et al.* 2008:3104)

Taking measurements from a three-dimensional scan can include traditional measurements taken by hand as well as measurements that are more difficult to record without the scanning procedure. Karasik and Smilansky focus their measurements on the profile curve of the pot sherds, though measurements such as diameter of the completed pot and wall width can also be taken. Of note is the difference between a profile taken at a particular point and the mean profile of the entire sherd. The second measurement is used for final drawings and comparisons as it minimizes defects in the sherd. Grosman *et al.* collect standard width and length measurements, as shown in figure 4.11, along with those made accessible due to the three dimensional nature of the scan, such as volume, surface area, and the center of mass (Grosman *et al.* 2008: 3106).

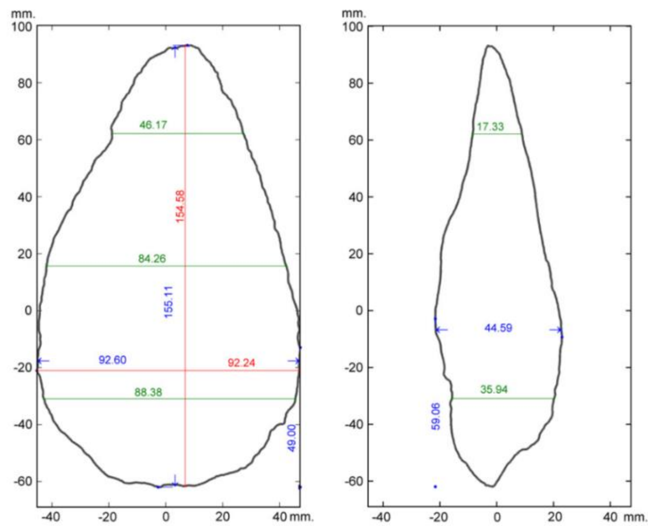


Figure 4.11: Length and width measurements (Grosman *et al.* 2008:3107)

Once measurements are taken, comparisons can be made for classificatory purposes. Here, the two case studies differ slightly. Karasik and Smilansky use an automated classification system while Grosman *et al.* compare different measurements as indicators of temporal related shape change.

The method Karasik and Smilansky use relies on the mathematical representation of the radius, tangent, and curvature of the sherd profile. This separation allows multiple sherds to be compared by the individual aspects of the curve, or by taking all three into consideration. For example, the radius emphasizes size difference, tangent emphasizes thickened areas of the vessel, and curvature emphasizes finer details of the shape (Karasik and Smilansky 2011: 2646). The mathematical representation also allows for a theoretical mean of a sherd type to be created based on multiple sherds of that type. Figure 4.12 shows the representation of these values on two ceramic sherd profiles. Once the mathematical representations have been computed, the "distance", or difference, between multiple sherds can be calculated. To do this, first a principal component analysis is performed. This transforms the data such that redundant data are removed and only portions of the profile which provide variability are considered. Next, a cluster analysis is done to create a branching tree. The original types are created by looking at overall profile, and then each branch is separated out by emphasizing finer aspects of the sherd profile equations, resulting in multiple levels of "type-codes". Then, a discriminant analysis test is run to confirm the statistical significance of the groups. Finally, the groups should be analyzed by an archaeologist to determine if the groups make sense or if the parameters need to be adjusted and the functions re-run.

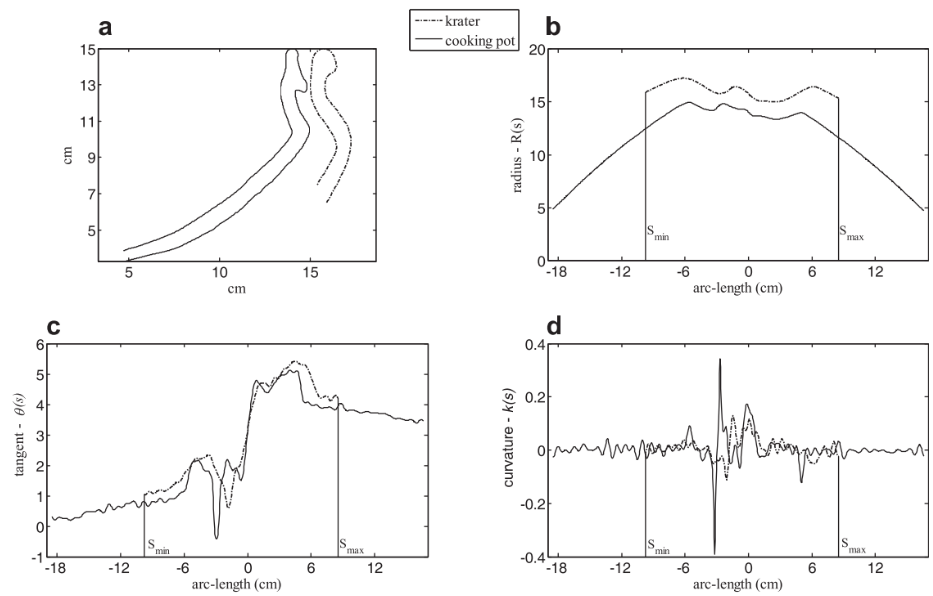


Figure 4.12: Comparison of the profile curve (A), radius (B), tangent (C), and curvature (D) of two sherds. (Karasik and Smilansky 2011:2645)

Grosman *et al.* take a less automated approach. In their study of 90 hand axes, classification is determined two ways. The first is by plotting length and width measurements taken from the 3D scan data. This method mirrors traditional methods of classification. Once completed, Grosman *et al.* plotted volume against the distance between the center of mass and the center of the enclosed cube, the minimum square area in which the hand axe fits, (Figure 4.10). This secondary method provided similar conclusions to those of the first method, namely that hand axes from the Nahal Zihor E site differ from the other groups. Thus, those hand axes are likely from an earlier time period. The authors note that even though the refinement, raw materials, and manufacturing technologies of the other three groups differ, they cluster in both the traditional plots and the plots generated from three dimensional dependent data.

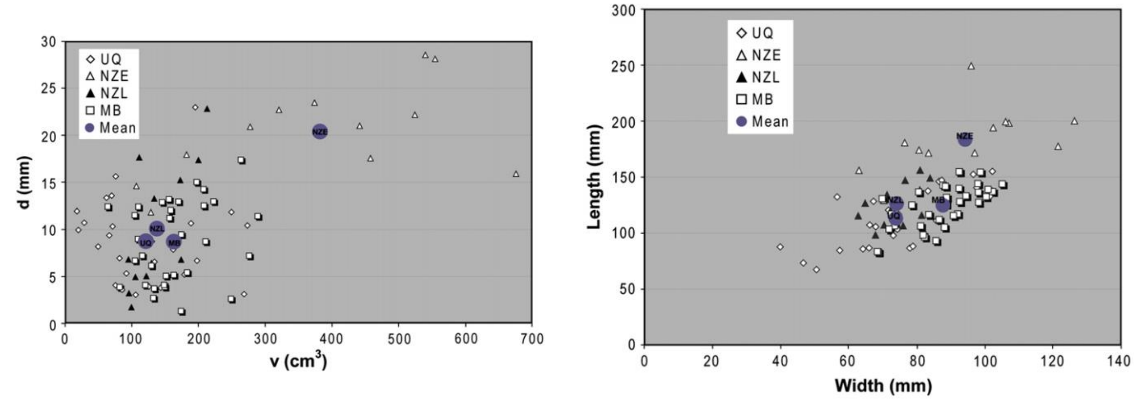


Figure 4.13: Traditional measurements and 3D dependent measurements plotted for comparison (Grosman *et al.* 2008:3109).

CONCLUSIONS

3D scanning, shape analysis, and geometric morphometrics provide a means for quantifying and comparing the shapes that make up objects. In the case of an object that has a set shape, such as the bronze swords in this study, this is a powerful tool for observing the minute details that separate one object from the next. These data combined with style and other observational data provide the connections which will make up the networks observed. They can be compared in part (i.e. style is one connection and blade profile a separate connection), or they can be used in total as a conglomerate of all the decisions the smiths make. Thus, the blades can be compared for overall similarity in determining the possibility of coming from the same workshop as well as be used as separate nodes on a network. When the blades are their own nodal points, it is important to note that they represent the knowledge of the smith encapsulated in a single object and not the smith him/herself.

PART II:
THE LATE BRONZE AGE, SWORDS, AND SWORD MAKING

Chapter 5: The Late Bronze Age

Late Bronze Age life provided the context and worldview within which swords smiths operated. Their craft and knowledge of that craft was informed by their everyday life and the social construction around them. This chapter discusses different aspects of life primarily during the Late Bronze Age. In the following order, subsistence, settlements, craft and technology, societal organization, religion, and hoarding will be discussed. Later chapters will discuss the smiths themselves and the casting process.

The period known as the Bronze Age in temperate Europe roughly refers to the years between 2000 – 800BC. The name itself comes from the three age system developed by the Danish antiquarian C. J. Thomsen published in 1836 and refers to the use of bronze as the main material for tools and weapons. During this time, bronze was used for axes, swords, shields, sickles, scythes, figurines, and jewelry. The use of bronze increased gradually throughout the Bronze Age. Eventually, it was to make objects previously made using clay, such as bowls, and stone, such as axes or hammers. Traditionally, the Bronze Age is divided into an Early, Middle and Late period. The primary focus of this discussion is the Late Bronze Age, defined here as circa 1200-800BC, in Central Europe, one version of which is depicted in Figure 5.1. The majority of examples will come from this area. Given the large time frame and geographic area to be covered, it is inevitable that there was local variation in culture and finds; however many of the major aspects of life were consistent throughout the Bronze Age and across the European continent. Where better examples exist from the Early or Middle Bronze Age or neighboring geography, they will be used.

Several chronologies are used across Europe to define the Bronze Age. For this disseration the following definitions are used: Early (2000-1800BC), Middle (1800-1200BC), and Late (1200-800BC) as descriptors; however it is worth mentioning the system developed by Reinecke (1899). The Reinecke system has been adopted by the majority of researchers writing about the Central European Bronze Age. Reinecke based his system on typological changes of primarily bronze artifacts. This system is the one

Figure 5.1: Map of Central Europe. Map created using Google Maps. Imagery ©TerraMetrics

used in the *Prähistorische Bronzefunde* series, in which much of the data concerning bronze swords has been published. The Reinecke system is prevalent among works discussing the Central European Bronze Age and spans the *Bronzezeit* (Bz) and *Hallstatt* (Ha) terminologies. Both the Bz and the Ha are divided into A-D periods, with some subdivision within these as depicted in Figure 5.2. The Late Bronze Age spans the

HaA1, HaA2, HaB1, and HaB2/3 periods. The Ha C and D periods cover the Early Iron Age (Roberts, Uckelmann, and Brandherm 2013:20).

The Late Bronze Age is distinguished from the earlier periods by an intensification of agriculture, the introduction of metal hilted swords as opposed to organic hilted swords, an increase in metal production, a shift in burial practices, and the beginnings of defensive settlements with indications of specialized craftworkers. The burial shift from inhumation graves to cremation graves is of particular note during this period as it suggests a change in religious practices and beliefs. The period is often given the name the Urnfield period. This descriptor references the fields where groups of cremation graves in urns have been found.

SUBSISTENCE

Subsistence during the Bronze Age is characterized by small agricultural communities with domesticated cattle, sheep, goats, and pigs (Earle 2002:310), with some hunting of roe and red deer as well as other wild animals. By the Late Bronze Age, most land across Central Europe had been cleared for the purpose of fields. The clearing period was followed by intensification of agriculture coupled with pastoral practices, as is indicated both by archaeological structures as well as pollen diagrams (Kristiansen & Rowlands 1998:104).

Domesticated animals are present in the faunal record in the form of cattle, sheep/goat, pigs, and dogs (Sørensen 1989:470). Figure 5.3 shows a distribution of suid, caprid, and bovid species as observed across 238 sites (Bartosiewicz 2013:330).

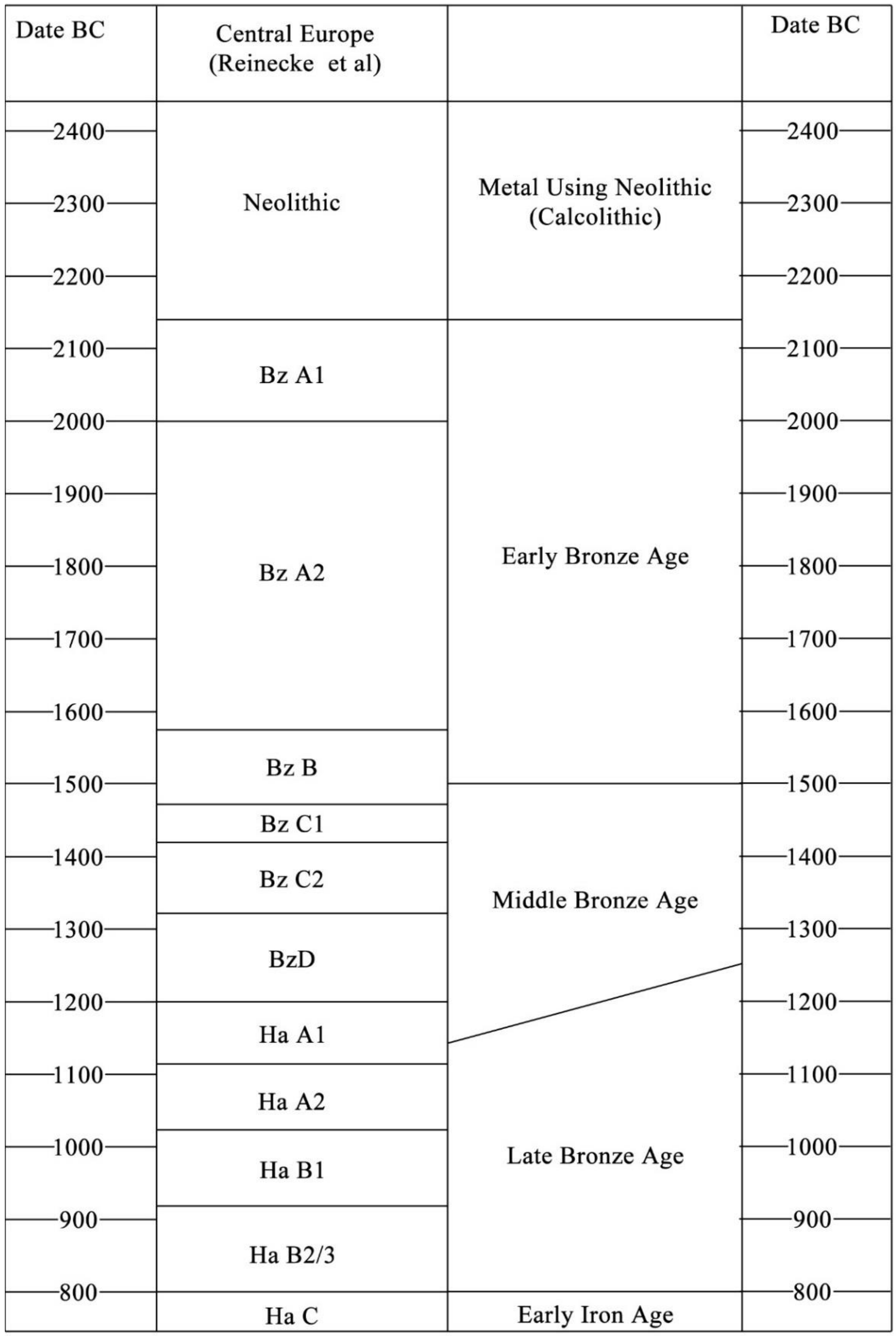


Figure 5.2: Breakdown of Reinecke chronology after Roberts, Uckelmann, and Brandherm (2013: 19-20)

Some areas, particularly in Hungary, also contained finds of horse bone, though typically less than 5% of the animal population consisted of horse where they are found (Müller 1993). In contrast to the rising number of domesticated animals, the number of wild animal finds related to human activity such as hunting decreased throughout the Bronze Age. Wild animal finds typically consist of red deer, roe deer, and aurochs (Vretemark 2010:158). This distribution of domestic versus wild animal bones on sites indicates a reliance on primarily domesticated animals.

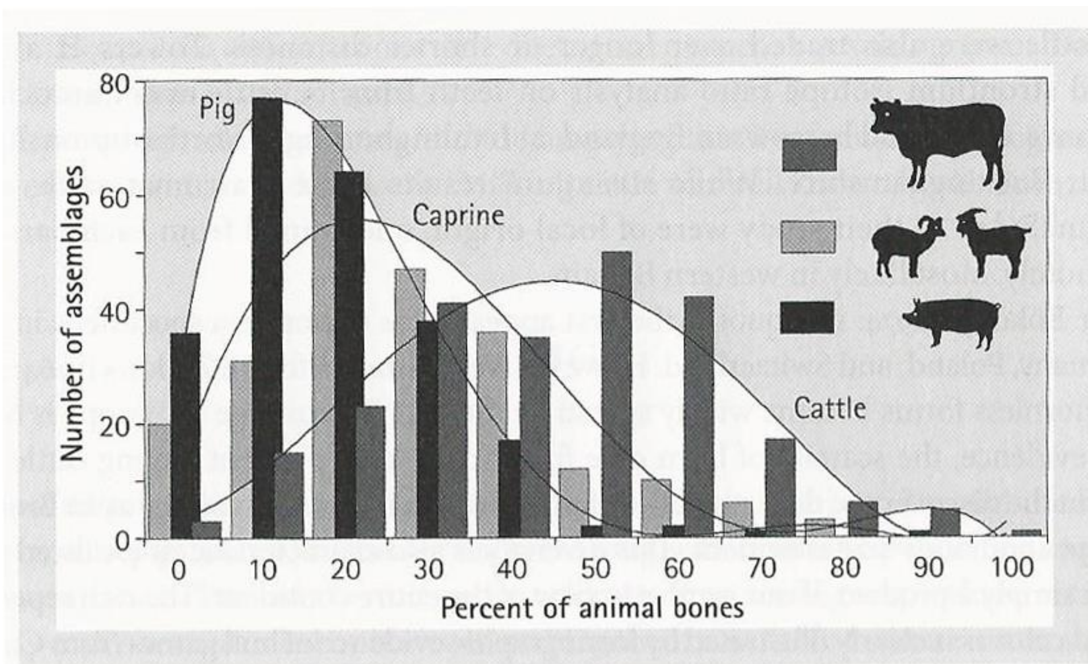


Figure 5.3: Cattle, suid, and caprid distributions across 238 Bronze Age Sites. (Bartosiewicz 2013:330)

Animal husbandry provides resources beyond meat. Animals used for other resources, such as milking cows, typically live for longer than animals raised for meat. The age and distribution of animals remains change based on their use. For example, in Százhalombatta-Földvár, Hungary (Figure 5.4) during the LBA the bones of sheep were skewed towards having older animals with approximately two-thirds of the population being female. The age at death profile indicates that the sheep were being bred for the purpose of wool. Pigs at the site rarely made it past the juvenile stage, which is more consistent with breeding for meat (Vretemark 2010:158).

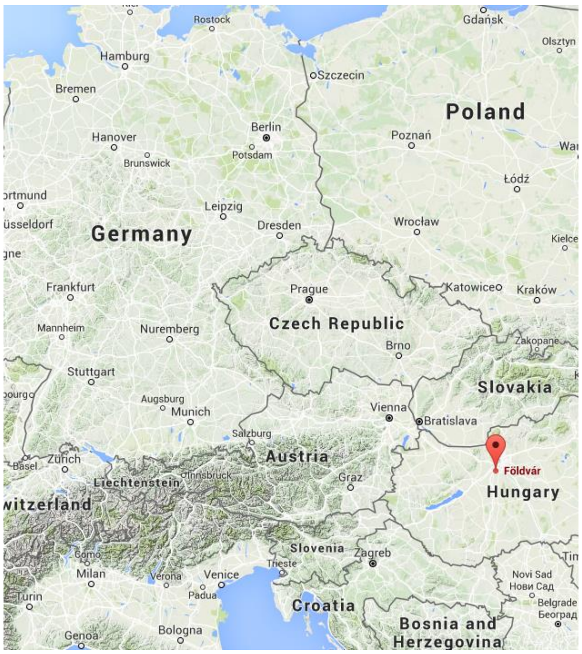


Figure 5.4: Százhalombatta-Földvár, Hungary
Map data ©2016 Google

The major crops grown included wheat, barley, lentils, peas, and beans. During the Late Bronze Age, crops such as spelt wheat, millet, legumes, flax, and oil-bearing plants became more prevalent. In addition to cultivated crops, there is evidence that people gathered plants, such as fruits. Organic remains of fruits and berries have been found in the wet preserved sites near the Swiss Alps (Stika and Heiss 2013).

In addition to plant and animal remains, a number of artifacts have been found which support the use of domesticated plants and animals. Sickles and reaping knives are found throughout the Bronze Age, with their number increasing during the LBA. This increase in number and the use of bronze to make the sickles is another indication of increased agricultural production during the time (Wells 1989). The rise of sickle production is also notable as sickles are one of the types of bronze materials that frequently show up in hoards. Farming implements were also made from antler, bone, and stone. Tools such as spades, ards, and digging sticks, all of which are primarily made of wood, are not common and often are prone to preservation issues, but have been found in sites such as Sergeevsk and Vebbestrup in Denmark (Harding 2000:126). These types of tools would have been necessary for planting.

Other evidence for plant and animal domestication is found in rock art and the presence of fences. Rock art in the Camonica Valley depicts several farming activities, including an ard being pulled by animals, possibly oxen as shown in Figure 5.4. Post holes in a shape that indicates fencing have been found at of Trelystan, Powys in the United Kingdom (Britnell *et al.* 1982). These structures could have been used to delineate field boundaries for the purpose of keeping other people out and their animals in. These types of evidence in conjunction with animal and plant remains show that LBA peoples had integrated domesticated plants and animals into their way of life.

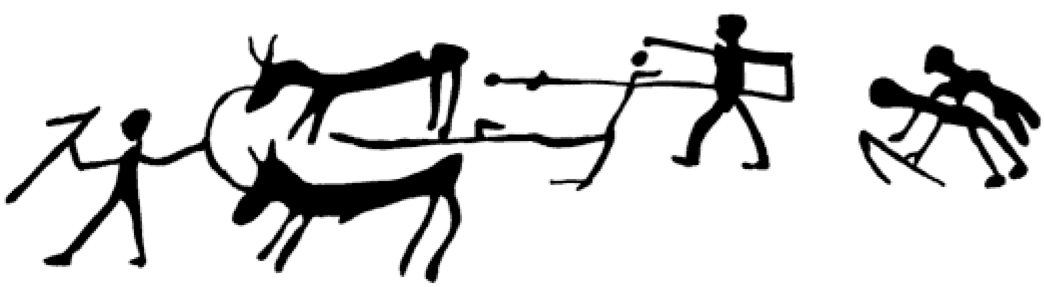


Figure 5.5: Rock art from Camonica Valley depicting the plowing of fields. (Anati 1961:117) Map data ©2016 Google

SETTLEMENTS

During the LBA, most settlements were small, agrarian villages composed of family units (Earle and Kristiansen 2010:16), though a few sites present evidence for somewhat larger fortified hill sites including Nitriansky Hrádock in Slovakia (Figure 5.6) (Točík 1981), Wittnauer Horn in Switzerland (Bersu 1945) and the Bia and Sóskút hillforts in Hungary (Earle and Kristiansen 2010:76) . The size of settlements is typically determined by the acreage and the size of associated grave sites. LBA settlements range from half a dozen people in a single farmstead to two or three hundred in a large village (Earle and Kolb 2010:71,83). A settlement consists of several enclosed buildings, evidence of a hearth, oven, or other cooking place, and artifact debris. Most settlements fit one of the patterns discussed below and contained houses that are rectangular in their shape.

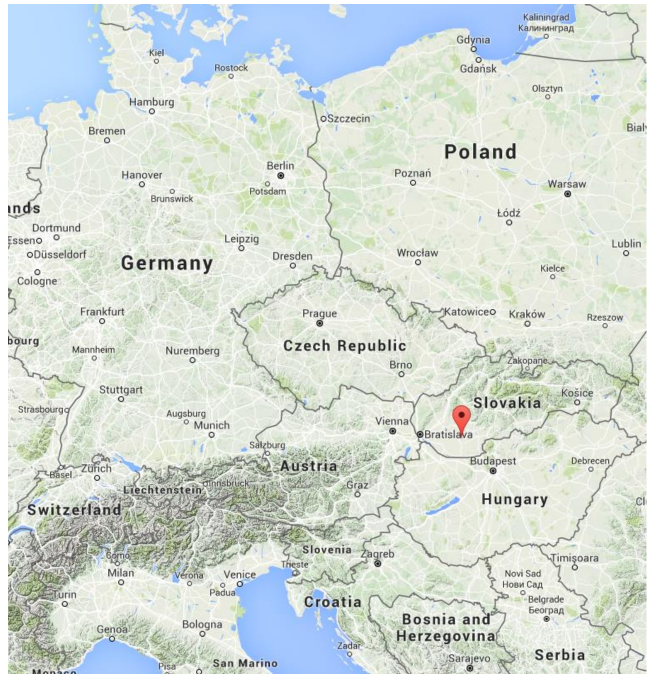


Figure 5.6: Nitriansky Hrádock in Slovakia
Map data ©2016 Google

HOUSES

Houses are a distinct category of building defined by their size and function. These buildings may be, but are not necessarily, related to family units. Sørensen's definition of a **household** is "a constellation of people who live together most of the time and who, between them, share the activities needed to sustain themselves as a group in terms of sustenance and social needs" (Sørensen 2010: 125). This unit is not necessarily a family unit, though it can be. A house, therefore, is the environment in which household activities take place.

During the Bronze Age, there were two main types of houses found throughout Europe. These include circular houses and rectilinear houses. Rectilinear houses comprise the majority of houses throughout Central Europe during the Bronze Age. The size and shape of houses are determined by the placement of post holes and the occasional beam or low stone banks, which would have helped support the walls. Most houses were made using the wattle and daub technique. Wattle and daub buildings are constructed by laying a base latticework of posts and sticks, the wattle, which is then filled in with mud, clay, and debris, the daub (Figure 5.7). The floors were often packed clay, but there are some examples of wooden floors. The site of Zürich-Mozartstrasse, preserved by waterlogged conditions, exhibited stone floors in earlier phases and wooden floors built on top of the stone in later phases (Harding 2000:40). These types of

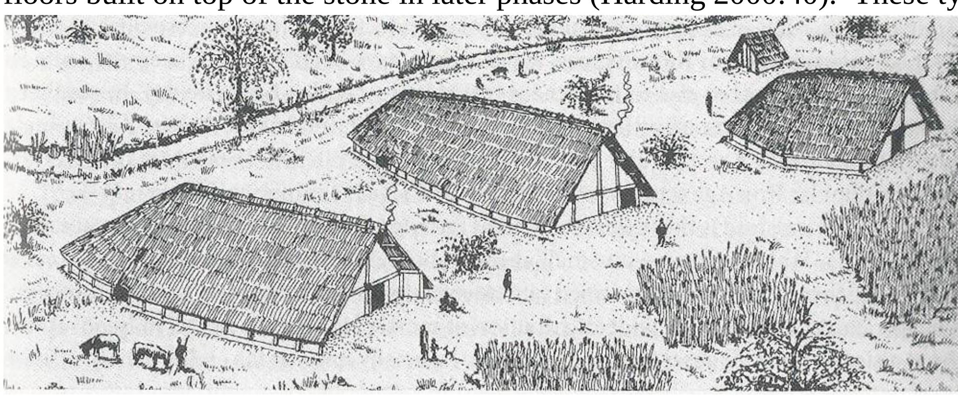


Figure 5.7: Reconstruction of Wattle and Daub buildings at Zuchering-Ingolstadt. (Jockenhövel 2013:738)

structures are also found further north, such as the Trappendal site. Housing beams are evidence that some of the homes may have been either one or two levels high. Structures associated with houses include well heads, posts for fences, hearths, storage pits, and deposits. There is no evidence that access to buildings was restricted through the use of keys during the Bronze Age.

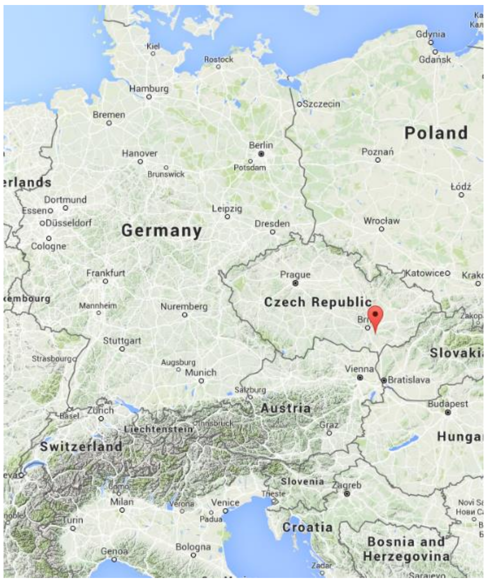


Figure 5.8: Lovčičky, Moravia
Map data ©2016 Google

Rectangular houses varied, with larger buildings being up to 35m in length or more (Harding 2000:48). The Late Bronze Age has more evidence for smaller homes that likely housed units of five to seven people. While large buildings are present during the LBA, smaller buildings are more frequent than previously. This shift is also marked by individual buildings being used for specific purposes outside of home uses. Lovčičky, Moravia (Figure 5.8) was a village site that contained 48 such buildings of mixed sizes. The structures varied from 7-32m^2 in size (Harding 2000:50). A small number of the structures included a central row of posts, suggested a specialized purpose for the buildings.

In some cases, large buildings are divided into multiple rooms. These larger buildings could have been used by larger groups or be single units where specialized activity was divided among the space in particular ways. The presence of a division in longer houses is often accompanied by evidence of different activities occurring in the different sections, suggesting specialized use for the different rooms. One such example is a building at the site of Százhalombatta-Földvár, Hungary. The site contains a house separated into two rooms with the use of a clay wall. One room contained a baking oven, hearth, clay bench, and fragments of cooking vessels. The second, smaller room did not have any evidence of furniture and was possibly used for sleeping or storage (Sørensen 2010:138).

VILLAGES

Villages are groups of houses that have either a dispersed or a clustered pattern to them. Dispersed villages are laid out with plots of land closer to buildings, leaving more space between the sites. This pattern suggests that land ownership was most likely determined by proximity. Clustered patterns of villages keep the living quarters closer together, with the cultivated land spreading outwards from the homes. As a result, it is possible to have larger land plots and ownership is mostly likely determined by factors other than proximity. In addition to villages, there are also small **farmsteads** with only one or two houses and their related structures too small to be called a village during the LBA. Villages likely held between 60-180 people (Kristiansen & Rowlands 1998:252).

Dispersed villages tended to be smaller in size, with a few homes and occasionally one or two larger buildings that may have been more public spaces. These types of villages were more common than clustered settlements (Harding 2000:66). The buildings that are most likely to have been homes do not show an inclination to social stratification in terms of access and size, as these variables are similar for all houses.

Individual houses tend to have access to a hearth and storage facilities, either inside the structure or nearby.

Tells are a particular type of clustered settlement where buildings are built close together and on top of previous buildings. In the context of the Late Bronze Age in Central Europe, these types of sites are found in Hungary. The continuous occupation and rebuilding of these types of sites results in mound-like structures upon which the most recent settlements are built. Often, the demolition and re-construction of the buildings on tells is intentional and controlled, as confirmed by stratification at excavations including Százhalombatta-Földvár (Sørensen 2010:135). The buildings found in these Tel sites most often consist of wattle and daub buildings. Occasionally there are also buildings of the *Blockbau* technique as well. *Blockbau* buildings are constructed with logs similar to a more modern log cabin. In all of these buildings, the succession of house plans and floors are used to map how the settlement changed over time. Often, the floors were re-plastered with clay or built over with a new layer of wood. Houses in Tel sites are found close together, and typical signs of occupation can be found throughout the site.

FORTIFIED SITES

During the Late Bronze Age, **fortifications**, such as the stone rampart in Velim, Bohemia, had developed to a point where they can be seen in the archaeological record. Fortified settlements are a particular type of village that also include some structure that could have been used for defense. The two primary types of fortification found during the LBA are series of **banks and ditches** and hillfort sites. It is likely that these fortified sites could provide a place of trade for different groups (Kristiansen & Rowlands 1998:85), but they also could herald an increase in conflict between neighboring peoples. The site of Heunischenburg, Germany (Figure 5.9) shows signs that a wooden wall and gate were burned down, and the ditches around Velim contain numerous skeletons (Thorpe 2013:240).

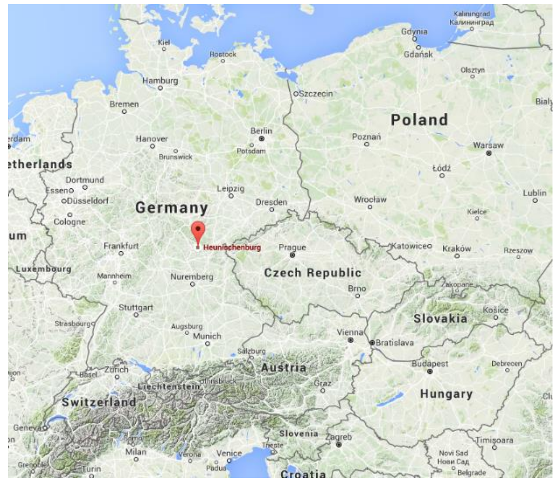


Figure 5.9: Heunischenburg, Germany
Map data ©2016 Google

While these are not definitive signs of warfare and violence, they have been interpreted as such by some archaeologists (Harding 2006:510). Despite the appearance of fortified sites during this time, it is important to note that the majority of people were still living in open villages or small farmsteads (Earle and Kolb 2010).

URNFIELDS

Urnfields are the places where the dead were laid to rest. During the LBA, individuals were usually cremated, their remains and some grave goods placed into a ceramic urn, and then the urn was buried in a central location. While there are some inhumations, such as Milavče in Bohemia, this cremation process was the dominant burial rite during the LBA. While some cemeteries contained a mix of cremation and inhumation, e.g. the Przeczyce site contained 727 inhumations and 132 cremations, others are exclusively composed of cremations, e.g. the 1260 cremation burials of

Moravičany in Moravia (Harding 2000:112). Urnfields were typically flat expanses of land with cremation deposits.

The shift from inhumation to cremation is often taken as a sign of "profound changes in attitude to death, with preservation of the body after death no longer being seen as important" (Harding 2000: 112). The presence of Urnfields are fairly consistent throughout the LBA in Central Europe, with most sites being similar in nature. This tradition of burial is one which unites most of Central Europe and can be interpreted as a general trend towards higher population density during the LBA. This increase in population density is coupled with a larger number of metal grave goods than previously, which further supports the intensification of production during the LBA.

Despite the increase in metal grave goods, the overall number of grave goods associated with the Urnfield period are few in most cases (Sørensen 1989). These usually consist of a small number of ceramics, and perhaps some metal jewelry or a sickle. Grave goods during this time tend to be gender specific and show a mild differentiation in status. Men's grave goods include pots, razors, knives, bronze pins, neck rings, and bracelets while women's grave goods consist of bronze ornaments and pots (Gimbutas 1965:287). In cases where there are indications of elite burial goods for individuals of higher status, those burials are often separate from the urnfields. Elite burial goods include weapons, armor, cups, and cauldrons.

Craft and Technology

Bronze working is one of the main types of craft discussed in terms of the Bronze Age, but it is by no means the only one. Ceramic working, stone tools, grinding stones, and worked bone are also found in abundance, not to mention the construction of the very houses within which daily activity occurred. Evidence for most craft working is not found in houses, but rather in communal areas (Sørensen 2010:133).

BRONZE CRAFTING

Copper for bronze came mainly from the Carpathian Mountains and the Alpine region through trade. Evidence for bronze working can be found in many villages in the form of slag and sometimes small pieces of molds. Few sword molds, however, have been found. Metals played a significant role in trade throughout the region both as ingots and trade goods.

Intensification of bronze working is indicated by a wider variety of tools being made in bronze as well as a shift towards more swords with elaborately decorated metal hilts. The types of objects being made were more complicated than previous, and likely required clay molds made from three or more pieces. In addition, the increase of lost-wax casting would have allowed for more intricate pieces to be crafted (Mödlinger 2008:1). These new techniques would account for the increase in *Vollgriffschwerter* (swords with metal hilts), as lost wax casting in clay molds would have enabled more efficient casting of the hilts. A more extensive discussion of bronze casting can be found in Chapter 6.

CERAMICS

Ceramics during the LBA consist mostly of storage vessels, bowls, cups, and jugs of a variety of shapes and designs. Ceramics were often locally made though they were occasionally involved in trade. It is likely that those vessels involved in trade were traded for the goods they carried rather than the vessels themselves. Potting techniques during the LBA included slab building and coil building. There is no evidence of wheel turned pottery in Central Europe during this time (Sofaer 2010:194).

OTHER CRAFTS

Ceramics, woodworking, weaving, sewing, and jewelry – both bronze and otherwise - were manufactured during the LBA. Woodworking was particularly prevalent in the formation of tools, such as the farming equipment discussed above. Jewelry was made of both metal work as well as stone work. Amber traded from Denmark, gold, and silver have also been found in jewelry. Evidence of weaving has been found in the form of loom weights. Bone needles used for sewing are present in the archaeological record. While these crafts are often treated as distinct entities, they often overlap in knowledge. For example, part of the casting process includes creating molds out of either stone or clay. In this way, bronze smithing is a craft that requires either broader knowledge of other crafts or the participation of other individuals alongside the smith to create the final object. While this dissertation focuses primarily on bronze casting, these other crafts are mentioned as a reminder that bronze casting did not exist in a creative vacuum. Rather, the practice would have been done within a community of individuals who were acutely aware of the various ways in which people manipulate the raw materials around them for nearly every aspect of their lives.

RITUAL AND RELIGION

Ritual and religion are complicated aspects to discuss in the archaeological past. Religion references a belief while ritual is an action that is repeated and may or may not related to a belief. As an example, many Americans brush their teeth twice a week, though this is not necessarily related to any particular belief system. Where these rituals appear to have a relationship to a belief system, they are often considered religion. In terms of the LBA, three particular phenomena bear mentioning. The iconography of waterbirds, cosmological representation, and the appearance of hoards (buried deposits of goods) are all interpreted as indications of ritual or religious activity. As hoards can be separated into multiple categories, they are discussed in their own section.

The representation of cosmology is another important practice present during the Bronze Age. The Nebra disc, circa 1600BC, is one such object. The object itself is a bronze disc with gold inlay with depictions interpreted as the sun, the moon, and the stars, including the Pleiades constellation (Meller 2013). It is possible that it was used as a means of tracking the solar and lunar cycles throughout the year. Another possible depiction of cosmology can be found in the Trundhom Sun Chariot of Denmark (Kristiansen 2010). This bronze sculpture is also decorated with gold leaf on one side. One final example of potential cosmological depiction is that of the four so-called gold hats found in Central and Western Europe, of which the one in Berlin is best preserved. These tall pointy conical artifacts are decorated with horizontal bands and rows of symbols separated by raised lines. The decoration is thought to be another type of calendar to track the solar and lunar changes (Harding 2000:349).

HOARDING

Hoarding is a behavior that is particularly prevalent during the Bronze Age, and particularly during the LBA. This prevalence indicates that the behavior held some importance to the Bronze Age peoples above and beyond other time periods. Bradley defines a hoard as a collection "of buried objects that were apparently deposited together on the same occasion" (Bradley 2013:122).

Hoarding is a significant activity because it is one in which people intentionally deposited items into the ground, thereby removing them from the system of wealth that was currently in place. Understanding the benefit that those people might have gained from this activity helps get at social and religious systems of belief that may have been acting on people at the time.

LBA hoards are typically composed of metal objects, but a few have also been found which consist of ceramic deposits (Harding 2000: 331). Hoards can be separated into different types that include founder's hoards, scrap hoards, merchant's hoards, and ritual hoards. Founder's, scrap, and merchant's hoards are all considered hoards with a utilitarian purpose. The description of a utilitarian hoard indicates the belief of the archaeologist that the hoard was created with a particular intent. This intent does not preclude the possibility that these hoards also have a ritual component. See Table 5.1 for Levy's criterion for determining if a hoard is ritual or not.

Founder's hoards typically include materials useful to smithing, such as bronze ingots or smithing tools. The variety and state of the materials are usually interpreted to mean the hoards were deposited by a bronze smith. Merchant's hoards are typically composed of multiples of the same type of object, a series of new, unused sickles for instance. This kind of hoard is sometimes interpreted as a cache by a merchant that is intended to be retrieved at a later date. Scrap hoards are collections of metal pieces that are not useful in and of themselves but held the possibility of being melted together for a later re-casting. Each of these utilitarian hoards could also have been deposited for ritual reasons, with the importance of smithing and trading being a key component of the deposition of this particular wealth into the ground (Brück 1999:328, Bradley 2013:123).

Table 5.1: Levy's table of ritual versus non ritual criteria for hoard classification. (Levy 1982)

Ritual hoards are characterized by one or more of the following:		Non-ritual hoards are characterized by one or more of the following:	
Context:	Wet area Great depth Under a stone Grove Grave mound	Context:	Dry land Shallow depth Beside a stone
Content:	Ornament/weapon Intact objects Cosmological referent	Content:	Tools Fragmentation Raw material
Association with food:	Animal remains Pottery Sickles	No association with food	
Arrangement:	Inside vessel Encircled by ring Parallel objects	No special arrangement	

While not in Central Europe, the hoard discovered in Portfield Farm, Whalley, Lancashire is a good example of a founder's hoard. The hoard is interpreted as such based on the inclusion of slag in the hoard, a material that is closely related to the casting process. The hoard consisted of both bronze and gold items (seven bronze, two gold).

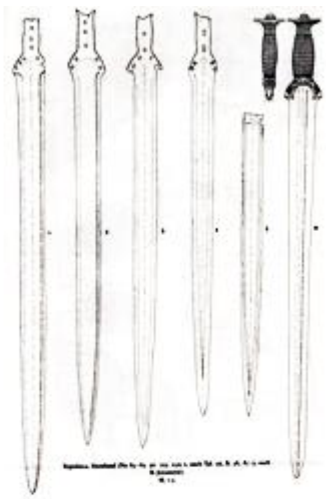


Figure 5.10: Tapolnica Hoard (Harding 1995)

The bronze pieces consisted of two socketed axes, two pieces that formed a tanged knife, part of a blade, a socketed gouge, and a piece of metal. The damaged bronze weapons that make up the majority of the hoard are the reason that the authors believe the hoard to be a founder's hoard. "The small fragment of rough metal, clearly a byproduct of smelting, shows that the hoard was the property of an actual bronze-smith." The hoard is dated to the eighth century BC (Blundell and Longworth 1967:11).

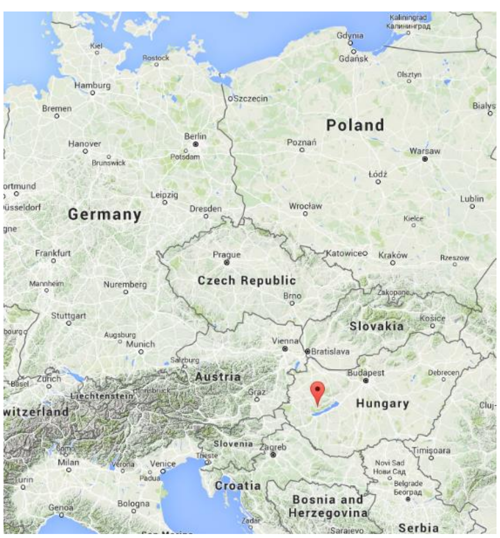


Figure 5.11: Tapolnica, Hungary Map data ©2016 Google

An example of a potential trader's hoard of six swords was found in Tapolnica, Hungary (Figures 5.10 and 5.11). One of the blades has a bronze hilt attached while the other five do not have a hilt. Four of the remaining blades have a tang intact which could allow either a bronze or wooden hilt to be attached. The combination of six very similar blades creates a context that could be related to a trading deposit, where the individual planned to retrieve it later. Alternatively, the lack of tools or other manufacture related objects could just as easily categorize this hoard as a ritual hoard.

Ritual is intentional, repetitive behavior that has some meaning, whether individual, social, or spiritual. Many hoards appearing to consist of the same pattern of objects can be interpreted as ritual behavior, as is sometimes the case for hoards containing swords. This category of ritual hoards includes hoards in watery deposits. 26.7% of swords from southern Germany, Austria, and Switzerland were found in watery deposits. In lieu of an obvious pattern, ritual deposits are often identified as hoards that appear to have been intentionally deposited and do not seem to have a logical purpose (Brück 1999:314). Founder's hoards and grave goods can be separated out by examining the context. Hoards that include newly crafted objects that appear intentionally broken are often categorized as ritual. Religion is related to ritual in that it is the component that creates the spiritual meaning of rituals. In this way, it is possible that ritual hoards might be able to reflect some aspects of religion that are being acted on by the community or an individual. It is for this reason that ritual hoards are so important to helping understand the religion of those who are depositing ritual hoards.

Figure 5.12: Water deposit from the Rheine (Schauer 1971)

The hoard found in the Rhine is an example of a water deposit, Figure 5.7. Water deposits as ritual deposits are strongly supported by looking at the frequency of swords found in these types of deposits. 61% of swords in Upper Austria during the Late Bronze Age were found in water deposit a percentage that is higher than that of even other metal objects (Harding 2000: 362). This trend of water finds holds for Bavaria as well, but not for eastern Austria, where swords are more likely to be found in graves. This change in deposition patterns suggests a ritual component that varies with location.

Hoarding as a whole is most likely an activity that includes both ritual and utilitarian aspects. The ritual-utilitarian divide was likely more a continuum rather than a black and white divide. In the cases where there is a more ritual emphasis, it is likely that that emphasis is one that is related to religion. During the Middle Bronze Age, the deposition of grave goods increased as hoarding behavior decreased. During the LBA, hoarding intensified as deposition of grave goods decreased. It is likely that these two activities were providing a similar societal purpose (Kristiansen & Rowlands 1998:76).

SOCIAL ORGANIZATION

CHIEFLY WARRIORS?

Cheifdoms and cheifly warriors are often associated with the Late Bronze Age. Harding defines a ***chiefdom*** as a hierarchical structure that includes heritable status, economic stratification, and central locations for economic, religious, and social activities (Harding 2000:329). It is arguable whether or not LBA society fully fits the definition of chiefdom; though there are some supporting factors. As discussed above, there are examples of uneven wealth distribution in grave goods. This unequal distribution of wealth does not appear to extend to differences in house sizes or living accommodations (Earle and Kolb 2010). That is to say, there is no clear “chief’s” house in a settlement.

Uneven distribution of raw materials necessary for the production of LBA goods also supports a social organization based on the control of those materials. The usual interpretation is that male leaders assume tenuous positions of power and fight to keep those positions, thus leading to the discussion of the chiefly warrior (Brück and Fontijn 2013:198).

The distribution of wealth is often interpreted as an individuals' personal accumulation of wealth; Brück argues that the exchange is done on a societal level (Brück 1999:334). In her model, hoarding behavior is a means to control wealth and the amount of wealth available to society. The driving force between exchange is an economic one of gift economy with power infused into the objects being traded, deposited, or broken rather than power being by a chiefly influence or the use of the object being decided by a chief like figure (Brück and Fontijn 2013:204). Her argument is strengthened by the lack of distinct social stratification in houses.

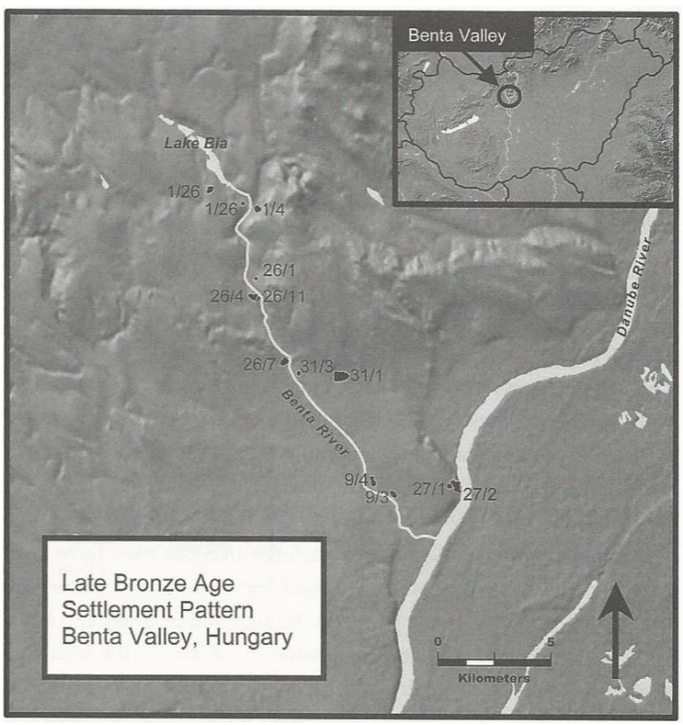


Figure 5.13: Benta Valley Settlements. (Earle and Kolb 2010:77)

The existence of a social hierarchy is supported by the placement of fortified settlements in relation to both conditions of the land as well as the ability to control trade routes. The

Benta Valley in Hungary provides an example of how this works. During the LBA, a total population of 1000 individuals is estimated to have resided among the valley. The largest settlement was the site of Tárnok. Though there are fortified settlements nearby which housed an estimated 37% of the population, Tárnok itself was not a fortified settlement. Earle and Kolb suggest that there were two hierarchies existing simultaneously, one for agrarian settlements, and a second one for fortified settlements. Settlements in the valley were of a hierarchical nature consisting of one large village, five small villages, and four hamlets or farms. Earle and Kolb estimate that the population density for each of the settlements remained between 30-40 people per hectare (Earle and Kolb 2010).

Figure 5.14: Possible ritual fighting, from the Late Bronze or Early Iron Age (After Anati 1961:185)

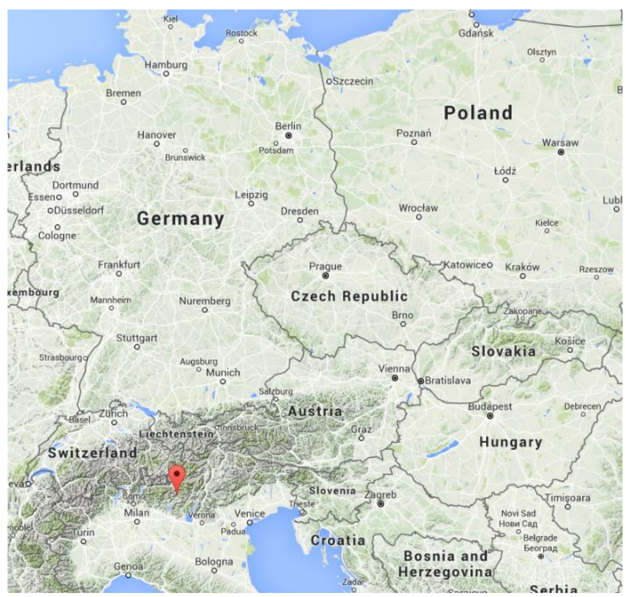


Figure 5.15: Camonica Valley
Map data ©2016 Google

The warrior aspect comes from the prevalence of weaponry, armor, and depictions of warfare throughout the LBA in Central Europe. Bronze swords were often highly decorated, with some showing signs of use. The density of sword finds is highest in Central Europe (Harding 2000: 279). Some swords show signs of use, some appear to have never been used, and some are buried in hoards almost straight from the casting mold. It is clear by the investment in time, technology, art, and raw materials that they held a significant role in LBA society, particularly in Central Europe. Rock art depictions such as those in the Camonica Valley (Figures 5.14 and 5.15) provide evidence that combat was conducted in a one to one manner.

Defensive armor in the form of breast plates, helmets, shields, and greaves had also been found in the archaeological record, though as of yet not as a complete set. It is likely that these types of armor also existed in other materials, such as leather or wood, that would not have survived in the ground. While bronze armor is not as effective as its leather or wood counterparts (Uckelmann 2011:195, Molloy 2009:1061), experimental archaeology has shown that the armor is at least capable of protecting an individual. Thus, it is likely that the bronze replica of warfare paraphernalia is a status symbol rather than a tool of war, at least in the sense of defensive equipment. While there are no counterparts to bronze swords, the same glorification could be argued to have been placed on some of the more decorative swords that do not show signs of use. In other words, an individual who owned such equipment could well be projecting the message that he is strong enough, powerful enough, and wealthy enough to own and keep such extravagant goods, thus becoming the fabled chiefly warrior.

TRADE

Trade networks expanded during the LBA, particularly along the Rhine. Trade is reflected both by exotic materials, such as amber and gold (Wells 1989), as well as by the intensification of bronze working. The main sources of copper for Central Europe include the Alps and the Carpathians. Outside of Central Europe, copper is also found in the Harz, some parts of Brittany, Ireland, Cornwall, and Spain. The most common alloy found in bronze is a tin-copper alloy, with tin most likely being sourced from the Carpathian Mountains and the Alps. Other raw materials that were traded include gold, silver, and Baltic amber from Northern Europe.

Raw materials were not the only objects to be traded. Exotic trade goods such as swords, metal vessels, worked amber, and glass beads have also been found throughout Europe. The movement of these items suggests a network of trade that stretched from Scandinavia to the Alps, with a small amount of trade even traversing the Alps at this time, though it is not until the Iron Age that major trade began to occur across the Alps.

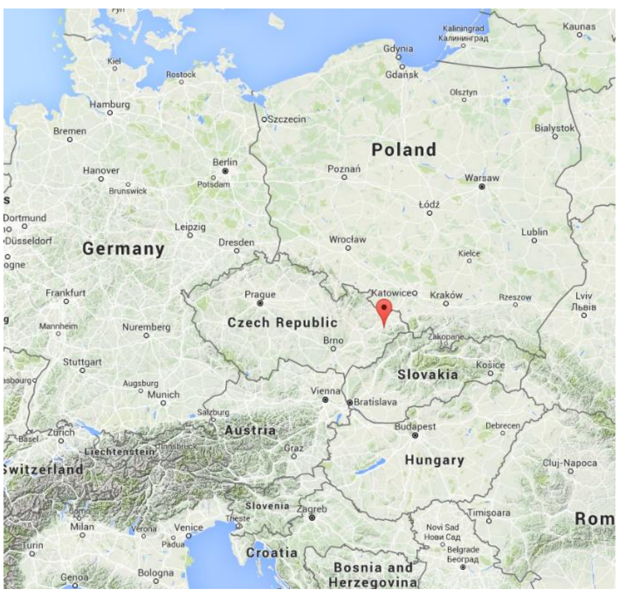


Figure 5.16: Stramberk- Koptouc hoard, Moravia
Map data ©2016 Google

Intensification of bronze working in Central Europe could only have occurred in tandem with such extended trade networks. The Jensovice cups found in the Stramberk-Koptouc hoard in Moravia (Figure 5.16) reflect the presence of long distance trade. They were likely traded across long distances between fortified sites before reaching their final resting place. Long distance trades like these would have been done in conjunction with smaller local trades for items such as sickles, creating both a local and a long-distance trade network (Kristiansen &

Rowlands 1998:89). Other such elite drinking vessels have also been known to travel long distances along these networks. Often these items are deposited as specialized burial goods, further solidifying the position of elite individuals as people who have enough wealth or are deemed important enough for such valuable goods to be deposited into the ground with their remains.

Travel was achieved through a number of means. By this time, the wheel had been invented and was being used in carts though there are no known examples of paved roads. Sewn plank boats and paddles are evidence that the rivers would have been used for travel.

Conclusions

Bronze smiths were part of a multi-faceted economy focused around agricultural villages. Most people during the LBA lived in small settlements. The social structure was most likely somewhat hierarchical in nature, with weapons and at the very least the threat of warfare playing an important role in reinforcing power. Despite evidence for discord, there is also evidence for an extensive trade network that was maintained. Smiths would have interacted with both warfare and social aspects of life in a very immediate way. It is through the trade networks that they would have acquired their material and sold their goods. The communication between areas would have provided them routes along which they could interact with those of their profession and other crafts. These existing structures helped to define the possibilities open to the smith and where he or she fit into the prevailing society, which will be explored further in the next chapter.

CHAPTER 6: THE PRODUCTION OF BRONZE SWORDS

Bronze sword production is a complex technology that incorporates many different aspects of specialized craft knowledge. Smiths are afforded several areas where they can make multiple decisions. In addition to smithing choices, there are other choices along the way as well, such as how the metal itself was acquired. Dietler, Herbich, and Lemonnier suggest that operational sequences are inherently a part of cultural choice (Lemmonier 1992:51, Dietler and Herbich 1998:235). To this end, if a technological operation leaves markers behind on the finished product it is possible that these markers may be reflective of a cultural choice. At the very least, they may be indicative of a particular smith's choice in operational sequence.

In this chapter, I outline the process of bronze sword production. Ingold makes the argument that when studying materials, one must pay attention not only to the meanings of the materials but to the materials themselves as well (Ingold 2007:1). To that end, the discussion of bronze sword production follows the process from the very beginning of the process (ore acquisition) to the end of the life of an item. The production of swords does not begin with the casting process, nor does it end once the metal is cooled. This treatment allows all of the processes involved to be fully appreciated and broadens the reader's understanding of the production.

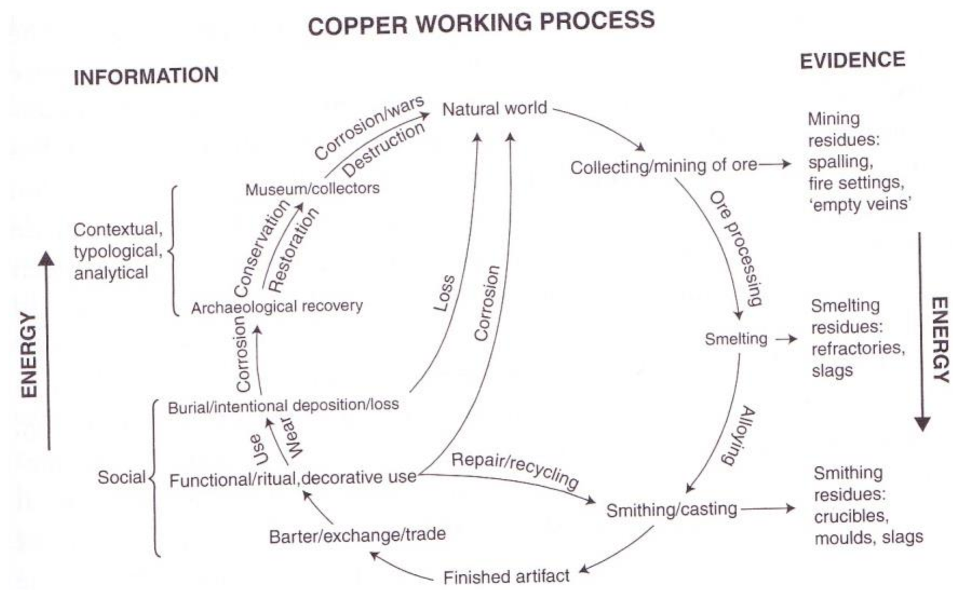


Figure 6.1: The life cycle of bronze. (Hanks 2009:159)

SMITHS

Much discussion has occurred on the nature of the smith. While I have been careful not to identify the gender of bronze smiths, in this section I will refer to those individuals as male. The reasoning for this is that it is the way in which many early archaeologists referred to smiths. Recent ideas on gender in archaeology have broadened the interpretation on gender roles in the prehistoric past. These ideas are beyond the purview of this dissertation, but open up the interpretation that either gender may have been involved in various tasks.

ITINERANT, SEDENTARY, OR OTHER

The most common discussion in reference to smiths is whether they were itinerant or sedentary. In the early work on Bronze Age archaeology, Childe suggested that the smith was an itinerant individual who traveled from town to town peddling his trade (Childe 1930:10). This conclusion was based on the insufficient evidence that some of the more exotic bronze items, such as swords, were produced in any particular place. The lack of material evidence, in conjunction with the relatively low demand for these specialized objects, supported his hypothesis of a craft worker who moved from town to town wherever the demand brought him.

Since then, the competing theory of a sedentary smith has arisen. In this case, the smiths would be tied to a location and their product would move. Instead of having a smith who was able to produce many different types of bronze objects, the smith would specialize in tools, jewelry, sheet metal, or weapons. The craft worker's choice of specialization would be dependent on the size of the community he lived in, with larger communities supporting those individuals who made more specialized items (Pearce 1938:231).

What is missing from this conversation is the interaction between smiths. Ethnographies of iron workers in Africa show semi-itinerant practices where smiths have a home base, but travel between locations on occasion as well as meet up in larger groups (Neaher 1979:357). This cooperation between metal workers is something that I have experienced in my own work as well. One such example is the *Umha Aois* experimental group in Ireland. These meetings consist of individuals who study archaeological bronze casting and come together once a year for the purposes of knowledge exchange and experimentation. All of these examples have a common thread of individuals who join together on a semi-regular basis. This meeting of smiths provides a mechanism through which knowledge is transferred between groups. Furthermore, while casting can be done alone, there are significant benefits to having multiple individuals partaking in the process. Partitioning out the work of keeping the furnace warm through pumping the bellows, pouring the metal into the molds, and making sure nothing nearby catches fire during the casting process makes for a smoother pour.

For the reasons above, I find that it is better to think of smiths as part of a workshop instead of lone individuals. A workshop can consist of one individual or more. Different individuals can have different specialties, such as a ceramics craft worker who aids in the production of molds or a smith whose specialty is engraving designs into the blade. Each workshop's makeup can change as the task requires, and individuals can be part of multiple workshops. Since an individual workshop consists of different members, the knowledge of their craft is defined by those individuals who make up that workshop. Workshops that consist of similar people will have similar collections of knowledge. Those individuals who move between workshops consisting of different people act as links for knowledge transference. In the terms of network theory, I envision workshops as the nodes in a network and the links between those nodes are the individuals who make up the workshops.

THE SOCIAL ROLES OF THE SMITH

Smiths play several roles in society. They are keepers of specialized knowledge, makers of tools and weapons, potential links between communities, and potentially even religious figures. I have previously discussed the importance of specialized craft knowledge in Chapter 3 and their value as links in the previous section. Here, I focus on their social status, how ritual and religion may intersect with bronze smithing, and finally how they reinforce the social status of others.

Ritual and religion may have had a role in the smith's position as well. Bronze working is, by its very nature, a transformative process. Smelting, alloying, and casting all require that at least a portion of the material being worked with is turned from solid to liquid and back. Budd and Taylor argue that this transformative process would have been the most public part of metalworking, creating a spectacle to be observed by all (1995). The transformation of metals during casting as a public ritual with religious or magical implications is supported by modern ethnographies of the Benin people (Dark 1973:55). Furthermore, Budd and Taylor make the case that the act of ritual is a way in which knowledge of the craft could be passed on from one individual to another. Ritualization couches the memorization of a complicated procedure into a series of actions reinforced by the ritual (Budd and Taylor 1995:140).

ORE ACQUISITION

Ore acquisition is the first step in bronze sword production. Bronze is an alloy of copper and another element, typically tin. Therefore, both materials must be available to the smith in order to make bronze. Much discussion has occurred about whether or not the composition of bronze can lead to a reliable method of sourcing (Northover 1988, Hamilton 1991). The current consensus is that the practice of re-use of bronze leads to a melting pot effect (Hanks 2009:157). The reuse of metal in turn creates an amalgam of many different types of bronze and would make sourcing through this manner unattainable.

Sourcing aside, the method of mining copper and tin is represented through several sites and archaeological assemblages. Finding copper and tin sites is a matter of knowing the local geography. Both can be found in vein deposits of ore that occasionally appear on the surface. The color and density of the ore can alert the prospector to its existence (Forbes 1950:295). Ore is a mineral deposit that includes extractable and valuable minerals, such as copper or tin. Tin is only found in ore whereas copper can be found both in ore form as well as in natural form (Coghlan 1951:16). In addition to veins of ore, tin can be found by washing through alluvial deposits in rivers and lakes.

Figure 6.2: Fire setting at the Mine 2, Aghios Sostis, Siphnos, Greece (Weisgerber and Pernicka 1995:174)

Figure 6.3: Copa Hill, Cwmystwyth. Wales Map data ©2016 Google

Once a vein is identified, the ore deposit must be separated from the rock. Veins of ore can be mined by following the vein or cutting out a trench through an area that is rich in veins. Some stone, such as sandstone, requires no preparation for the extraction of the ore. Others require fire-setting. Fire-setting is a practice where a large fire is lit next to the stone and left to burn out. The heat of the fire cracks the rock and makes it easier to break. Fire-setting is evidenced both by burn marks on the remaining stone as well as the shape of the mine, which has more natural curves instead of sharp changes in direction (Figure 6.2). Once fire-setting has occurred, the ore can be extracted from the rock by hammering it out with stone tools. Evidence of mining work is particularly well preserved at Copa Hill, Cwmystwyth in Wales. In addition to antler billets and stone tools with signs of hafting, remnants of baskets and rope were preserved (Timberlake 2001). This artifact assemblage suggests that the ore was likely transported up to the top of the mine through baskets and pulleys.

SMELTING

Smelting is a process by which one type of mineral is extracted from the rest of the ore. Bronze alloys during the LBA consist primarily of bronze and tin though arsenic and lead are also known to have been used (Charles 1967:25). During ore acquisition material would be picked out by hand as evidenced at Copa Hill and crushed via hammer stones and pestles (Timberlake 2001). Further preparation included washing the ore to retrieve smaller bits and roasting it at a temperature that will oxidize the iron in copper sulphides (the most commonly found copper ores) but not the copper, making it easier to smelt (Forbes 1950:306).

Smelting the copper (or tin) from the ore requires temperatures of 1050° – 1200°C in order to melt the ore into liquid form. A temperature lower than that will not change the ore to liquid, and a higher temperature will degrade the copper. Temperatures of this magnitude require furnaces that allow the user to control air flow, fuel type, and heat loss to maintain the high temperatures needed for smelting. Trees were likely the main source of fuel and one way in which the temperature could be reached. Different trees react to heat differently. Oak, as an example, is better for smelting purposes (Craddock 1995). Trees would have needed to be cut down, dried, and burned to create charcoal before use in a smelting furnace, a process which would have been time consuming. The three main types of furnaces were bowl furnaces, bowl furnaces with the use of a crucible, and shaft furnaces.

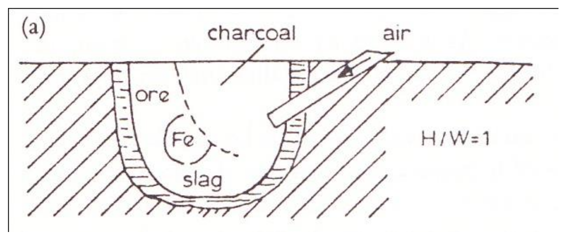


Figure 6.4: A bowl furnace without the use of a crucible (Tylecote 1987:153)

In a bowl furnace, the ore is placed in direct contact with the source of heat (Figure 6.4). Then, air is introduced to elevate the temperature. This allows for the ore to melt and the different materials to separate. Copper (or tin) then cools into pellets separate from the rest of the material, which becomes the slag (Craddock 1995).

Alternatively, the copper can continue to collect at the bottom of the furnace until a large amount of copper is obtained.

The use of a fired clay crucible allows ore to melt in the crucible instead of directly in the fuel. Once the ore liquefies, the liquefied slag floats to the top, and the copper or tin remains on the bottom. At this point, the slag can be skimmed off the liquid ore. The advantage of using a crucible is the ability to keep the furnace hot between batches instead of allowing it to cool in order to collect the copper (Tylecote 1987:107).

The major difference between a shaft furnace and a bowl furnace is the mechanism for controlling air flow. A shaft furnace resembles a kiln (Figure 6.5), except with the introduction of a hole for a tuyere (Coghlan 1951:69). A tuyere is a hollowed out clay artifact that allows for the introduction of air either from a bellows or human breath (Figure 6.6). The tuyere is one aspect of the furnace which is more likely to preserve and be found in an archaeological site that points to evidence of metalworking.

Copper smelted in the methods described above still has a number of impurities in it. These impurities make the copper brittle. Purification of the copper from the

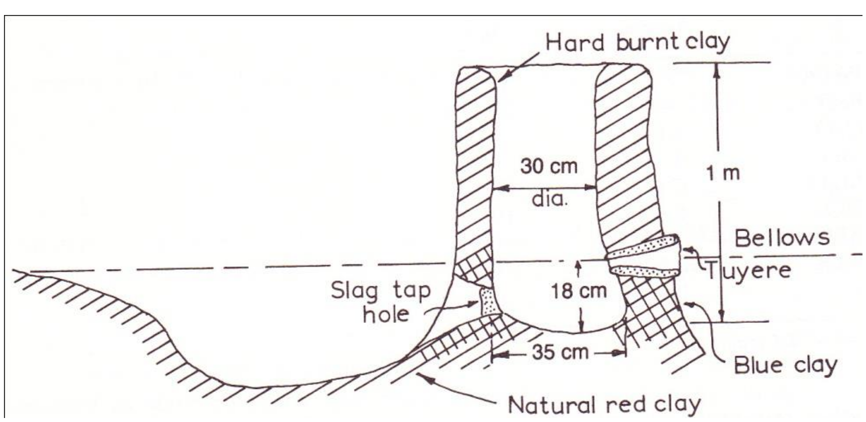


Figure 6.5: Shaft Furnace (After Tylecote 1987:170)

remaining slag can be done by melting. Melting is similar to the smelting process except that the metal has already been extracted from the ore. This process allows for further purification when the copper is melted in an oxidizing environment. Copper does not oxidize as quickly as other materials. Any lead inclusions will float to the top due to density differences and can be removed by skimming. To purify the copper from a bowl furnace, a crucible must be used to remove the rest of the slag. Copper does not need to be purified after the first smelting process, but purified copper will yield a better quality final product. Once the smelting and purifying process is complete, the copper can either be made into ingots as is, alloyed and then made into ingots, or made into the final product. Bronze is the product of copper and other ore, thus alloying must occur next. Arsenic, tin, and lead are the metals that are alloyed with copper to make bronze.

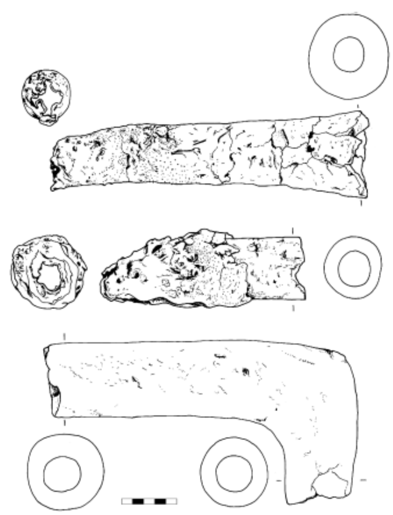


Fig. 4. Types of tuyères.

Figure 6.6: Examples of archaeological tuyeres from Cyprus. (Hein et al. 2007:143)

ALLOYING

Arsenic seems to be the earliest metal alloyed with bronze. Arsenic is found naturally with copper, and thus it is possible to co-smelt the arsenic from the ore at the same time as the copper (Rostoker and Dvorak 1991:18). Cementation, a process whereby copper is placed nearby arsenic while it is turning into its gaseous form, may also be used to alloy arsenic and copper (Craddock 1995). Axes from northern Italy tend to have less than 1% arsenic whereas daggers and halberds average up to 7% arsenic (Northover 1988:50). This differentiation suggests a conscious choice to use an arsenic alloy in the daggers and halberds but not in the axes.

Lead and tin could be alloyed with copper through mixing or introducing the solid alloying material to the liquid copper. Essentially, the copper is melted first and then the solid tin or lead is dropped into the molten copper, at which point the tin or lead melts and fuses with the copper. Fusion through mixing works well for both tin and lead, but the latter method is better suited to tin. Copper melts at approximately 1200°C while tin melts at a mere 232°C allowing for fusion without pre-melting the tin (Rowlands 1976). Both tin and lead have the effect of strengthening and hardening copper. Tin causes the melting temperature of bronze to drop, but too much can cause the resulting bronze to be brittle. Rowlands references a standard mix of 10% tin and 3-4% lead as the ideal mix though Miller cautions the use of a modern standard to Bronze Age workings (Rowlands 1976; Miller 2007:157).

CASTING

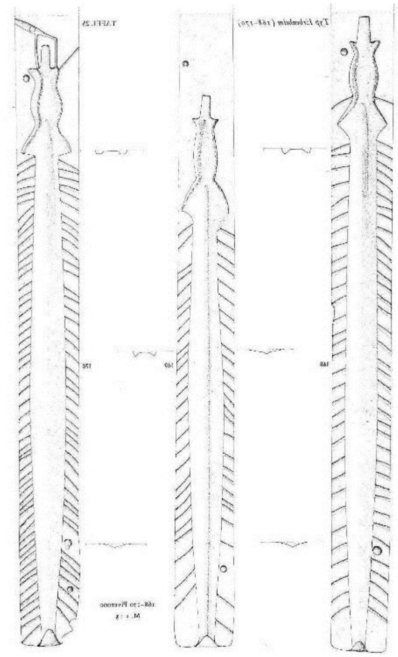


Figure 6.7: Sandstone mold from Picerone, Italy (Bianco Peroni 1970)

Bronze swords are cast using two piece molds of stone or clay that must be lashed together during the pouring process. The hilts are cast separately from the blades and joined later in the process. Stone molds are created by carving out a relief of the object in stone and then pouring the bronze in (Figure 6.6). Stone molds require risers and shafts to vent out air during the molding process (Tylecote 1987:220). Bronze constricts as it cools. The lack of porosity in stone requires the use of risers and spinets to compensate for this deficiency. Stone molds are more durable both for reuse purposes as well as in the archaeological remains but are also heavier.

Figure 6.8: Modern replica of a clay sword mold (Jordon 2004)

Clay molds (Figure 6.8) and sand molds (Figure 6.7) would have been more portable than stone molds, but are often a one-time use product. Clay must be dried thoroughly before being used as a mold, as any moisture will turn to steam upon connection with the molten bronze and weaken the bronze (Tylecote 1987:227). Clay molds are found in the archaeological record as broken bits, but successful experiments have been done to recreate them (Jordon 2004). The dearth of stone molds indicates that

Figure 6.9: Erlingshofen, Germany Map data ©2016 Google

clay and sand molds would likely have been used in their place (Mödlinger 2011:105). Sand molds are very resistant to heat, but weather easily with wind and water. Clay and sand would also have been used for the lost-model method of casting. This method of casting requires making a model out of wax or other similar material and dipping it in clay. This step is repeated until the wax object is sufficiently coated in clay. Then the wax is melted and let out through a hole in the mold. Finally, the bronze is let into the mold to cool. Once the bronze has cooled, the mold must be broken to remove the object; hence the term lost-model (Craddock 1995). This method has the advantage of picking up many details in the wax that transfer easily into the bronze casting.

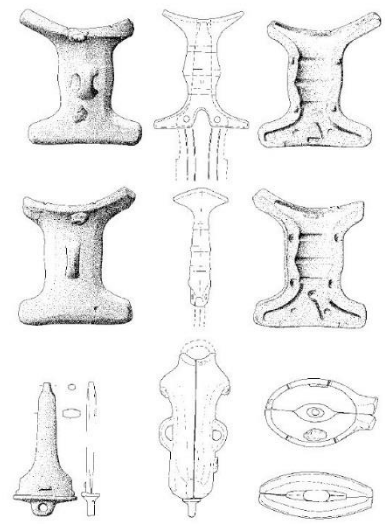


Figure 6.10: Four-part bronze mold from Erlingshofen, Germany (Wirth 2003)

In the Late Bronze Age, permanent bronze molds were sometimes used. Bronze has the advantage of durability that stone has without the weight. While it may seem counter-intuitive that bronze can be used as mold for molten bronze, the practice is still done today. Archaeological examples of bronze molds have been

Figure 6.11: Cast hilt from Erlingshofen mold (Wirth 2003)

discovered (Coghlan 1951:112). Wirth experimented with a four-part bronze mold from Erlingshofen, Germany (Figure 6.9) to successfully cast a bronze hilt as shown in Figures 6.10 and 6.11 (Wirth 2003). Bronze, as well as stone, clay, and sand molds, must be heated before the molten bronze is poured into it. Heating the mold prevents the mold from cracking when the bronze is poured in. Stone works best when heated to 200-400°C whereas bronze only needs to be heated to 170°C (Tylecote 1987:221). Stone and bronze also change the way in which the molten bronze cools, allowing the metal to cool faster and thus leaving a finer internal structure than with clay molds.

X-Ray Fluorescence Spectroscopy (XRF) is a method that measures the chemical composition of a material at the surface. In some fields, such as lithic analysis, the technique can be used to determine the source of the stone. However, given the nature of bronze as a recyclable material, it is unlikely that XRF could be used in metallurgical studies for the purpose of sourcing. This being said, it does have something to offer in terms of understanding the composition of the alloys used in bronze working.

As discussed above, copper was alloyed with tin, arsenic, and lead to create a bronze alloy during the LBA. Different amounts of the alloys create different strengths of bronze, with a 90/10 composition of copper (Cu) tin (Sn) accepted as the best allow for swords. The Mödlinger study included 16 swords from Austria and Hungary (Mödlinger and Ntaflos 2009). In this study, she found that 15 of the 16 blades had a ratio of Sn between 7-11% and a variety of trace elements (Sb, Fe, Ni, Zn, As, Pb, and Sb all less than 1%), which fits within the expected ranges. The 16^{th} blade had 1.7% Sn and 1% Sb (antimony) in addition to trace elements of Ni and Pb. The blades with 7-11% tin all exhibited signs of cold working, which is more effective within this range of CuSn ratios. The author does not remark on the 16th blade though it is interesting that the numbers are so drastically different. The CuSn ratio on that particular blade is low enough that it could be a natural inclusion of Sn and not a purposefully alloyed material.

Neutron Resonance Capture Analysis (NRCA) refers to a type of elemental measuring technique which relies on measuring the neutrons in different materials. It has been used with similar purposes and effects as XRF. The difference between the two is that NRCA focuses on the bulk of the material being examined while XRF focuses on the surface. In this way, NRCA self-corrects for patina material (Postma *et al*. 2011:664).

FABRICATION

Fabrication is the working of metals when they are solid. Bronze is typically cast first and then modified through fabrication either with heat treatment or cold working. An object that has been subjected to alternating heat and cold contains distinctive microscopic markings on the bronze. While heat treating erases most marks of cold working, there is some evidence left in the form of twin bands with slag inclusions (Peterson 2009:201). Cold worked objects that have not been annealed afterward show signs of slip bands and also an increase in grain size after recrystallization. Figure 6.12 shows some examples of the microscopic evidence of heat treated and cold worked bronzes. The methods for this analysis and an example of this type of study will be covered in the following section.

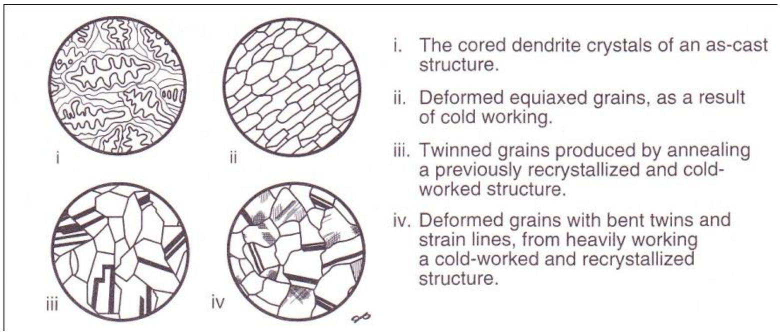


Figure 6.72: Bronze microstructure evidence of different working types (Peterson 2009:202)

Bronze swords often undergo heat treatment through annealing. Annealing is the processes of heating and then slowly cooling the bronze. This process causes the homogenization of the bronze and the strengthening of the metal. Any bronze that has more than 6% tin content needs to be annealed before cold working to homogenize the material and prevent damage to the bronze. The process of annealing, hammering, and repeating was likely done to sharpen and harden bronze swords (Kuijpers 2008:99).

Metallographic analyses allow the researcher to view the structure of the metal through thin sections, leading to a better understanding of the manufacture process. The major drawback to this type of analysis is the destructive nature of it. In order to examine an artifact, a portion of the blade must be removed. The sample is then mounted in resin, ground down, polished, examined with a metallurgical microscope, etched with an etching solution, and often recorded by photomicrography (Scott 1991: 61). The two shapes that appear to be most useful for archaeological bronzes are the annealing twin lines and the dendrite structure, as shown in Figure 6.13. The dendrite structure is indicative of a cast object while the annealing lines are the product of annealing the blade in heat. A stretched dendrite structure indicates cold working without annealing, and a pattern of stretch and distorted annealing lines indicate cold working after annealing.

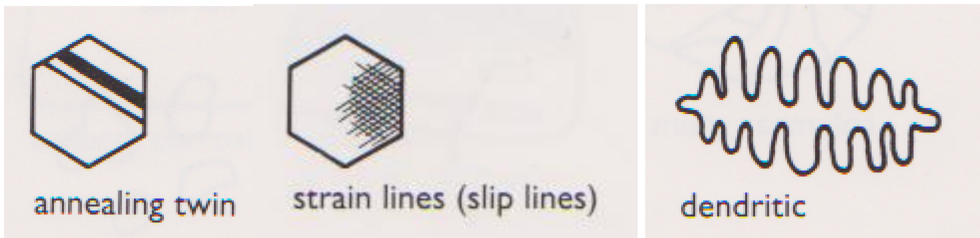


Figure 6.13: Common metallographic terms used in bronze studies (Scott 1991:79)

Mödlinger's dissertation work included the metallographic analysis of 53 bronze swords from Central Europe. Samples from each object were taken from the blade and etched with $FeCl_3$. Only one sample of each blade was taken, thus restricting the results to apply to only that part of the blade. This method of sampling requires that the author assume the entire blade was treated the same, though it is understandable that destructive samples would be kept at a minimum. All of the 53 bronzes were cast, as evidenced by the dendritic structure. Mödlinger suggests that the spacing of this structure also suggests a slow cooling time and a poor cast caused either by a wet mold or overheating of the metal. Once the casting process was finished, the final working of the blades showed different types of finishing techniques, with most of the blades going through several rounds of cold working and annealing. In total:

> “All sampled blades were cold worked on the edge after casting. Six swords did not receive any further treatment. Most of the blades were annealed after cold working. Seven swords were not cold worked again. Three swords were exposed to the fire of cremation, so the intensity of cold working can be seen only be the grade of deformation of the CuS-inclusions. 37 out of the 53 swords were cold worked as a final production stage” (Mödlinger and Ntaflos 2009 pg. 195)

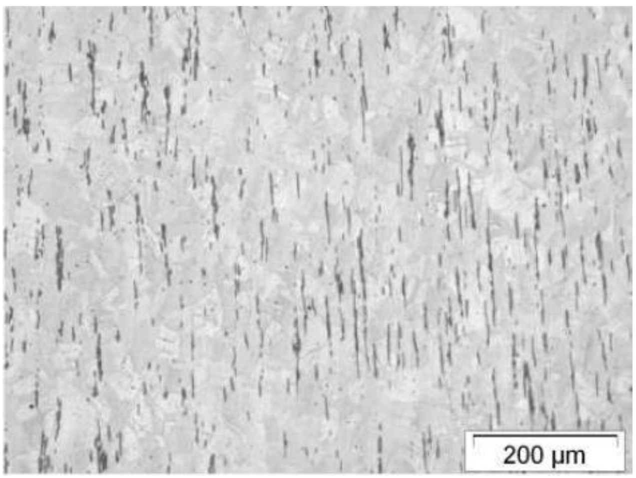


Figure 6.14: Stretched dendritic and annealed structure, indicating 80% homogenization of the bronze. (Mödlinger and Ntaflos 2009:195)

What these studies show us is the differing manufacture of the blades. The majority of these blades went through several rounds of being annealed (heated up and worked with a mallet of some sort) and cold worked. This type of manufacture homogenizes the material, see Figure 6.14. Mödlinger estimates that some of the blades increased their hardness up to 300% of the original hardness. Since none of the blades were fully homogenized, they never reached their full hardness potential. Expanding this research to try and understand in what circumstances the differing processes are used and why some blades are worked more than others could lead to interesting results.

The two main methods of joining the hilt to the blade are casting on and riveting. “Casting on” is the process of pouring molten bronze onto heated bronze in order to create an extension to the existing piece (Figure 6.15). Rivets are often made of a lower tin content than the bronze sword and are added once the hilt and the blade have cooled independently. Rivet holes were likely made by drilling after the casting process to prevent uneven distribution of the bronze while casting (Tylecote 1962:118).

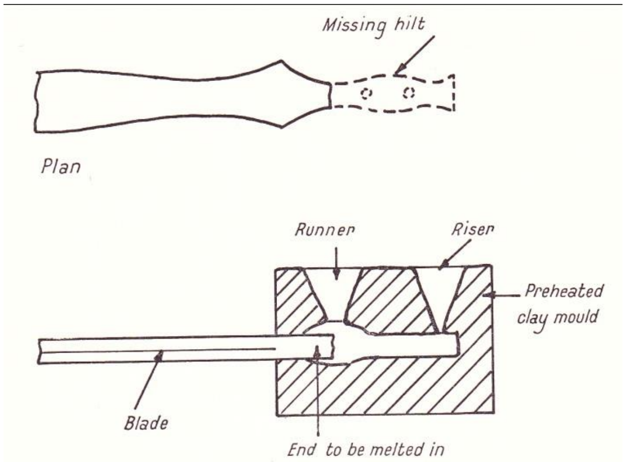


Figure 6.15: Casting on of a hilt. The area labeled runner is also known as the sprue. (Tylecote 1962:118)

X-ray and CAT scans allow for a look at the interior of the blade, and thus the manufacture of the hilt and the joining of the hilt to the blade. This interior look also leads to discoveries about the manufacture process of the blade. Figure 6.16 indicates the void between the blade and the hilt as well as the disturbance on the interior of the blade (Mödlinger 2008:2). This residue was hardened clay, which would have been used as a core for a lost-wax casting. The presence of shrink holes near the grip suggests that the gate and sprue was located in that particular area. The weak point at the hilt caused by the choice of sprueing and gating ultimately gave way.

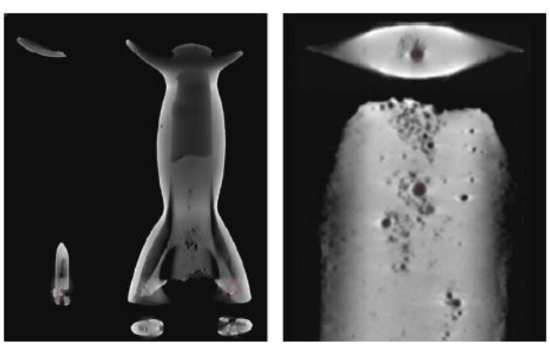


Figure 6.16: X-ray image of hilt (Mödlinger 2008:2)

Most of the decoration on blades were introduced through the mold, though stamps, punches, hammering into patterns, polishing, engraving, plating, abrasion, and inlay could also be used (Rowlands 1976). While most of the evidence of cold working is reflected in the piece, anvils, stone hammers, hammer stones, grinding stones, whet stones, polishing stones, punches, chisels, tongs, and awls could be used for cold working of bronzes (Kuijpers 2008: 99).

Production experiments cover a range of different activities. These types of experiments attempt to understand how it is that production was achieved in bronze objects both by reproducing the objects as well as comparing reproduced objects to artifacts. Following are three experiments that represent different types of production techniques: smelting, casting, and fabrication. They have been included here in order of production process.

Tylecote conducted a number of early studies on copper casting and smelting. His 1980 study attempted to understand what the smelting procedure was like and how early copper smelting could produce the purity of copper that has been found (Tylecote 1980). His first observation was that the ore he was able to procure was relatively pure ore to begin with. Thus, he felt the need to create an artificial ore for the purpose of his smelting experiment. He smelted the copper two different ways – once with a single tuyere and the second time with two tuyeres. During the smelting process, he used an iron-oxide flux, a process that was used as early as the fourth century BC. The ore smelted with a single tuyere produced copper pellets with relatively low trace elements of Pb, Zn, and Bi. The elements left in this process were As and Ni, which Tylecote suggests are easy to remove during subsequent refining in oxidizing conditions. The ore smelted with two tuyeres, and therefore in a hotter environment, produced a copper ingot with almost all of the trace elements removed, with the exception of some of the Ni. Tylecote thus concluded that the successful smelting of a pure copper could be obtained with a single tuyere, especially if relatively pure ores were obtained.

Casting experiments have proliferated during the past two decades (Ó Faoláin and Northover 1998; Wang and Ottaway 2004; Kuijpers 2008:131). These experiments have been integral into understanding how to study bronze blades for evidence of working as well as the manufacturing process as detailed earlier in this paper. Artifacts help create the boundaries of process constraint, but it is only through experimentation that the effects of process on the object can be systematically observed. Wang and Ottaway conducted an actualistic study that reproduced casting techniques and studied the effects of different casting materials. The authors cast a total of 84 axe blades (24 in sand molds, 36 in clay molds, and 24 in bronze molds) controlling for 12 different alloy types and 2 different cooling methods (air cooled or water cooled) to determine the effects on the material (Wang and Ottaway 2004). Their casting methods followed LBA methods as much as possible, including recipes for sand and clay molds where available based on artifacts. They then compared the microstructure of the bronzes as well as the hardness of the bronzes using metallographic techniques. Their conclusions were that the microstructure of the bronze was significantly different dependent on whether the tin content was high or low, if the bronze was cast in a bronze mold, and which cooling method was used.

Fabrication experiments focus on the use of tools to create decoration. Lowery *et al.* suggest that the most likely method of decoration would be engraving after the casting process is completed (Lowery *et al.* 1971:167). For examples of tools, they used silversmith tools for their experiments and suggested that LBA bronze engraving tools would likely have been similar though there are few if any examples in the archaeological record. The tools examined included a scriber (a pointed tool), a graver (a sharp, shaped, cutting tool), a tracer (consisting of a curved edge), and a scorper (a broad chisel-like tool). Once identified, the authors made several markings on gilded bronze metal for comparison of tool types. Additionally, they sandblasted some of the materials to resemble wear marks. This experiment created a collection of materials which can help researchers determine what type of tools were likely used for decorative purposes.

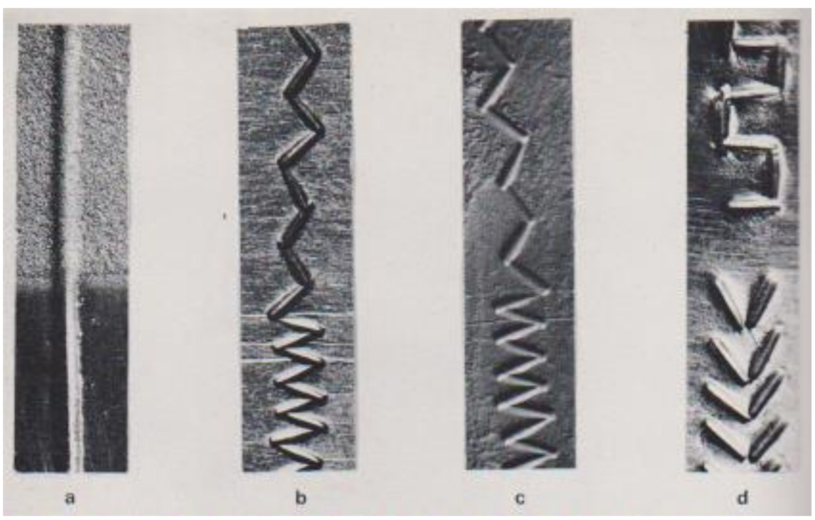


Figure 6.17: Experimental marks made from silversmith tools, "a" has been sandblasted on the upper half. (Lowery *et al.* 1971:186)

CONCLUSIONS

This chapter has discussed the role of the smith in society as well as the production of swords from ore to blade. While I presented this information in a linear fashion, that is not necessarily the route that each blade would have taken. Bronze has the ability to be re-melted and thus recycled into new material. The existing blades today could have been composed of previous blades, daggers, sheet metal, or other bronze artifacts. Nonetheless, the material found in each blade that is found in the archaeological record would have needed to go through each of the steps above at least once.

CHAPTER 7: SWORDS

A number of works have been written on LBA bronze swords dealing with manufacture technique and style. Early works written in the late nineteenth and early twentieth centuries included several monographs about swords (Sacken 1868, Bastian and Voss 1878, Naue 1894), though the first comprehensive typological chronology was published by Müller-Karpe (1959). During the mid-twentieth century, publications were written on bronze sword studies (Coghlan 1951; Rowlands 1976; Tylecote 1962, 1987), production experiments (Lowery 1971; Tylecote 1980), and typological categorization of the blades. The largest of these works is the *Prähistorische Bronzefunde* series (PBF), which contains 17 volumes describing bronze blades found mainly throughout Central Europe. The volumes cover the geographic areas of the United Kingdom, Ireland, Spain, eastern France, Germany, Switzerland, Austria, Italy, the Czech Republic, Slovakia, Hungary, Romania, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Albania, Macedonia, Bulgaria, and Greece. Not all areas contain *Vollgriffschwerter*, but all areas do contain bronze swords. The PBF contains catalogues of the blades and includes drawings, find locations, find types (burial, river deposition, hoards, construction finds, and so forth), associated artifacts, and detailed typologies of each blade along with various types of analyses. Further experimental studies have been conducted to help determine possible uses and manufacture methods of the blades (Craddock 1995; Rostoker and Dvorak 1991; Wang, Quanyu, and Ottaway 2004) as interest continues in studying cast bronze swords (Peterson 2009; Scott 1991). Stockhammer's 2004 re-examination of the blades has reconsidered some of the classifications and changed earlier typological assignments for the blades. Finally, Mödlinger has done a number of compositional, microscopic, and use wear analyses showing the utility of the blades as functioning weapons in addition to their symbolic uses (Mödlinger 2007, 2011).

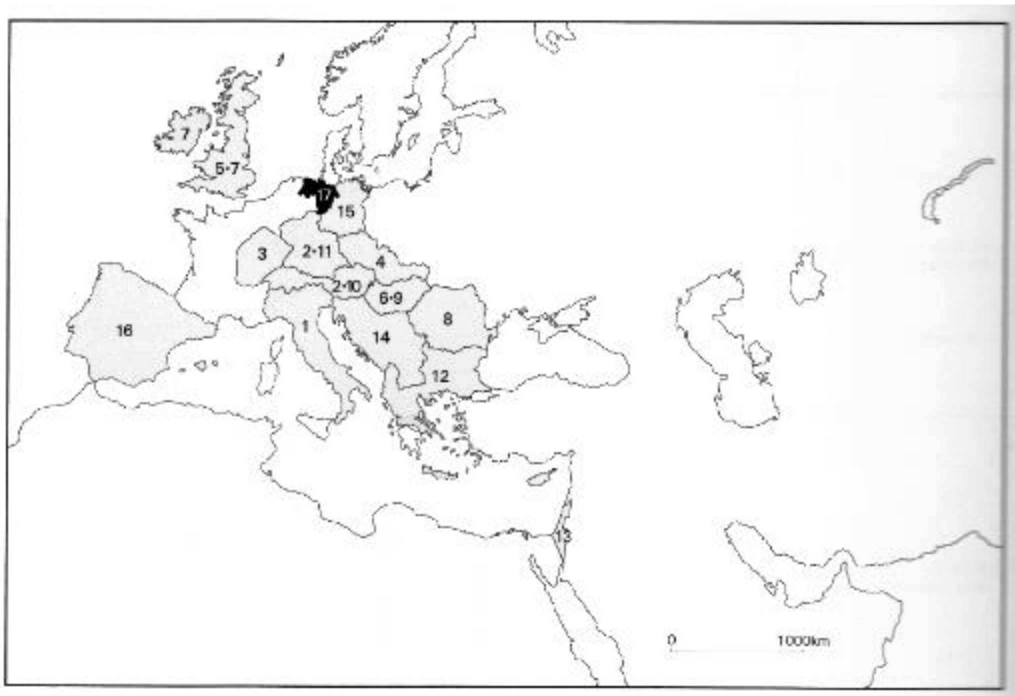


Figure 7.1: This map illustrates the areas covered in the PBF series, represented by the grey and black, shaded areas. Each outlined area refers to the area covered by one or more of the volumes. (Laux 2009)

While a few of the more recent studies have looked at blades across a wider geographic area (notably Stockhammer 2004), many of the earlier publications focus on a smaller section of Central Europe. By looking at the larger geographic area, l am integrating data from previous publications in an effort to understand manufacture related communication networks across Central Europe rather than within modern nation-states.

The sword's association with high status individuals and use as a specialized trade good (Kristiansen 1987:42; Kristiansen 2011:202; Earle 2002:325; Peterson 2009:191) provide a number of potential network structures in which the smith may have participated. The structure of sword smith communication is debated in the literature, with the two most prominent theories being that smiths were either itinerant workers or worked locally and lived sedentary lives (Coghlan 1951; Tylecote 1962:116). The question of the smith's role in Bronze Age social structures has been addressed in specific geographic areas, such as Kuijpers study of smith's status in Denamrk (2008), as well as in modern ethnoarchaeology analogs (Neipert 2006). My study attempts to look at the larger network to which smiths belong. While it is unlikely that scholars will ever be able to identify individual workers in the archaeological record, an analysis of manufacture technique can add to the debate by examining the knowledge networks, or distribution of similar manufacture knowledge and choices, apparent through manufacture decisions. My study not only advances a statistical framework for analyzing manufacture decisions and communication networks across societies, but also provides a more coherent analysis of the complexities of communication networks and thus side-steps the problematic itinerant vs. sedentary smith debate.

In this dissertation, I am examining the technological and stylistic signaling choices made during manufacture as preserved in the morphology of LBA bronze swords to explore how these choices reflect the enculturation of craft workers and the network of manufacture knowledge that existed during the LBA in Central Europe. Furthermore, examination of this issue will lead to a better understanding of the complex trading, communication, and manufacture networks during this time.

HISTORY

Bronze swords begin to appear in the archaeological record circa 1800BCE. Bronze axes preceded swords, with early specimens dating to circa 2500BCE (Schauer 1973). As the casting of copper and eventually bronze developed, daggers were improved on and lengthened into the earliest swords. Early bronze swords were manufactured with a copper/arsenic alloy with a copper/tin alloy introduced during the middle Bronze Age. This change in alloy allowed for a stronger blade, as discussed earlier in this paper.

Early bronze swords were made using organic hilts and, therefore, did not require the use of three or more part molds. The blades were relatively simply with little to no decoration, a rounded end, and rivets for attachment. There are a few thousand of these blades known and documented in the *Prähistorische Bronzefunde* series. The blades are one of two shapes: straight-edged blades that are better for stabbing, or leaf shaped blades optimal for slashing. While both are found without bronze hilts, the leaf shaped blade is more prominent in the early and middle Bronze Ages.

The end of the Middle Bronze Age and the beginning of the Late Bronze Age mark the introduction of bronze hilts. This is likely due to a change in manufacturing methods, such as the increased use of lost wax casting and multi-part molds (Mödlinger 2011:105). Bronze hilts require the ability to successfully cast a piece with a core, thus allowing the blade to fit into the hollow hilt. A shift in manufacture technique would accommodate this increase in production. The bronze hilts were often decorated with stylistic motifs including parallel lines, concentric circles, and dots. The shape of the hilt also varied from round to an octagonal shape. During this period, bronze hilted swords shift from a 6% copper/tin alloy to a 10% copper/tin alloy, resulting in a stronger metal (Wüstemann 2014). While bronze hilted swords appear in large numbers during this time, numbering in the high hundreds to just over a thousand, swords without bronze hilts were still being manufactured.

USE

The basic function of a sword is that of a weapon. The blades were constructed in two main shapes, the leaf blade and a straighter blade, which aided different types of martial combat. The leaf shaped blade has a curvature to it which shifts the center of balance to the widest part of the blade and enhances the blade's cutting effect when using a slashing motion (Mödlinger 2011:109; Bridgford 1997:103). The straight, rapier-like blade is a shape that is better suited to a stabbing effect. Mödlinger suggests that the direction of the sprue (the pouring area for the metal) was dependent on the shape of the blade and the intended offensive action. Stabbing blades would have been sprued near the tip of the blade, strengthening that area of the blade. In contrast, leaf shape blades would have been made using a typical sword sprue, near the hilt. (Mödlinger 2011:106). As the blade shape relates to offensive actions, Bridgford suggests that the change from straight blades to leaf shaped blades is indicative of a change in warfare tactics. Straight-edged blades appear in greater frequency earlier, reflecting an offensive strategy of one-on-one fighting. As leaf edge blades become more prevalent, she believes this change reflects a warfare strategy where multiple people were fighting each other at the same time, where a slashing motion would be more effective (Bridgeford 1997:113).

In addition to use as a weapon, swords could also have been used to denote social status. Due to the large number of flange-hilted swords in comparison to *Vollgriffschwerter* (Harding 2006:507), this interpretation does not seem out of the range of possibility. Kristiansen argues that this use as a status marker would have been the primary use of swords in the Nordic area of Europe. He bases this interpretation on his 1984 study, where he determined that 60-65% of Nordic *Vollgriffschwerter* were not sharpened and only 10% or fewer were heavily sharpened (Kristiansen 1984). Sharpening of the blade suggests wear, and, therefore, use as a weapon. These data and subsequent interpretation has led Kristiansen to argue that *Vollgriffschwerter* were used solely for symbolic purposes. Primary among these purposes is the distinction of warrior from chief. Kristiansen suggests that *Vollgriffschwerter* indicate that the owner is a chief and that the blade is a symbol of his office. In this system, owners of the flange-hilted swords (which Kristiansen sees here as functional weapons) would have been warrior elites (Kristiansen 1999:177, 2011:202).

Kristiansen's interpretation has been challenged by several authors. Mödlinger's 2011 paper focused on Austrian bronze blades and came up with different results (Mödlinger 2011). This study examined the manufacture and damage done to the blade. In most cases, she was able to document damage to the blade from thrusting and slashing activities as well as evidence of damage to the bronze rivets, thus suggesting the sword's primary use as a weapon. It is here that she noted a change in a sprue and gate system from near the tang to near the blade. This change occurred in the bronze hilted swords, but not in the wooden hilted swords. Even when casting defects were present, the blades still showed signs of use as weapons. Additionally, blades of this type were often cold worked and then annealed to harden the blade, a step that would be unnecessary unless the weapon were used as such (Mödlinger 2008:3). Gener discusses the issue of quality, stating that a blade of good quality would have been one which was sufficient for the intended use as opposed to our current understanding of quality (Gener 2011: 119). This is the issue on which Thrane disagrees with Kristiansen (Thrane 2006:500). Namely, since both types of hilts are equally effective as weapons, the use of the blades as purely a symbolic role would be a non-sequitur. None of these authors argues that the blades held no symbolic role; they simply argue that the blades would not have held a purely symbolic role and were still valid weapons.

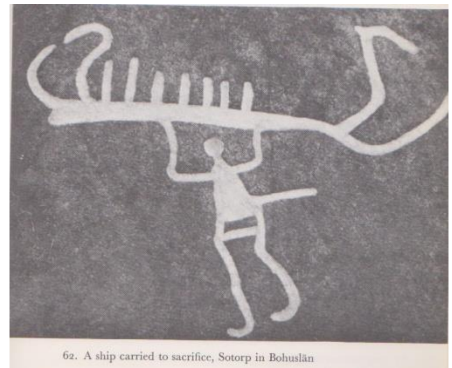


Figure 7.2: Man with a sword, from Boglösa (Coles 2000)

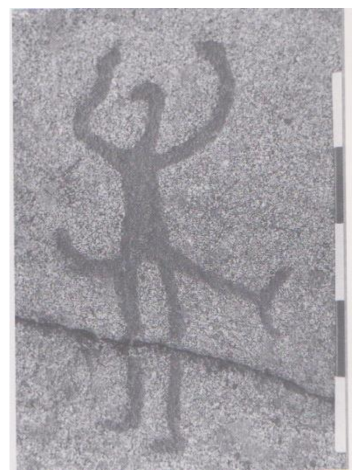


Figure 7.3: Man with sword carrying a boat, Rock art from B Bohuslän (Coles 2000:51)

Figures and representations from the past can also be used to infer use of the blades. The Camonica Valley in Italy and Boglösa, Sweden provide the best examples of weapons in rock art. The images at Boglösa depict wheels and boats most often, but when people are depicted, they are usually accompanied by a sword hanging from the waist. Coles interprets figure 7.3 as a male figure holding a sword at the hip. Here, the disc at the end of the sword is the pommel (Coles 2000:51).

In contrast to the sheathed weapons of Northern Europe, the Rock art at Camonica Valley in Italy often shows the weapons being brandished. Rock art which dates from 1000BC to 800BC includes outfitted warriors with swords and shields, but it is not until after 800BC that battle scenes are depicted frequently (Anati 1961:194). The distinctive shape of the weapons being used are one of the markers for dating the rock art. Of particular note is the inclusion

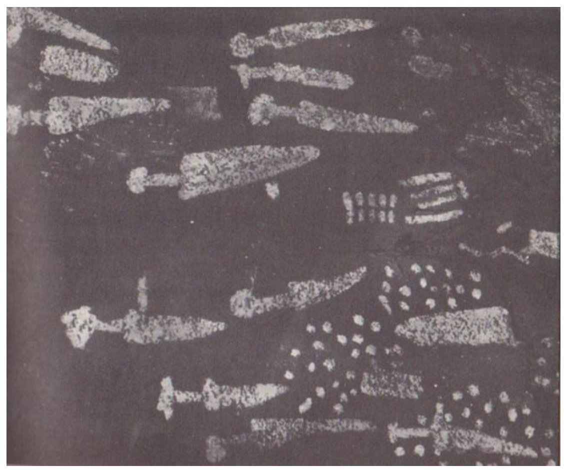


Figure 7.4: Possible ritual fighting, from the LBA or Early Iron Age. (Anati 1961:63)

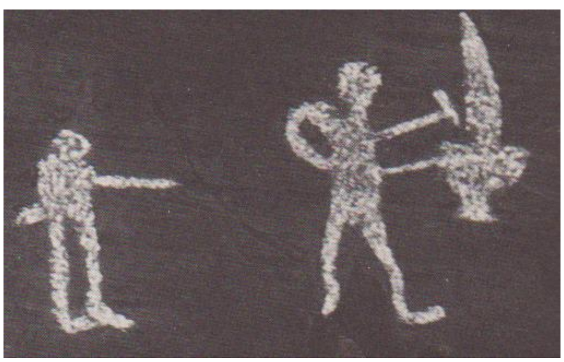


Figure 7.4: Smithing activities (Anati 1961:135)

Figure 7.7: Swords typical of the Late Bronze Age (Anati 1961:185)

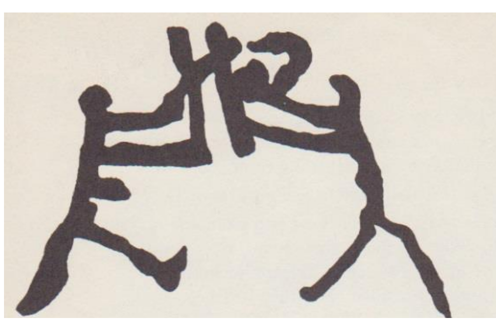


Figure 7.6: Two figures fighting, from the late Bronze Age or Early Iron Age (Anati 1961:184)

of strange garments and a third individual holding a disc shape in Figure 7.7, suggesting that the combat has some ritual significance (Anati 1961:185). Combat is not the only activity depicted in the rock art. Figure 7.6 depicts work of a smithy. Anati attributes this art to the Iron Age, suggesting that this image depicts the forging of a sword (Anati:135). This type of activity could also be related to the annealing of a bronze blade. Finally, the depiction of blades in groups with dots could symbolically represent the ritual activity of hoarding, one of the main contexts that bronze swords are found in.

Since the experiments in the early 1900s, bronze swords were often dismissed as weapons and categorized only as social objects due to conclusions that the materials were not suitable as weapons. This interpretation has recently been challenged with several use wear studies and experiments. Most notable are those of Molloy and Kristiansen (Molloy 2008,2009; Kristiansen 2002) where bronze blades, armor, and shields were reproduced and used in combat situations. In both cases, the bronze shields were shown to hold up better than leather shields to blows from the swords. This is contrary to early findings by Coles (1962), wherein he concluded that bronze shields were inferior to wood or leather shields which may have been available at the time. Kristiansen’s study also suggested that the holes in the pommel were likely used for small leather loops that would increase the ability of the user to control the blade. He also looked at damage to the blade, concluding that notches on the cutting edge could be indicative of damage done by another blade or the edge of a shield.

Typology

A discussion on current typologies of LBA bronze swords would be remiss without discussing the *Prähistorische Bronzefunde* (PBF) series. This series is an attempt to catalog all bronze finds in Europe, separated out by object type and location. *Abteilung* IV deals specifically with bronze swords and currently includes 15 volumes covering the area shown previously in Figure 7.1. Bronze swords have also been recorded in Spain, France, and Denmark though they are not covered in the PBF series. Each item is cataloged with the following information: detailed typology, find location, other objects associated with the sword, length, where the sword is currently housed including accession number, any publications that reference the sword, and a drawing. The blades are organized by an overall type, a subtype, and in some cases a variant of the subtype. The organization of type group has gone through several adaptations beginning with Naue's 1903 publication. The most recent of the PBF series uses the adaptation established by Müller-Karpe in 1961 (Wüstemann 2004). Types are defined by the handle shape with subtypes and variants separated out by decorative motifs (Krämer 1985). Subtypes or variants can have as few as two or three swords assigned to them. The two basic distinctions in sword typologies are those with bronze hilts and those without, presumably to be used with organic hilts. Organic hilted sword types include *Griffplattenschwerter*, *Griffzungenschwerter*, and *Griffangelschwerter*. *Griffzungenschwerter* are also known as flange-hilted swords. Bronze hilted sword types include *Vollgriffschwerter, Riegseeschwerter*, *Dreiwulstschwerter*, *Achtkantschwerter*, *Antennenschwerter*, and *Mörigenschwerter*. While there are more types, those listed here are the most common throughout the volumes. The detailed subtypes and variants will not be discussed here. For constancy's sake, all types will be referred to using the German type name. The following type definitions are based on Krämer's definitions published in the PBF IV.10 volume (Krämer 1985).

Organic hilted swords, *Griffplatten-*, *Griffzungen-*, und *Griffangel-schwerter*, are the earliest and simplest of the swords. The difference between the three types is the shape of the tang. *Griffplattenschwerter* do not have much of a tang, and the hilt end of the blade is rounded with rivets or a hole for their attachment. *Griffzungenschwerter* have a flat tang, often with raised edges around the tang. *Griffangelschwerter* have a thin, rounded tang. It is likely that the hilts associated with the swords would have been made from wood and riveted onto the sword in the same manner that bronze was. Due to lack of preservation, it is hard to determine if these hilts would have mimicked the decoration on those with bronze hilts. Most of these blades are plain though some have lines running parallel to the midrib or concentric circles near the hilt.

Vollgriffschwerter are full grip swords. This is an umbrella term that refers to all bronze swords that have a bronze hilt attached. Some authors separate it out from *Riegseeschwerter*, *Dreiwulstschwerter*, and the others to use as a catch all type for blades that do not fit in other categories. Other authors use it to include these types. Either way, the distinctive feature of a *Vollgriffschwert* is the presence of a bronze hilt. This study includes swords classified as *Riegseeschwerter*, *Dreiwulstschwerter*, *Achtkantschwerter*, *Mörigenschwerter*, and *Schalenknaufschwerter*. *Riegseeschwerter* are named after the type sword found in *Riegseeschwerter*. The type refers to a hilt with an elliptical cross-section, a flat circular pommel, and a round knob at the end. *Dreiwulstschwerter* have a hilt with three parallel bands along the length of the hilt. *Achtkantschwerter* have octagonal hilts with either a circular or elongated oval pommel and knob. *Antennenschwerter* are characterized by the antennae that curl upwards from the pommel. Finally, *Mörigenschwerter* are characterized by cupped pommels, an elliptical cross section of the hilt, and groups of lines along the width of the blade. Most of these pommels are accompanied by incised or stamped decoration that can appear on either the blade or the hilt. Decorative motifs include concentric circles and semi-circles, parallel lines, swirls, chevrons, dots, and curved lines. Figures 7.8 and 7.9 depict each of these types, both in decorated and undecorated forms.

The swords in the PBF series are separated into a detailed typology. Table 7.1 presents the types and variants associated with the categories of blades used in this study. The types and variants are limited to only those found in PBF volumes 10, 11, 14, and 15 - those volumes from which blades were collected for the study. Volume 9 has been excluded from this list as it employs it is own classification system with types A-Z. \Some of these typologies directly correlate to the types below, others of which appear to be similar, and still others which are unique to the area. These further classifications reflect differences in how decoration is used within the styles. Many of the subtypes and variants are composed of only one or two blades. I assigned a type of "other" to those blades that were either assigned as unknown types or described as "a blade found in X" or "a single blade with X design", where X is a place or general descriptor. These tables are presented here to give the reader an idea of the extent of stylistic analysis and classification that has been performed on Late Bronze Age swords. The PBF series provides this type of data for a variety of bronze objects, with series IV focusing on all bronze swords. The series in an invaluable resource for any researcher interested in examining the archaeological record of bronzes during the Bronze Age in Central Europe.

Figure 7.8: Non-metal hilted swords. (Wüstemann 2004)

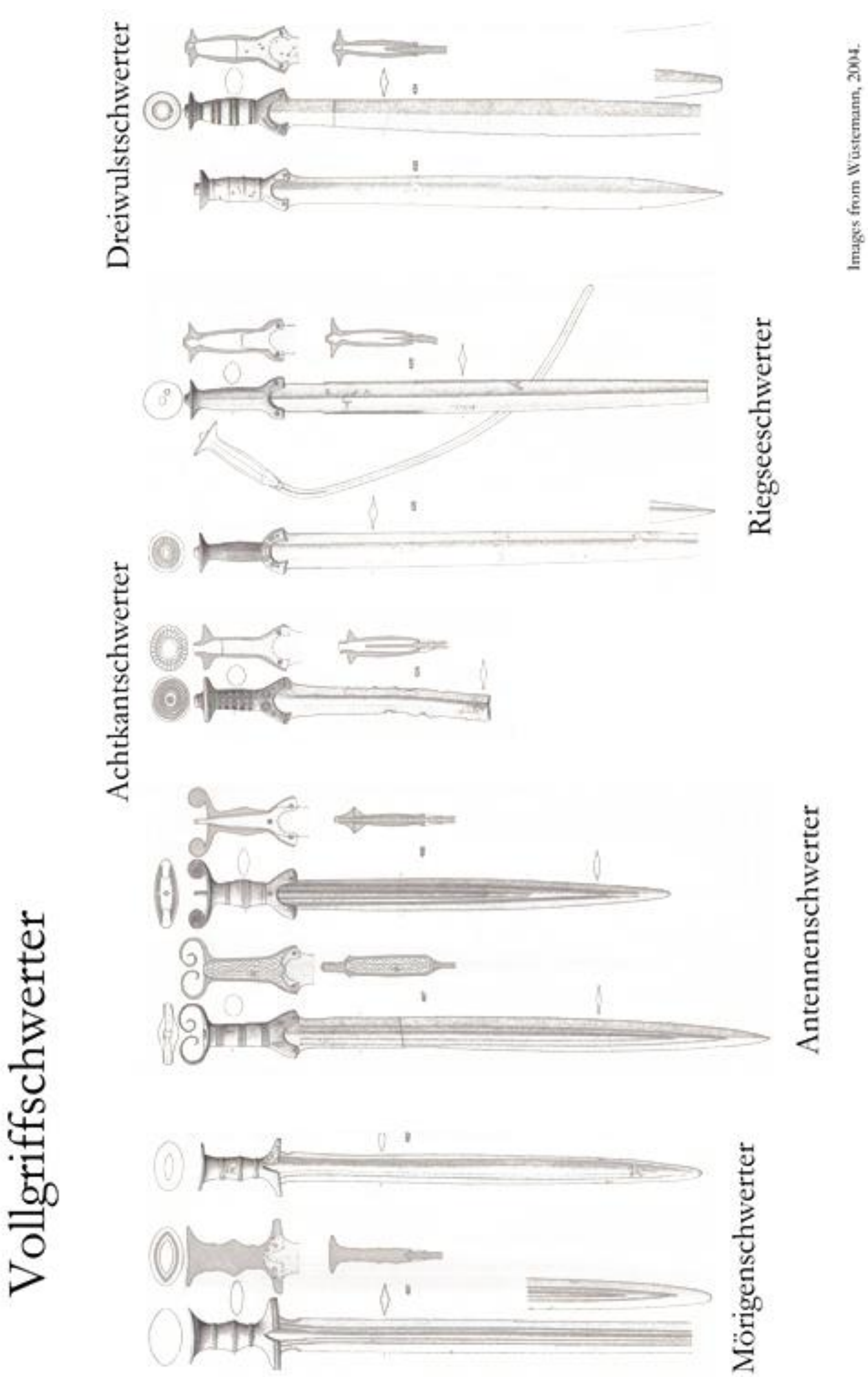


Figure 7.9: Vollgriffschwerter. (Wüstemann 2004)

Table 7.1: Detailed typologies from PBF IV

Group	Type	Variant	Number
Achtkantschwerter			77
	Ådum		1
	Erbach	Roskilde	2
	Erbach		1
	Forstmühler Forst	Hammoor	4
	Forstmühler Forst	Bedsted	24
	Forstmühler Forst		2
	Group 1 from Schoknect		2
	Group 2 from Schoknect		1
	Group 3 from Schoknect		3
	Group 4 from Schoknect		1
	Kirchbichl		4
	Leonberg	Aichach/Schrobenhausen	2
	Leonberg		2
	other		28
Riegseeschwerter			68
	Kissing		1
	Kressbronn		1
	Lorch		1
	Nöffing		3
	Other		16
	With a rounded grip		7
	With an obtuse angle		4
	With eight sided cross section		13
	With four welts		1
	With oval or rhomboid cross section		21

Group	Type	Variant	Total Number
Dreiwulstschwerter			133
	Aldrans		5
	Aldrans	St. Valentin	1
	Děčín		1
	Donauwörth		1
	Erding		10
	Erding	Punitovci	1
	Erlach		16
	Gundelsheim		9
	Högl		4
	Högl/Liptau		10
	Illertissen		9
	Illertissen	Strmec	1
	Karlstein		1
	Liptau		3
	Liptau	Ormož	1
	München		1
	München	Port	1
	Nassenfels		1
	Other		22
	Pilzknauf		4
	Rankweil		3
	Schwaig		13
	Unterradl		2
	With conical knob		12
	Zsujta		1

Group	Type	Variant	Total Number
Schalenknaufschwerter			38
	Grižane		1
	Königsdorf		5
	Königsdorf	Tiszalök	1
	Königsdorf	Spišská Belá	1
	Moškjanci		4
	Other		13
	Stockstadt		6
	Wörschach		7
Mörigenschwerter			84
	"Brieskow-Finkenheerd"		1
	"Sachsen"		1
	Corcelettes		3
	Kuckenburg		2
	Morungen		1
	Nächstenbach		17
	Other		8
	Otterstadt		3
	Preinersdorf		9
	Variant I		7
	Variant II		9
	Variant III		1
	Variant IV		2
	Variant V		4
	Weisenau		11
	With horizontal welts		4
	Zürich-Wollishofen		1

CONCLUSIONS

Swords played several roles in the Late Bronze Age, though there is some contention about their importance in each role. The shape of the blade, and the fact that it is a blade, means that the swords were optimized for fighting between humans in a way that no other tool at the time was. Differences in blade curvature, whether leaf like or straight, suggest different fighting techniques which relied on slashing or stabbing motions respectively. There were a large number of swords during the LBA, more than 1,000 published in the PBF which represent only a small fraction of the blades likely in circulation at the time. From the introduction of *Vollgriffschwerter* at the end of the Middle Bronze Age till the end of the Late Bronze Age, the swords were not deposited in graves equally nor is there evidence of widespread warfare. The ornate decorations found on many of the swords coupled with their association with the few graves that could potentially be labeled as elite have led some researchers, such as Kristiansen, to suggest that they are signs of status. In terms of signaling theory, the decorative aspects of the blades can only be seen by one who is close enough to be hit by the blade. It is likely that these blades played an important role in social negotiations between groups by signaling the importance of the individual doing the negotiation while backing up potential threats of violence should that interaction not go as planned.

PART III:
CASE STUDY – RECONSTRUCTING A NETWORK FROM LBA BRONZE SWORDS

Chapter 8: Data Collection

The data for this dissertation consist of 111 swords that have been 3D scanned. Additional data for each specimen have been collected from the *Prähistorische Bronzefunde* Series (PBF). This chapter will provide an overview of the types of data collected, how and where it was collected, and the general make-up of the archaeological sample. More detailed information on the data collection process, including a more in-depth discussion on data processing and programs used, can be found in Appendices A, B, and C. All of the categorical and numerical data collected on the 111 swords using the methods described below for this study can be found in Appendix E. It is also available in .csv format through the DRUM depository for this dissertation at http://hdl.handle.net/11299/180367.

Sword Sampling

The sample was selected from the PBF, an excellent source of data for any archaeologists interested in bronze artifacts from the Bronze Age. Volume IV of the series consists of 14 books dedicated to bronze swords. Each book contains a catalogue of swords. The majority of swords scanned for this dissertation can be found in PBF volumes 9 (Kemencezei 1991), 10 (Krämer 1985), 11 (Von Quillfeldt 1995), 14 (Harding 1995), 15 (Wüstemann 2004), and 17 (Laux 2009). When determining which objects to scan, I used the following criteria:

- Is the sword a *Vollgriffschwert*?

- Is it one of the following types: *Achtkantschwerter*, *Dreiwulstschwerter*, *Mörigenschwerter*, *Riegseeschwerter*, or *Schalenknaufschwerter*?
- Is it complete?
- Is it in a public museum?

If the answer to all of the above questions was "yes", then the sword was considered for the study. Artifacts from the following museums were scanned: Landesmuseum Württemberg, Stuttgart, Germany; Archäologische Staatssammlung München, Munich, Germany; Arheološki Muzej U Zagrebu, Zagreb, Yugoslavia; Landesmuseum Hannover Das Welten Museum, Hannover, Germany; Magyar Nemzeti Múzeum, Budapest, Hungary; Universalmuseum Joanneum, Graz, Austria; Tiroler Landesmuseen, Innsbruck, Austria; Landesmuseen, Linz, Austria; and the Landesmuseum für Vorgeschichte, Halle, Germany. Of the 111 blades collected, seven blades were added from the museum collections which do not appear in the PBF series. I did not place these into stylistic categories. Some of the PBF blades are categorized only as *Vollgriffschwerter*. The new blades were placed into the *Vollgriffschwerter* category. *Vollgriffschwerter* includes the other sub-categories in this study and is often used as a catch all group for blades that don't fit with other style categories.

3D Scanning

Every blade included in this study was 3D scanned using a David SLS2 (structured light scanner 2). The scanner works by projecting a series of vertical and horizontal stripes onto the object and capturing images of these projections. The David program uses these images to measure how the stripes are bending and calculates x, y, z points for the object. Under ideal circumstances, the scanner can collect data with a resolution of .05mm. The hilts of swords scanned for this dissertation were scanned using the 30mm calibration plate, which is the calibration plate associated with the highest resolution. The scan quality was set to “high”, using a total of 58 patterns per scan. To capture as much data as possible, I did not use quality, smoothing, or outlier filters. Bad data, such as floating points or edges that flare away from the object, were removed by hand in post processing. Scans were taken approximately every 30 degrees. 24-36 scans per hilt were captured and merged together to create a single 3D object. Figure 8.1 shows an example of a 3D scan after it has been edited and merged to create a final object file. Due to the shape of a sword, a turn table was not used. Rather, I set up a rig where the blade was rotated on top of series of pre-cut foam wedges. Information about the scanning setup can be found in Appendix C along with the scanning protocol. Please see appendix D for further information on the protocol for converting the original scan data into final objects, or **post-processing**. Throughout the process of data collection and analysis, a variety of programs were used. Appendix C contains a list of those programs, the versions used, and the part of the process they were used for.

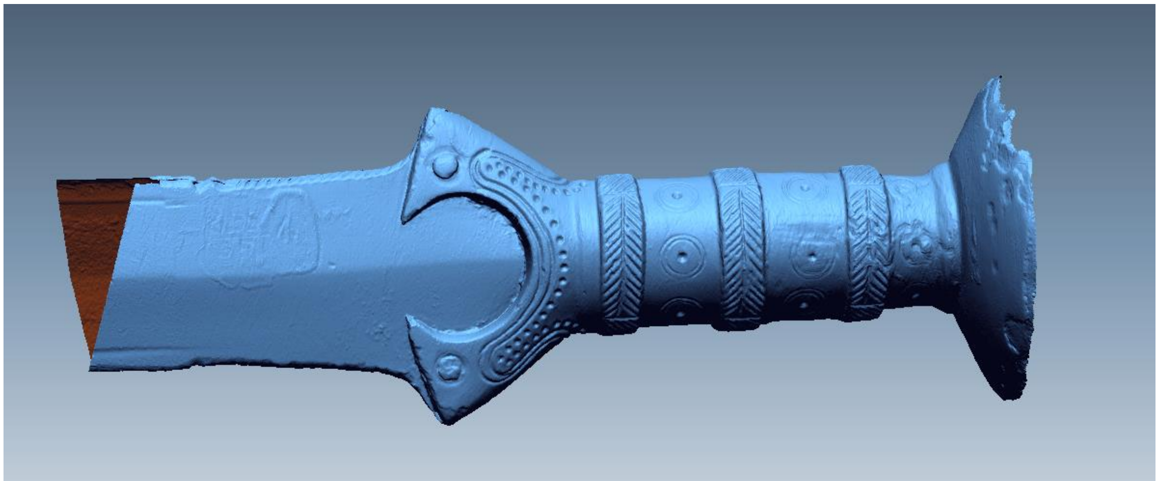


Figure 8.1: A 3D screenshot of sword 00.001. Sword scan ©Hungarian National Museum.

DATA TYPES

Tables 8.1 and 8.2 show the types of data that were collected from each blade. A full table of all numerical and qualitative data recorded can be found in Appendix G. In this study, the blades identification number is comprised of the PBF volume number followed by the blade number in that volume. The series number is IV for all of the volumes related to sword in the PBF. For example, blade 09.005 can be found in PBF series IV volume 9 under the blade number 5. Latitude and Longitude data were extrapolated from the published find site using the Latitude/Longitude Finder tool available at My Nasa Data (mynasadata.larc.nasa.gov).

DATA COLLECTION

The types of data that were collected can be separated into **continuous** and **non-continuous** data. Continuous data are numerical in nature and exist on a sliding scale, such as height and weight in a population of people. Non-continuous data are anything else. These include categorical data, yes/no data, or unique data, such as locations. With exception of location, the non-categorical data are used in this study to define different groups for hypothesis testing. For example, I use find type to examine if there are any differences in morphology that appear to correlate with the find type of the blade. An example of the type of question this can answer is: Are there certain blade profiles that are more likely to appear in cremations and inhumations than in river deposits? Each subsection below discusses the different types of data collected from the PBF series and the steps taken to obtain that data where further explanation is needed.

Table 8.1: Data collected from the Prähistorische Bronzefunde.

Collected from PBF	Find location	Latitude*
		Longitude*
	Find type	
	Total length	
	Fragment?	
	Museum and accession number	
	Blade Illustration / Profile	Fourier Transforms P A1 – P D10 (40 total) *
	Blade Cross Section	Fourier Transforms CS A1 – CS D10 (40 total) *

*Extrapolated from data present in the PBF series.

Table 8.2: Data collected from the 3D scans of sword hilts.

Collected from 3D Scans	Concentric Circles	Distance between centers**
		Outer Circle Radius**
		Distance between circle lines**
	Paralelle Curves	Distance between parallels**
	Parallel Straight lines	Distance between parallels**
	Waves	Height**
		Width**
		Horizontal distance between waves**
	Dashes	Length**
		Horizontal distance between dashes**
	Rivets	Total number
		X,Y,Z Coordinates R1
		X,Y,Z Coordinates R2
		Linear distance between R1 and R2
	Width of Tang	
	Hilt Top Profile	Fourier transforms HTP A1 - D20 (80 total variables)
	Hilt Side Profile	Fourier transforms HSP A1 - D20 (80 total variables)

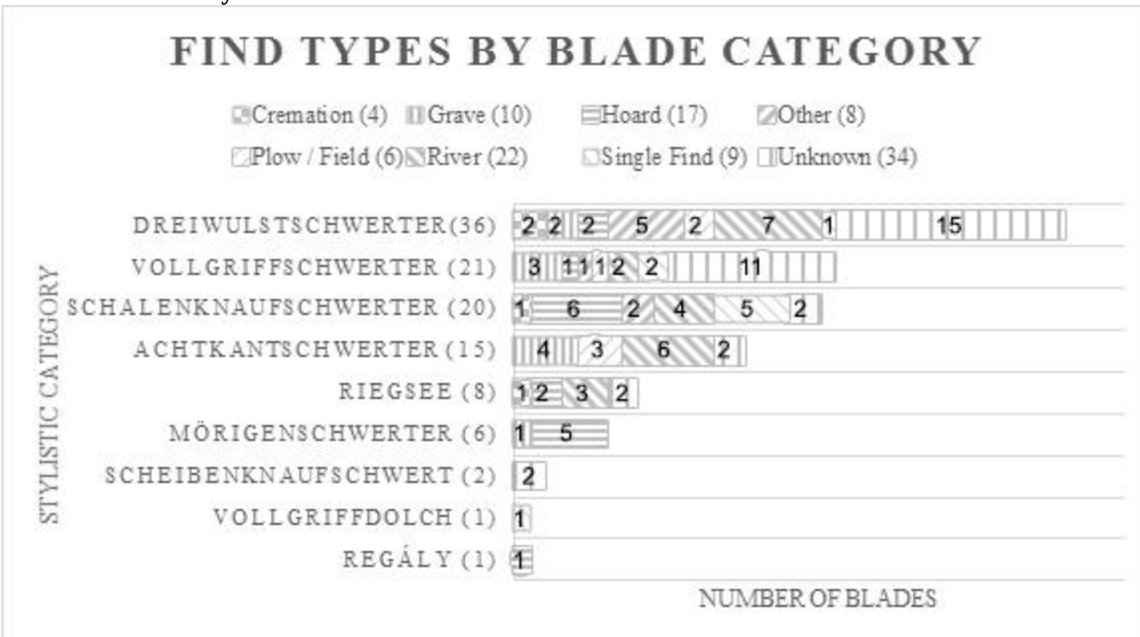
**Mean, Standard Deviation, and Ratio of Mean to Standard Deviation

NON-CONTINOUS DATA

STYLE CLASSIFICATION

The non-continuous data collected from the PBF series include the category, the find type, whether the blade is a fragment, and the museum accession number. The category of the blade was the highest level of classification available under *Vollgriffschwerter*. I chose this level of classification as it was the level most likely to remain consistent across books. In some cases, lower levels of classification can be found across PBF volumes, but the consistency of this was not sufficient to merit inclusion for the purposes of grouping the swords. Additionally, at the lowest level many artifacts are classified as a group of one. The majority of the blades were *Dreiwulstschwerter*, followed by uncategorized *Vollgriffschwerter*, *Schalenknaufschwerter*, *Achtkantschwerter*, *Riegseeschwerter*, *Mörigenschwerter*, *Scheibenknaufschwerter*, *Vollgriffdolch*, and *Regály* swords. There is one dagger in the collection, the *Vollgriffdolch*. Given the way the sample was taken, *Scheibenknaufschwerter*, the *Vollgriffdolch,* and the *Vollgriffschwerter* were not included in comparison of style types. *Vollgriffschwerter* ends up being a catch all category containing blades of very different types, and the other two categories contain too few numbers to be useful for comparisons against the other categories.

Table 8.3: Summary Statistics



FIND TYPES

Find types recorded in the PBF included swords found in cremations, inhumations, hoards, in a field context or by a plow, in rivers, as a single find, and other or unknown contexts. All of the find types included by category are summarized in Table 8.3. The "other" category contains one stray find, two construction finds, one find "near an urnfield", two drainage finds, and one find probably near a ruin. To keep the categories meaningful both in terms of numbers and usefulness of the category, I condensed the find type categories into Cremation/Grave, Hoard, Other, Single (a combination of field and single find), and River finds.

FRAGMENTATION, MUSEUM, AND ACCESSION NUMBER

Whether the blade was whole or a fragment was included for purposes of comparing total length. While the length for most of the blades was recorded, it was not used if fragmented. Finally, the museum the blade is housed in along with its accession number are recorded here. Where necessary, the accession number is updated to reflect the number found on the object at the museum.

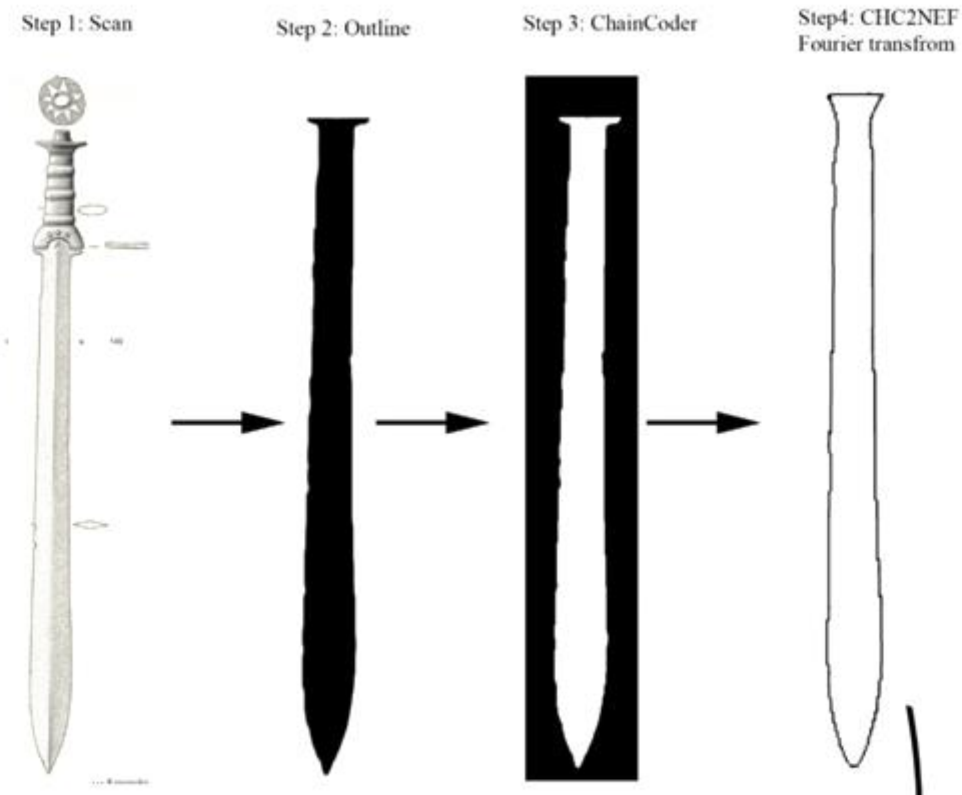
CONTINUOUS DATA

Continuous data include all of the numerical data collected for this study. Some of the data, such as length, are kept in their original form. Other data, such as the profile data, are extrapolated and transformed for use. A description of each data type and what extrapolations or transformations were done to the data can be found in the sections following. Data from the PBF series include length of the blade, location information, profile data, and cross section data. The remaining continuous data were collected from the 3D scans. All measurement data from the 3D scans is recorded in millimeters. The only continuous data collected directly from the PBF series without manipulation was the total length of the blade. If the blade was recorded as being fragmented, the length was not included in the study.

BLADE AND CROSS SECTION PROFILE DATA

The process of extrapolating profile data from the PBF series is based on the illustrations provided of the blade and of the cross sections. As the images were drawn by hand, these data are subject to variances by the original illustrators. Additionally, cross sections were not taken in consistent manner between, or sometimes within, books, nor are all swords accompanied by an illustration of the cross section. With these limitations in mind, one of the analysis sections includes looking at variances between the books to attempt to account for these limitations. Ideally, the blades would be 3D scanned in addition to the hilts to pull profiles and cross sections at regular intervals. While I have taken scans of the blades at this time, I have been unable to successfully post process those blades due to an insufficient overlap in scan data.

In order to turn the profile and cross section data into continuous data, the images were processed using SHAPE v1.3 to determine the Fourier transform descriptors. A Fourier transformation represents a shape mathematically as series of sines and cosines. These data can then be used to approximate the shape of the profiles and cross sections as numerical, continuous data. To do this, each illustration was scanned on a flatbed scanner and edited to a black and white representation of the outside of the blade. The profile was stopped at the widest part of the blade before it cuts in for the tang. This image was processed through the ChainCoder program and converted to a total of 20 Fourier harmonics (A-D for each, making a total of 80 variables per profile) based on the first harmonic option using the CHC2NEF program. Both programs are part of the SHAPE suite of software. Figure 8.2 shows what each step of the process looks like.



	a	b	c	d
1	1.00E+00	-2.24E-19	8.65E-18	9.62E-02
2	-4.94E-03	-6.15E-03	-2.96E-03	-1.05E-02
3	1.02E-01	-5.41E-04	-1.77E-03	3.14E-02
4	-4.92E-03	-1.82E-03	1.41E-04	-4.04E-05
5	3.09E-02	-1.08E-03	-1.74E-03	1.50E-02
6	-5.30E-03	-1.30E-03	-5.86E-05	3.61E-03
7	1.20E-02	2.71E-04	-5.65E-04	8.44E-03
8	-5.15E-03	9.40E-06	-1.16E-04	5.03E-03
9	4.99E-03	2.80E-05	2.64E-04	7.28E-03
10	-4.98E-03	7.39E-05	1.35E-05	5.61E-03
11	1.73E-03	4.46E-04	4.09E-05	5.64E-03
12	-4.40E-03	-1.17E-05	1.38E-04	4.82E-03
13	1.17E-03	5.38E-04	1.18E-04	5.08E-03
14	-3.55E-03	1.41E-04	3.46E-04	4.00E-03
15	1.91E-04	2.89E-04	5.25E-04	3.80E-03
16	-3.06E-03	6.68E-05	3.12E-04	3.45E-03
17	1.67E-04	6.05E-04	-8.83E-05	3.09E-03
18	-2.53E-03	2.57E-04	1.82E-04	2.62E-03
19	3.17E-04	2.11E-04	2.00E-04	2.30E-03
20	-1.84E-03	-2.30E-04	3.73E-04	1.62E-03

Figure 8.2: Proccessing the blade profile. Step 1: scan the image. Step 2: Create a solid black and white image. Step 3: ChainCode program. Step4: Fourier transform of the outline. Original image from 09.145 (Kemenczei 1991:T35)

DECORATIVE DATA

Decorative data consist of numerical data associated with the decorations incised on the blades. For each blade, I began by marking the presence or absence of different types of decorative shapes. In the end, the following categories appeared in more than 20 blades: concentric circles (34), dashes (27) parallel curves (21), parallel straights (66), and waves (21). Refer to Figure 8.3 for an example of each type of measurement. Note that these are my personal descriptors and not based on the manner in which they are categorized in the PBF series. For each decoration type, I determined a number of variables that I felt quantified the shape in some way. Table 9.2 summarizes the measurements taken. Standard deviations were also taken from the measurement data. These were taken to account for variability within a blade and compare the constancy of shapes across blades. In order to help take the measurements, I used the curvature feature in Geomagic X. This feature uses a heat map to visually differentiate the peaks and valleys of the geometry. In this way, I was able to get better accuracy during measurement. Decorative data was only taken from one side of the blade. Further measurement protocols can be found in Appendix A.

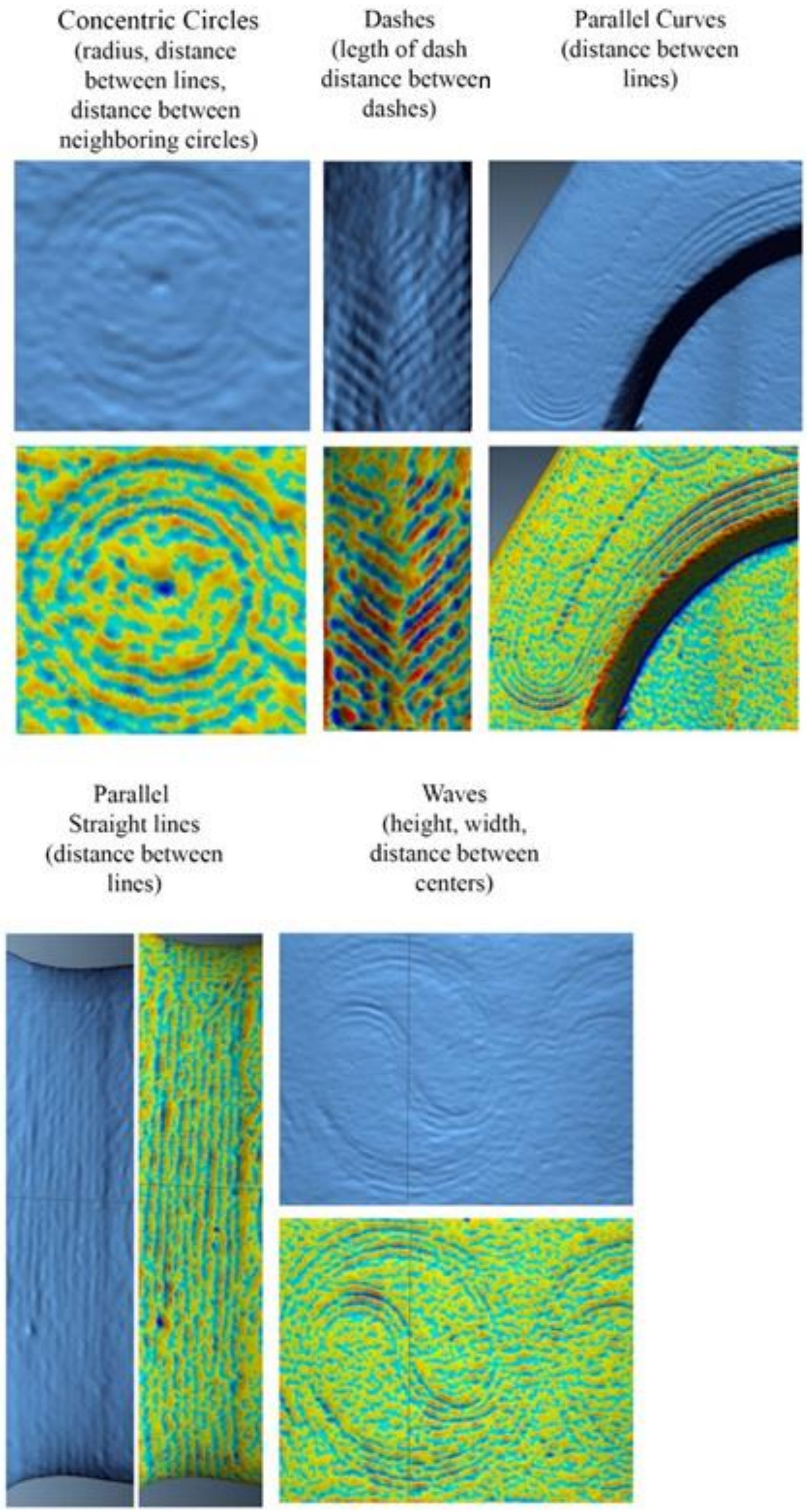


Figure 8.3: Examples of decorative shapes.

HILT PROFILES

Hilt profiles were extracted from the 3D scans in two perpendicular orientations: one from the side of the hilt and one from the top (when the blade portion is flat). Each hilt was aligned so that intersection of the hilt and the blade defined the z plane. The x and y plane were aligned so that it best bisected the hilt as seen in images 8.6 and 8.7. An additional plane was inserted to take the top profile which was defined by the point of inflection on the profile. Appendix E includes the process by which these planes were defined. The two hilt profiles were processed in SHAPE v1.3 in the same way as the blade profiles depicted in image 8.4. The image is processed slightly differently since it comes from a screenshot instead of a scan, but the general process is the same.

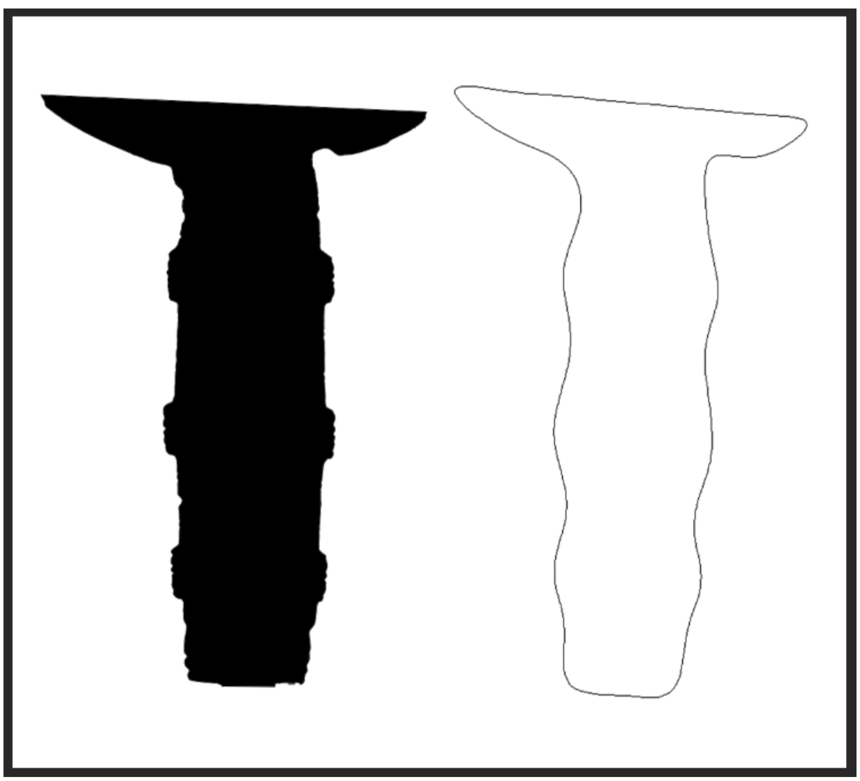


Figure 8.4: Top hilt profile for 00.001

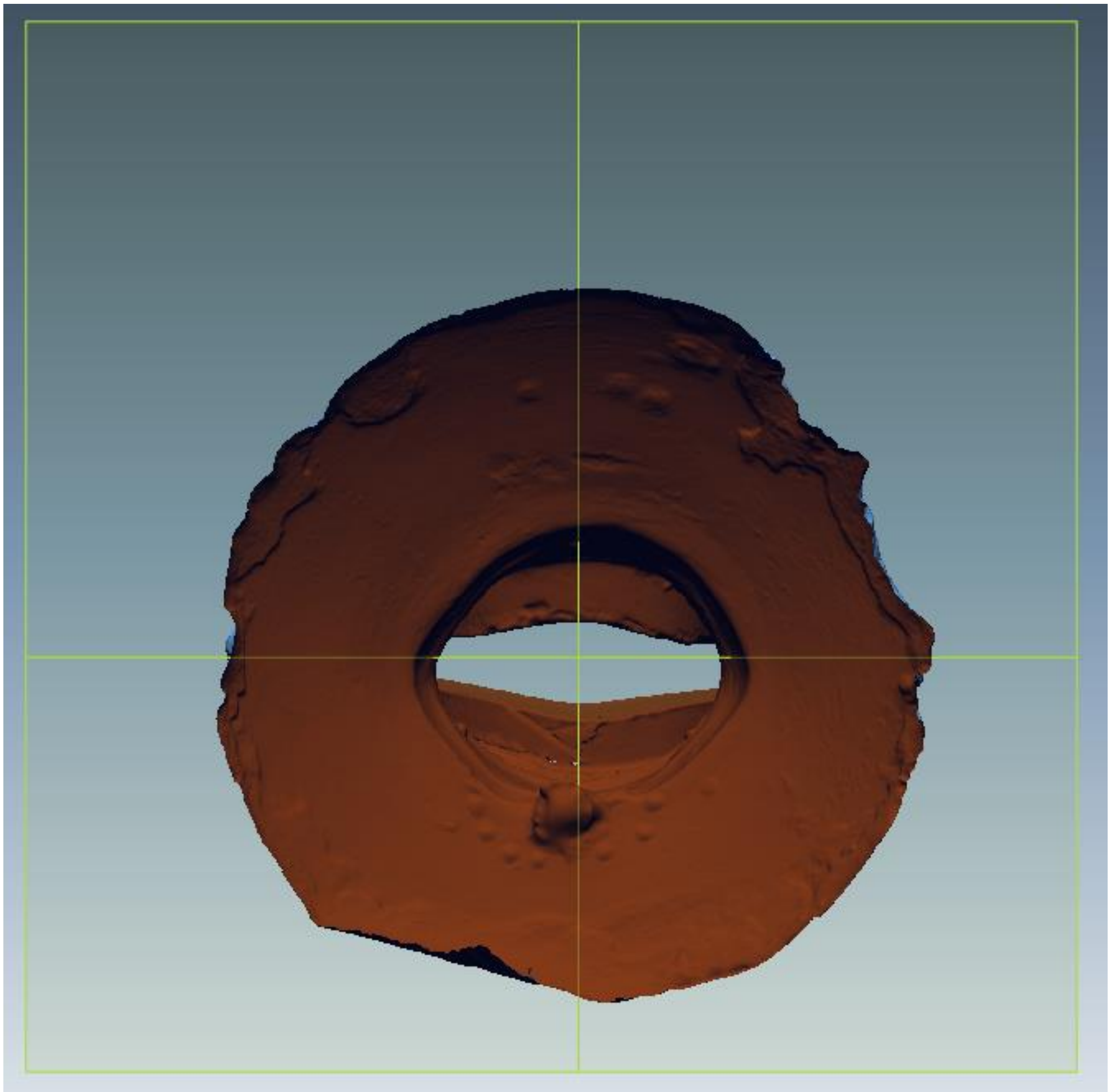


Figure 8.5: Example of how the hilt is aligned to the x and y planes. Blade 00.001. Sword scan ©Hungarian National Museum.

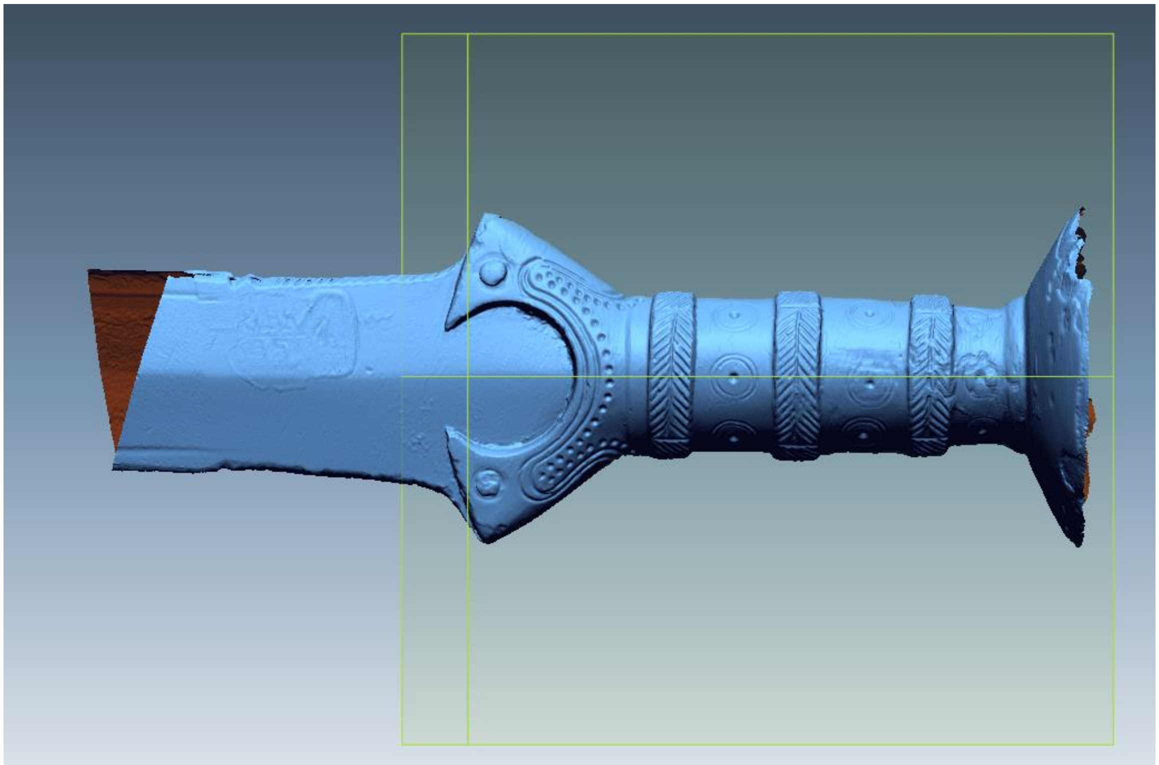


Figure 8.6: Top view of 00.001 after aligned to X, Y, and Z planes. Sword scan ©Hungarian National Museum.

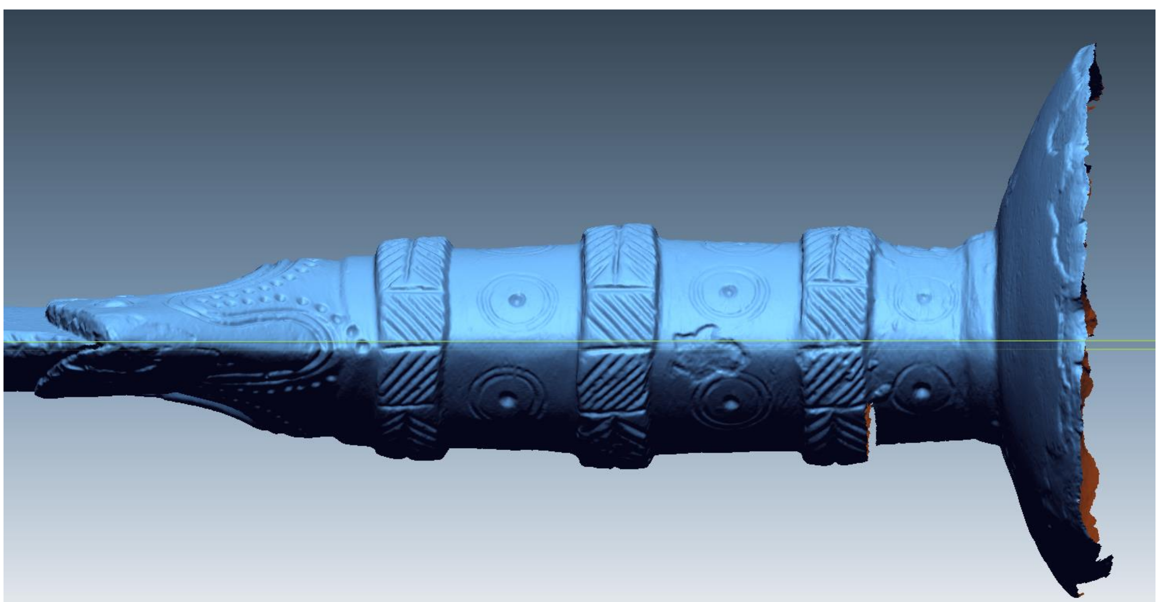


Figure 8.7: Side view of 00.001 after aligned to X, Y, and Z planes. Sword scan ©Hungarian National Museum.

LOCATION

Location data were used in this study to compare differences based on the distance between where the swords were found. For the most part, each artifact was recorded as being found in a different location. This means that the location data are unique to each blade, and not useful for comparing differences. In order to convert the data to continuous data for statistical analysis, each location was converted to a latitude and longitude data point using the Latitude/Longitude Finder tool provided by My Nasa Data (http://mynasadata.larc.nasa.gov/latitudelongitude-finder/). Blades with unknown locations or that had only a country recorded as the location were given a null value for the latitude and longitude. It should be noted that the latitude and longitude values are based on the center of the town rather than the exact location; however, these data are sufficient for comparing blades across different areas of Central Europe. Figure 8.8 shows a map of where all blades known were found, based on their latitude and longitude.

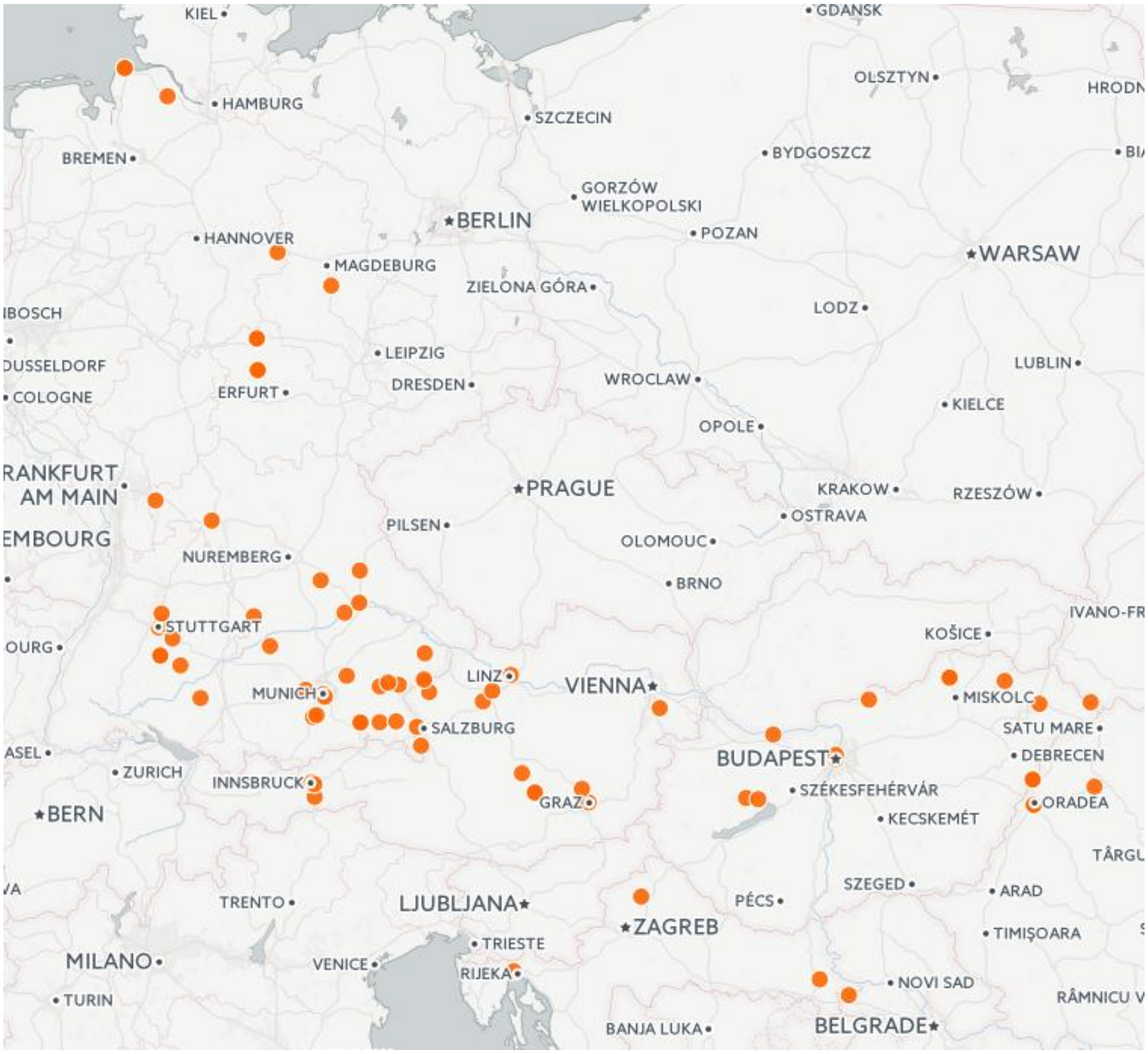


Figure 8.8: Known locations of swords used in this study. Base map data ©2016 CartoDB

RIVET PLACEMENT

Rivet placement was taken in an x,y,z form from the 3D data. Hilts in this study included between zero and five rivets. I numbered the rivets based on placement as shown in image 8.9. Only Rivet 1 and Rivet 2 appear in sufficient quantity for analysis. XYZ placement for the 2 rivets were recorded for each relevant item as well as the linear distance between the two points. The orientation procedure described in the hilt profile section places all of the blades into the same relationship to the origin point. Geomagic contains a function that allows you to select a portion of the object. That selection is turned into an average point. Figures 8.10 and 8.11 show how the rivet selection was made and the point which resulted from the process. In the event that the side of the blade chosen for measurements was negative, I inverted the y so that the point was positive. Since the blade is essentially (though not exactly) mirrored along the x plane, this does not significantly affect the measurement. Effectively, this change from negative to positive is the same as rotating the blade 180 degrees to flip the top and bottom. Another factor that would affect this is the relationship of the hilt to the center point of the 3D world. The method described above under hilt profiles and in Appendix D provides a way to consistently place the hilt within the 3D space and account for this potential variability.

Figure 8.9: Rivet placement. Sword 9.175. Sword scan ©Hungarian National Museum.

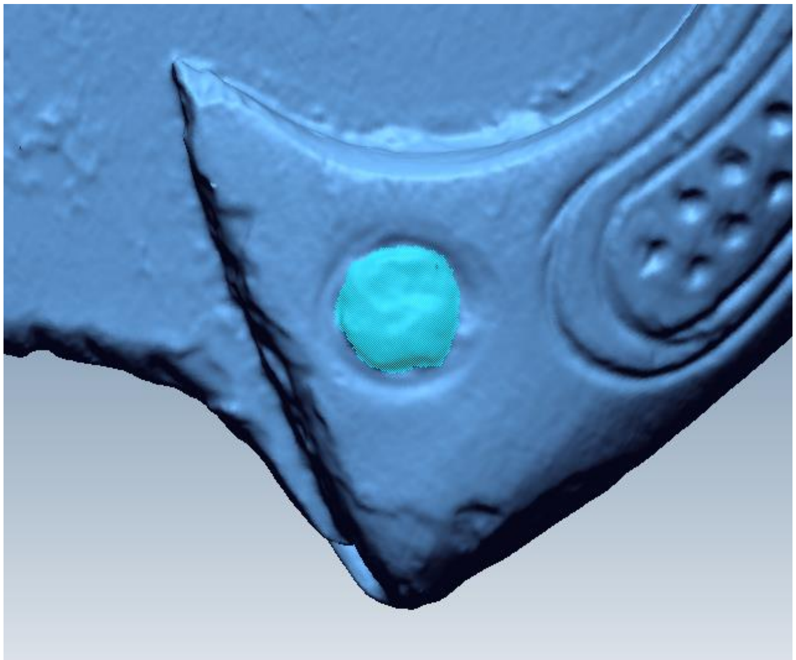


Figure 8.10: Selecting the faces that determine the rivet point. Blade 00.001. Sword scan ©Hungarian National Museum.

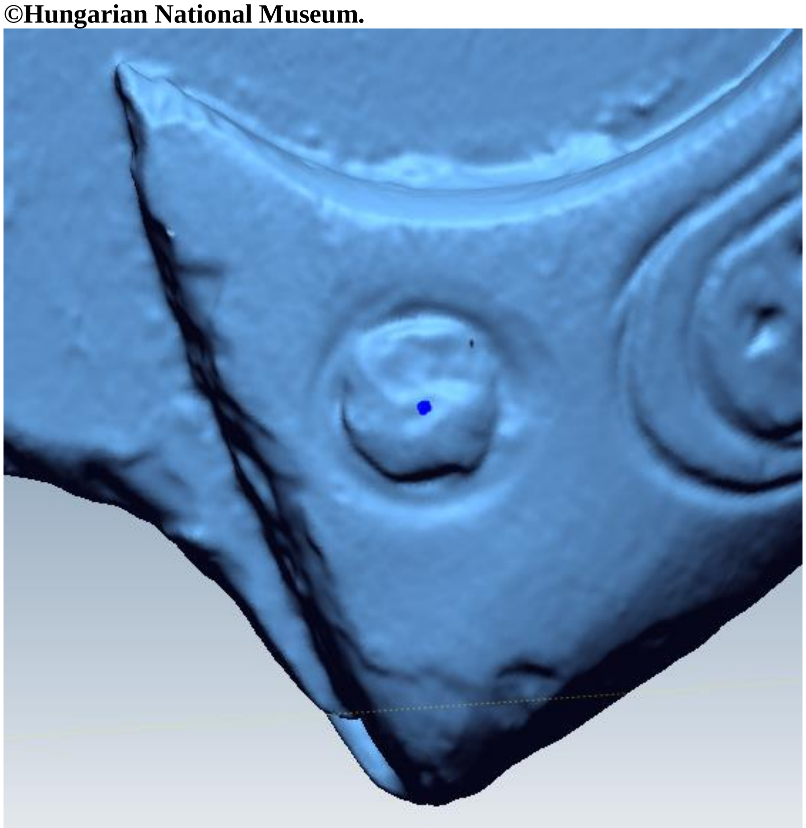


Figure 8.11: The final rivet point. Blade 00.001. Sword scan ©Hungarian National Museum.

TANG HEIGHT

The final piece of data extracted from the 3D data was the tang height. This measurement is the width of the blade where the hilt meets the blade along the central axis of the blade, as seen in Figure 8.12.

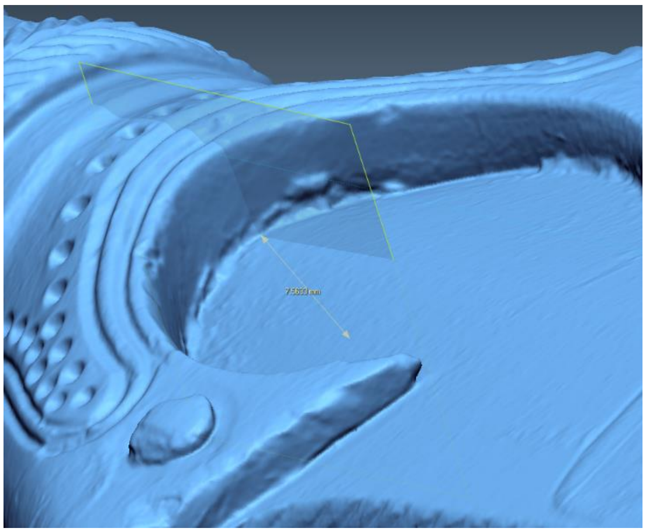


Figure 8.12: An example of how tang height is measured. Blade 00.001. Sword scan ©Hungarian National Museum.

CONCLUSIONS

It should be noted that not all blades contain all data types. There is also no single variable all 111 blades contain. Thus, the various analyses covered in the next chapter only contain a subset of the 111 blades. Analyses that contain more blades will have a stronger significance. While it would be ideal for every blade to have every variable, the data are reflective of the decorative and style choices found in the blade as well as preservation bias (such as the blade being fragmented). Each blade also has its own entry in Appendix C. Individual entries include screen shots of the 3D data, the profiles used for comparison, and the categorical data associated with the blade.

CHAPTER 9: METHODS AND ANALYSIS

This chapter goes over the methods and analysis used on the data collected in the previous section. Much of this chapter discusses the statistical manipulation of the data to get it from the data points collected as described and create a meaningful network map from those data. Each step is outlined below using the data collected from the blade profile as an example. These analyses were done to explore how the shape data cluster and to set up a method to test a series of hypotheses about how style, shape, and location interact. The hypotheses and their conclusions are presented in Chapter 10. The data were prepared and analyzed using SAS™ 9.4 software, and the network graphs were created using GEPHI 0.8.2. Charts and data used to make decisions for further steps can be found in Appendix B as noted in the examples below. The SAS code is available as a download through the University of Minnesota DRUM (Digital Repository for the University of Minnesota) service as well as a .csv of the data at http://hdl.handle.net/11299/180367 .

There are two types of data used for the majority of my analyses – non-continuous/categorical and continuous. The categorical data are used to group the blades. In some cases, I transformed the continuous data into categorical data to see how the blades were grouping out based on the morphology. Table 9.1 shows the categories I used in one column and the types of numerical data used in the other. Each category type was used to define a set of nodes. For example, the Style category includes nodes for *Achtkantschwerter*, *Dreiwulstschwerter*, *Mörigenschwerter*, *Riegseeschwerter*, *Schalenknaufschwerter*, and *Vollgriffschwerter*. For those categories that are defined by clusters, the node was determined using a clustering analysis as described below in Step 2. Blades were considered both by categories as well as indivdually. Links were determined by analyzing the shape data and measuring the difference between the groups. This required several stages of analysis and is described in steps 1, 3, and 4. Step 5 describes the method of taking the analyzed data and transforming it into link data. Figure 9.1 shows the steps used to analyze the data and create the network graphs. This chapter goes over each step of the process and explains the rationale behind each step.

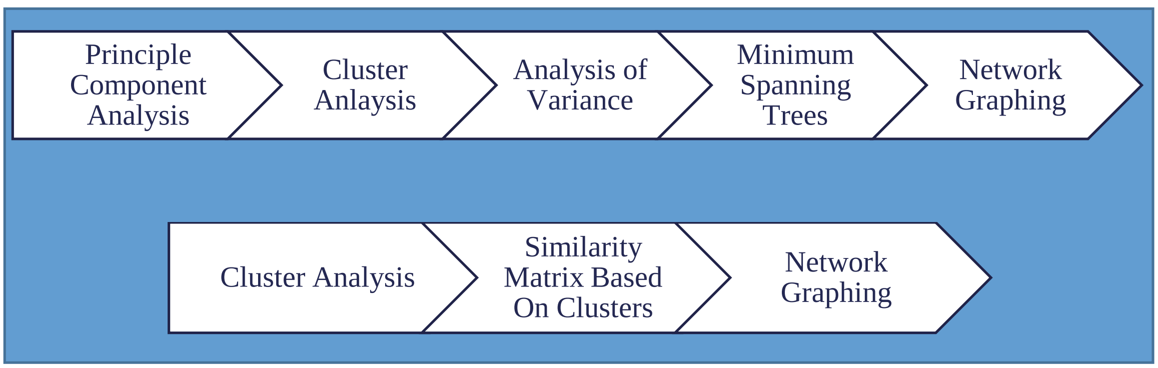


Figure 9.1: Statistical Analysis Steps

Table 9.1: Data used in statistical analysis.

Category	Numerical Data
Style	Decorative measurements (Circles, Dashes, Parallel curves, Parallel straights, waves)
Find type	Standard Deviation of decorative data
Location Clusters	Blade Profiles
Blade Clusters	Cross Section Profiles
Hilt Clusters	Hilt Profiles
Cross Section Clusters	Length
Rivet Clusters	Rivet Placement
	Tang Height

STEP 1: PRINCIPLE COMPONENT ANALYSIS

A large number of variables were collected per blade. For example, a single blade profile Fourier transform includes 80 variables. Given the maximum number of swords per comparison as 111, which split between several groups for analysis, it is important to narrow down the number of variables used. One way of doing this is by use of principle components. Principle component analysis (PCA) is a rigid rotation of the data. This means that the data are rotated in such a way that the variability is maximized on the first axis. Figure 9.2 show how a series of points with 2 variables per point (x and y) would be rotated using a PCA. Note that the relationship between the variables has not changed, only the way that they interact with the axes.

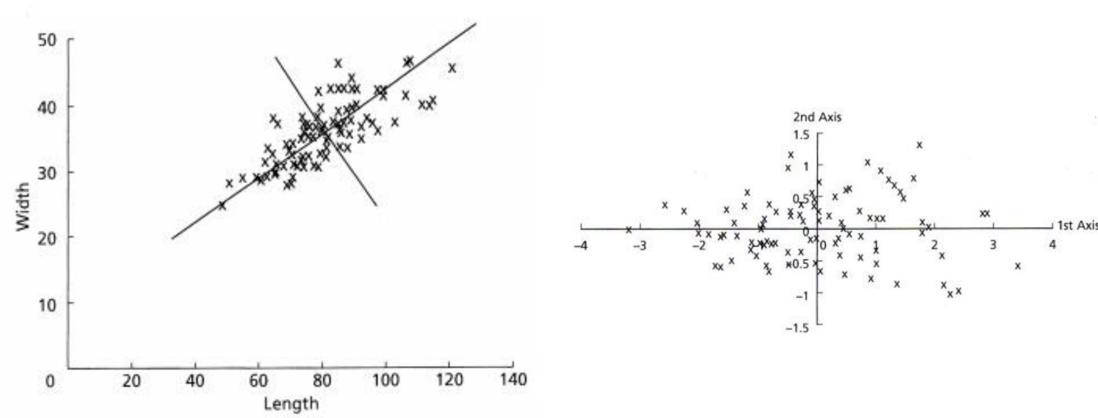


Figure 9.2: An example of principle component analysis using two variables. (Holand, 2008:1).

Principle Component Analysis was used to reduce the number of variables for the blade profile, cross section profile, the hilt profiles (both top and side were considered together for analysis), and rivet placement (x,y,z and the linear distance between the rivets). PCA was also run on all of the non-decorative data as a whole to examine how those variables were interacting in comparison to the groups. Each analysis nets a new set of variables for comparison. Additionally, the PCA outputs the amount of cumulative variance that can be explained with each new axis. An example can be seen in figure 9.3. In this example, 95% percent of the variation is summed up in the first two principle components. The 95% threshold is a typical threshold used in statistics, and it is this threshold I use throughout my analyses. In this case, I used only the principle components that make up 95% of the variation for a particular set of variables. Table 9.2 presents the number of variables that were used for each type of data based on the PCA.

Total Variance	0.0027074055

Eigenvalues of the Covariance Matrix				
	Eigenvalue	Difference	Proportion	Cumulative
1	0.00239607	0.00220209	0.8850	0.8850
2	0.00019397	0.00015950	0.0716	0.9566
3	0.00003447	0.00000910	0.0127	0.9694
4	0.00002537	0.00000666	0.0094	0.9788
5	0.00001871	0.00000718	0.0069	0.9857
6	0.00001153	0.00000359	0.0043	0.9899
7	0.00000794	0.00000407	0.0029	0.9929
8	0.00000387	0.00000058	0.0014	0.9943
9	0.00000329	0.00000098	0.0012	0.9955
10	0.00000231	0.00000047	0.0009	0.9964

Figure 9.3: An example of the output for a PCA. In this example, the cumulative variance reaches 95% with the second principle component.

Table 9.2: Variables used for each cluster type.

Data Type	Variables
Blades	Prin1-Prin2
Cross Sections	Prin1-Prin5
Hilts	Prin1-Prin11
Rivets	Prin1-Prin5
Circles	Radius, distance between circle centers, distance between circle lines
Dashes	Length, distance between dashes
Parallel Curves	Distance between curves
Parallel Straights	Distance between parallel straights
Waves	Wave width, wave height, distance between wave centers
Length	Length
Tang Height	Tang Height

STEP 2: CLUSTER ANALYSIS

One of the objectives of this dissertation is to examine how data pertaining to shape interact with one another and how they group. Cluster analysis was used as an exploratory method for determining how the data cluster along different variables. Cluster analysis is a type of analysis that quantifies where the data vary and splits the data into groups based on which points are more similar to each other.

The first step of cluster analysis is to prepare the data by determining how each point differs. Part of this process includes transforming the data to remove scaling and account for covariance. For my data, I assume that there is not equal variance between groups and that the clusters are more likely elliptical in nature. I make this assumption based on the limitations of the sample and the unlikeliness that all groups varied exactly the same across the geographic region. In the SAS software, I used the ACECLUS procedure (Approximate covariance estimation for clustering) to accomplish this transformation. The clustering algorithm is based off of the Art, Gnanadesikan, and Kettenring (1982) procedure with the following differences:

- ACECLUS uses any symmetric matrix instead of only an identity matrix.
- ACECLUS uses estimated covariances instead of a sum of squares and cross products matrix
- ACECLUS uses all pairs closer than a given cutoff instead of *m* pairs.

Further information on the ACELUS procedure can be found in the SAS 9.4 software support documents (SAS Institute Inc. 2008).

The ACECLUS procedure can be done without the need to know cluster membership or the number of clusters ahead of time. One of the outputs of this procedure is a graph of the cubic clustering criterion (CCC), pseudo F (PSF), and t^2 (PST2) statistics. These are used to help determine how many clusters should be used. CCC variables and pseudo F suggest clusters when the numbers peak or where they level out. The t^2 statistic is indicative of clustering at the number just after a peak. Figure 9.4 shows where the blade profile data may indicate significant numbers of clusters. I added the vertical lines to the SAS software output to show where I interpret there being significant clusters using the criterion above. Numbers that appear in two or three of the graphs are the ones chosen for a first look at the number of clusters. In this case, I chose to look at clusters of six and 12.

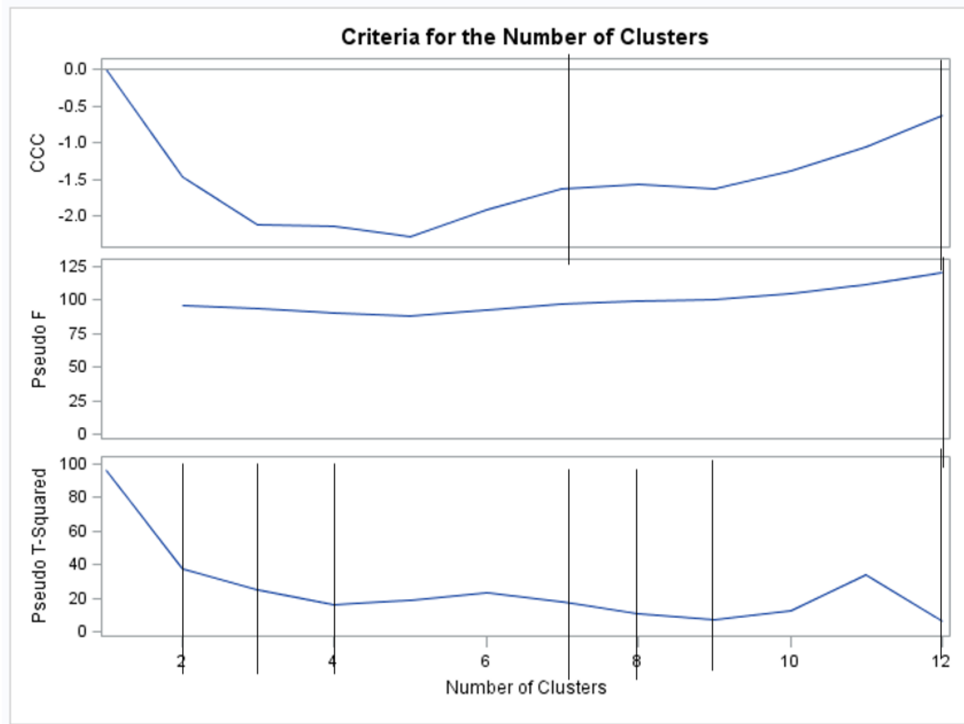


Figure 9.4: Graphs returned in SAS™ software using the ACECLUS analysis for determining the number of clusters to use.

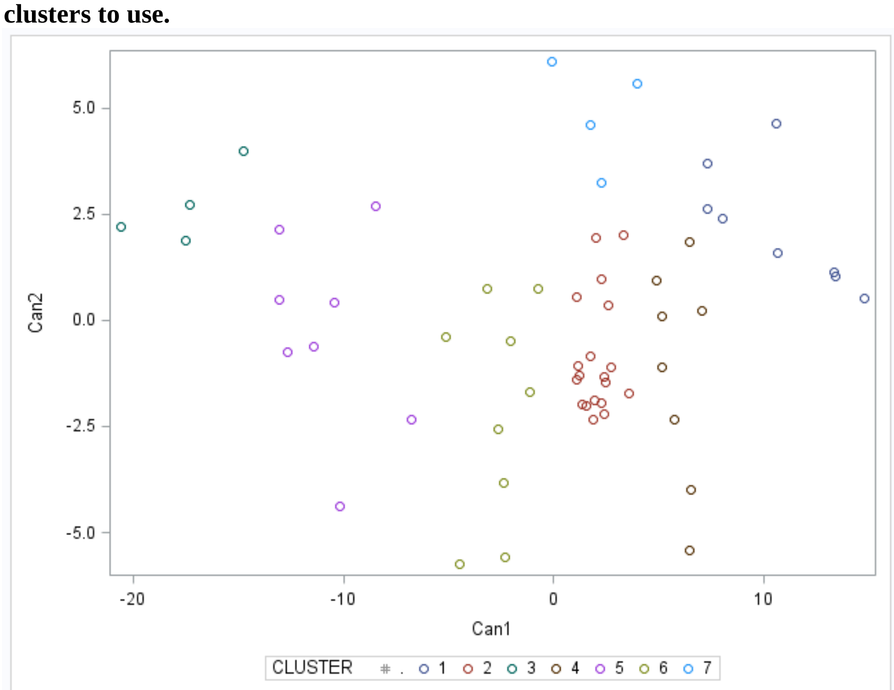


Figure 9.5: Graphing the clusters in a scatterplot using the first two canonical values SAS™ software.

Once the number of clusters was determined, I graphed the clusters to view the amount of variation each cluster represented and how they appeared in an x,y plot of the first two canonical values (these are the values calculated using the ACECLUS procedure). Figure 9.5 shows the distribution of seven blade clusters.

If outliers were present in the scatterplot, I chose to remove them from the cluster analysis. The focus of this dissertation is to look at how objects are similar, so outliers like these were removed and the cluster analysis was re-run.

Clustering analysis was done based on location, blade profiles, cross section profiles, hilt profiles, rivet placement, and a combination of all decorative data. Graphs of the clustering statistics and plots of the first two canonical values for each type of cluster can be found in Appendix B. Table 9.3 shows the variable group, number of clusters, and % of variation explained by the clustering groups used for ANOVA (analysis of variance) and MANOVA (multivariate analysis of variance). I chose not to use clusters representing under 50% of the variation. Variables that have more than one grouping object were run through ANOVAs and MANOVAs to confirm that the larger number of clusters did not result in groups that were too small. An increase of clusters can result in groups that show different levels of significance as the group number decreases and the cluster number increases. Cluster analysis was also done using the decorative shape data. These clusters were too small to compare between the groups, but the data were used in the creation of networks between individual blade nodes.

Table 9.3: Clusters for each variable.

Variable	# of Clusters	~% Variation
Location	6	90
Location	10	95
Blade	7	90
Blade	12	98
Cross Section	8	60
Cross Section	12	70
Hilt	6	60
Hilt	10	75
Rivet	15	75

STEP3: ANALYSIS OF VARIANCE FOR GROUP DIFFERENCES

Once the clusters were determined, I used ANOVA (Analysis of Variance) and MANOVA (Multivariate Analysis of Variance) to determine where there were significant differences between groups. These two tests look at the differences between the means. Tables 9.5-9.7 shows which data were analyzed with ANOVA or MANOVA tests. In short, where there was only one variable, an ANOVA test was performed, and where there were multiple variables a MANOVA test was performed. If the p value for the test was below .05, the analysis was interpreted to mean that there was a significant difference between at least two of the groups. A p value at this level means that there is a 5% chance that the difference between the means would appear in a random sample. The lower the p value, the more likely that the group means are significantly different beyond random chance.

I will present the data comparing six blade clusters to length as an example. Figure 9.6 shows the output from SAS software after the ANOVA is performed. Here you can see that the probability of the groups being the same is .0009. A low p value is indicative of at least two groups being significantly different along that value.

The SAS System

The GLM Procedure

Dependent Variable: Length

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.21950528	0.03658421	4.56	0.0009
Error	51	0.40922937	0.00802411		
Corrected Total	57	0.62873466			

R-Square	Coeff Var	Root MSE	Length Mean
0.349122	12.28142	0.089577	0.729373

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BladesCluster7	6	0.21950528	0.03658421	4.56	0.0009

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BladesCluster7	6	0.21950528	0.03658421	4.56	0.0009

Figure 9.6: SAS™ software output for an ANOVA. This ANOVA compares the length variable across six blade clusters.

Where the ANOVA and MANOVA results were found to be significant, those variables were used in the next step to determine values for minimum spanning trees and network analysis. Tables 9.5, 9.6, and 9.7 show where significant differences between groups appear. After looking at the number of significant differences between means and the number of blades in each group, I determined that it would be valuable to make network graphs of style, six location clusters, 12 blade clusters, and 10 hilt clusters.

These are denoted in the tables by having a dark green background.

Table 9.4: P Value table key

Reading the Correlation Charts

1	2	
		3*

1 - Clusters that are highlighted in dark teal will be used for minimum spanning trees and network analysis.

2 - Values that are highlighted green are significant at the p<.05 level.

3. Values that are highlighted yellow are significant at the p<.05 level, but there are less than 20 swords being compared across the clusters. Because of the low number, it is difficult to say if the results are meaningful without obtaining more data.

Table 9.5: P Values for decorative shape data.

Clustering Group	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
Style	<.0001	0.4207	0.0858	<.0001	0.2376
Find Type	0.1533	0.7188	0.0601	0.1628	0.4014
6 Location Clusters	0.1880	0.0083	0.4130	0.8025	0.1601
10 Location Clusters	0.1878	0.1713	0.4524	0.7849	0.3337
7 Blade Clusters	0.5922	0.0479*	0.5023	0.0366	0.4726
12 Blade Clusters	0.1009	0.0479*	0.6380	0.0686	0.0682
8 Cross Section Clusters	0.0183*	0.5573	0.3363	0.4878	0.3415
12 Cross Section Clusters	0.0288*	0.5573	0.3363	0.8538	0.5347
6 Hilt Clusters	0.0129	0.8243	0.0975	0.0254	0.3276
10 Hilt Clusters	0.0704	0.9259	0.3495	0.0157	0.6271
15 Rivet Clusters	0.0888	0.6351	0.0951	0.0059	0.3561

Table 9.6: P Values for standard deviation of shape data.

Clustering Group	St. Dev. Circles	St. Dev. Dashes	St. Dev. Curves	St. Dev. Parallel Straights	St. Dev. Waves
Style	0.0316	0.846	0.0043	0.0006	0.1286
Find Type	0.9768	0.549	0.0085	0.3316	0.7339
6 Location Clusters	0.1998	0.2850	0.0845	0.8619	0.0465*
10 Location Clusters	0.4389	0.3286	0.1094	0.9417	0.2620
7 Blade Clusters	0.394	0.0958	0.2704	0.046	0.2012
12 Blade Clusters	0.1661	0.0958	0.0286*	0.1462	0.0965
8 Cross Section Clusters	0.6081	0.9901	0.3013	0.4361	0.8266
12 Cross Section Clusters	0.6081	0.9901	0.3013	0.8156	0.3120
6 Hilt Clusters	0.3279	0.3529	0.3132	0.1480	0.3051
10 Hilt Clusters	0.2191	0.2533	0.0154	0.0967	0.6134
15 Rivet Clusters	0.3125	0.429	0.7573	0.3340	0.0798

Table 9.7: P Values for non-decorative shape data.

Clustering Group	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
Style	<.0001	0.0002	<.0001	0.9143	0.0001	0.3758
Find Type	0.0684	0.0787	0.0447	0.2552	0.525	0.0827
6 Location Clusters	0.0321	0.0260	<.0001	0.0575	0.0003	0.7206
10 Location Clusters	0.0723	0.0346	<.0001	0.1179	0.0081	0.0719
7 Blade Clusters		0.0631	0.2743	0.0009	0.4632	0.0007
12 Blade Clusters		0.0153	0.2133	0.0016	0.3931	0.0185
8 Cross Section Clusters	0.0018		0.1948	0.2164	0.0245	0.4577
12 Cross Section Clusters	<.0001		0.3833	0.0002	0.1481	0.8182
6 Hilt Clusters	0.0004	0.3555		0.0837	0.0343	0.3792
10 Hilt Clusters	<.0001	0.4635		0.0065	<.0001	0.2238
15 Rivet Clusters	0.27	0.5451	<.0001	0.711		0.1935

Finally, chi-squared testing was done to determine if the clusters significantly correlated with style, find type, or location. Location is particularly important for the graphing of the network structure. Where location correlates with the clustering, the latitude and longitude of the individual swords which make up the cluster can be averaged to display the center of that cluster on a map. Table 9.8 below displays the results of these analyses. Maps displaying the distributions of the clusters can be found in Chapter 10 under the relevant hypothesis test.

Table 9.8: Chi-squared values comparing clusters to style, find type, and location.

Cluster	Style	Find Type	Lat/Lon
Style		0.0085	<.0001
Find Type	0.0085		<.0001
6 Location Clusters	<.0001	<.0001	
10 Location Clusters	<.0001	<.0001	
7 Blade Clusters	0.0018	0.7551	0.0439
12 Blade Clusters	0.0014	0.7024	0.1810
8 Cross Section Clusters	0.0025	0.7747	0.0650
12 Cross Section Clusters	0.0048	0.5356	0.2119
6 Hilt Clusters	<.0001	0.0014	0.0004
10 Hilt Clusters	<.0001	0.0041	<.0001
15 Rivet Clusters	0.0133	0.3728	0.0002

Step 4: Minimum Spanning Trees

A minimum spanning tree is a network where the fewest number of links traveling the least amount of distance make up the network. For example, if you are out doing errands and know you need to go to the grocery store, the pharmacy, and the pet store you may plan your route so that you are driving for the least amount of time. By choosing to minimize your travel time, you are creating a minimum spanning tree between these three destinations.

In order to create a minimum spanning tree, you must have distances between your points. My analysis includes two types of points: individual blades and clusters. For the individual blades, I simply used the data output from the distance procedure. For the clusters I utilized information from the ANOVA and MANOVA tests. Where a significant difference between at least two groups appeared, I printed a list of distances between the means using a tukey adjustment. This type of adjustment is used to help eliminate Type 1 error across unequal groups and is appropriate for unequal groups of unknown size (Dallal 2012:ch.26). Type 1 error is a false rejection of the null hypothesis. In this case it would be incorrectly stating that the difference is not due to random chance. The output for this statement lists both the corrected differences as well as denotes specific group comparisons that are significant at the .05% error. Figure 9.7 shows an annotated output for seven clusters when length is compared.

Mean differences are shown as both positive and negative numbers, since each distance is measured both from point 1 to point 2 as well as from point 2 to point 1. Only values associated with positive numbers were considered. Data recorded from the ANOVA and MANOVA procedures were the distances between the means. For this matrix, I added up all the differences between the blades. This process created an overall weight of differences between groups. Weights are affected by how different the variables are. The standardization transformation done in step one helps to minimize this effect. I did not create a matrix for seen blade clusters, but the matrix and minimum spanning tree for 12 blades is found in Table 9.9 and Figure 9.8. Matrices of the count of the distances can be found in Appendix B.

Tukey's Studentized Range (HSD) Test for Length

Note: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	51
Error Mean Square	0.008024
Critical Value of Studentized Range	4.34022

Comparisons significant at the 0.05 level are indicated by ***.				
BladesCluster7 Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
2 - 6	0.04388	-0.07198	0.15975	
2 - 5	0.05667	-0.05920	0.17254	
2 - 1	0.06716	-0.05439	0.18871	
2 - 7	0.12845	-0.02278	0.27969	
2 - 4	0.14145	0.02558	0.25731	***
2 - 3	0.19941	0.04817	0.35064	***
6 - 2	-0.04388	-0.15975	0.07198	
6 - 5	0.01279	-0.12467	0.15025	
6 - 1	0.02328	-0.11900	0.16556	

Figure 9.7: SAS™ software output Distance between means and significance for length for seven blade clusters.

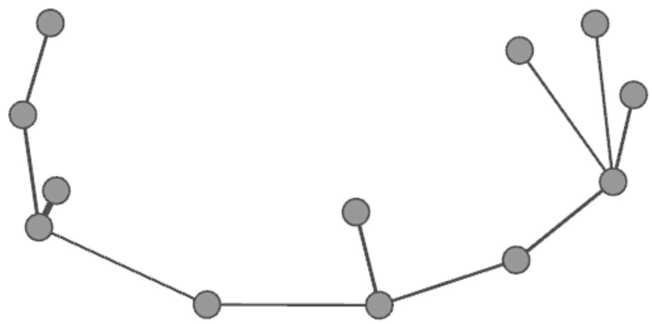


Figure 9.8: Minimum spanning tree for 12 blade clusters. Network map created in GEPHI 0.8.2.

Table 9.9: Weighted matrix of differences for 12 blade clusters.

Weighted Matrix												
	Blade 1	Blade 2	Blade 3	Blade 4	Blade 5	Blade 6	Blade 7	Blade 8	Blade 9	Blade10	Blade11	Blade12
Blade 1	0.000											
Blade 2	0.144	0.000										
Blade 3	0.119	0.163	0.000									
Blade 4	0.277	0.316	0.165	0.000								
Blade 5	0.737	0.757	0.619	0.338	0.000							
Blade 6	0.378	0.397	0.278	0.436	0.392	0.000						
Blade 7	0.218	0.243	0.127	0.044	0.539	0.230	0.000					
Blade 8	0.105	0.069	0.114	0.130	0.688	0.348	0.175	0.000				
Blade 9	0.236	0.279	0.163	0.288	0.659	0.294	0.172	0.242	0.000			
Blade 10	0.332	0.296	0.220	0.121	0.470	0.101	0.161	0.255	0.228	0.000		
Blade 11	0.185	0.239	0.089	0.097	0.558	0.192	0.054	0.190	0.120	0.146	0.000	
Blade 12	0.154	0.071	0.184	0.314	0.451	0.668	0.215	0.065	0.300	0.319	0.250	0.000

STEP 5: NETWORK CREATION

Where minimum spanning trees rely on distances between points to determine the closest routes, network analysis relies on the strength of the connection. For minimum spanning trees, a higher number indicates that the two nodes are further apart. In network analysis, a higher number indicates that the nodes are more closely related. For this reason, the matrices calculated in the previous step need to be inverted. To invert each matrix, I used the following formula: New variable = largest value + smallest value – original value. This formula results in a change where the largest number becomes the smallest number and each value in between inverts according to that scale. Figure 9.9 shows how this inversion would work on a scale from 3-11. Inverted matrices used to create network graphs can be found in Appendix B. This inversion is not done on the individual sword data, since those links are based on similarities instead of differences.

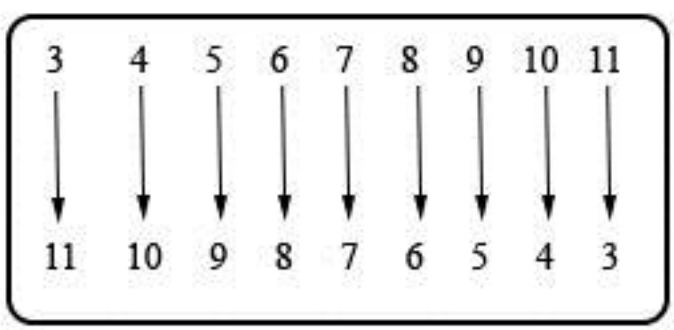


Figure 9.9: An example of transforming the data so the smallest number becomes the largest. This transformation does not change the relationship between the numbers.

Once inverted, the data are ready to be imported into GEPHI. Each cluster is a node on the network tree and the number in the matrix where those nodes meet is the weight of the link between them. The comparison between clusters of the same type is done using a force mapping, which spreads the nodes out based on link weight independent of geographical place. With the exception of blades, all of the clusters used for network graphs correlate significantly with location. For this reason, the nodes can be mapped based on geography as shown in Figure 9.10, and subsequently used alongside the weighted networks for interpretation of network formation in the next section. The example shown uses location clusters instead of blade clusters since blade profile does not correlate with location.

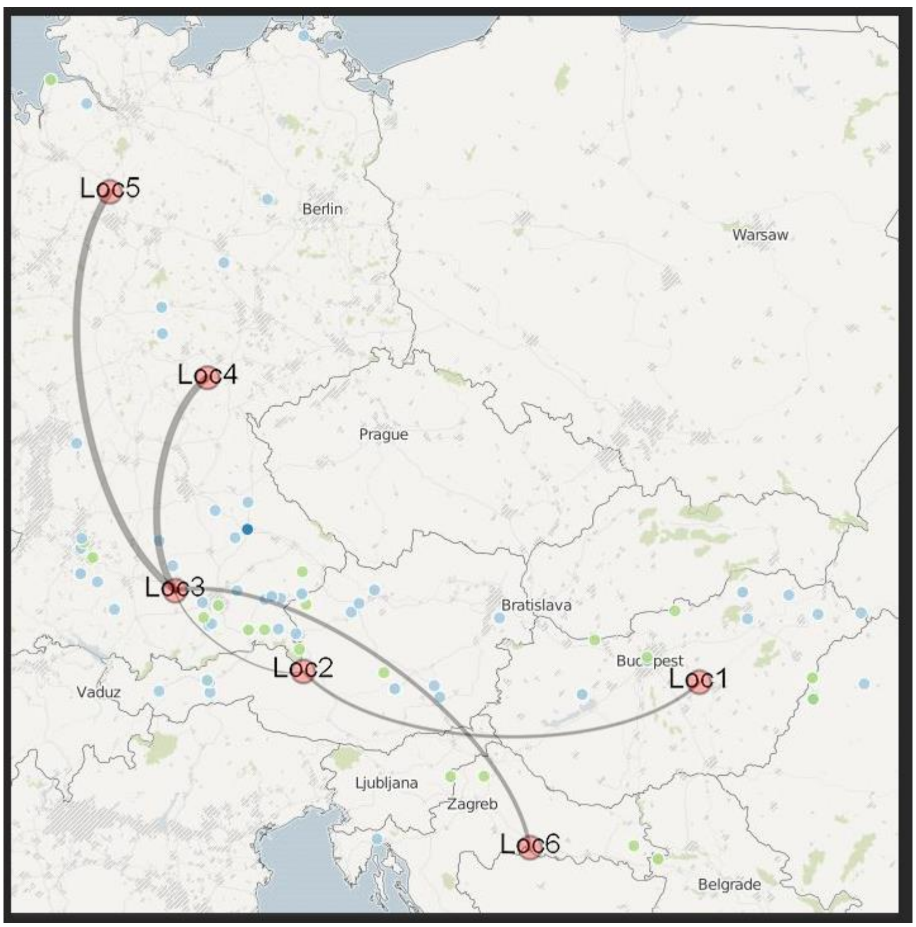


Figure 9.10: The minimum spanning tree based on location clusters mapped geographically. Base map data ©2016 CartoDB. Network map created in GEPHI 0.8.2.

STEP 6: NETWORKS FOR INDIVIDUAL BLADES

The steps up until this point have related to comparing clusters of swords based on shape data. The purpose of these analyses is to provide a base for exploring how these data interact across space and what networks that creates. However, the above analyses rely on treating the node of the network created in the next step as a group. Another level to examine the network at is by placing the node at the level of the individual object. A link could be established by measuring the multivariate distance between each blade based on a particular set of variables. This type of distance measurement would require a way to determine what multivariate distance between the points is meaningful for variation. In other words, at what distance between the points are differences between individuals being shown as compared to distances between sub communities or communities? The best way to determine this would be to take measurements from known individual smiths or communities, which is not possible at this time.

I chose instead to establish the links of the network by comparing how the swords clustered for individual variables or related groups of variables (*e.g.* all variables related to decorative circle shape would be considered together). To do this, I created a matrix by counting the number of links between blades. A link was defined as shared cluster. Each time two blades shared a particular cluster, a weight of 1 was given to that part of the matrix. Thus, every sword included in the cluster containing all of blade profile 1 (the first group identified by the ACECLUS algorithm based on the blade profile variables) shares a link with a weight of 1. Likewise, every sword included in the first cluster of hilts would contain a separate link weight of 1. An individual matrix consisting only of edges with a weight of 1 for shared clustering was created using the clusters based on shape data for blade profiles, hilt profiles, concentric circles, dashes, parallel curves, and parallel straight lines. By definition, each matrix on its only will only display a network of unconnected groups. This is because links are created by clusters, and there are no links between clusters of a single cluster type, since each sword can only be part of one of each type of cluster. Put another way, one sword cannot be part of hilt cluster 1 and part of hilt cluster 2. The use of these matrices becomes apparent when they are combined. By adding the matching cells of the matrices together, a secondary matrix was made where a weight of 1 represented either a shared blade or hilt cluster and a weight of 2 represents both a shared hilt and shared blade cluster. Additionally, since this matrix has multiple ways that two blades can connected, through either a shared hilt OR blade profile, the networks can show connections between isolated groups (*e.g.* two separate hilt groups may be connected by shared blade profiles between the groups, even though their hilt profiles cannot overlap). Combined matrices were created using blade and hilt data, all decorative data, and a combination of blade and hilt plus decorative data. These are available in the supplemental DRUM files (http://hdl.handle.net/11299/180367).

OTHER ANALYSES

In addition to the basic workflow above, a number of other analyses were done to explore the relationship between groups. Prior to PCA, all of the linear data measurements were standardized to a 0-1 scale. This does not change the shape of the data, just the magnitude. The standardization of the variables corrects for the difference in scale between measurements. This process is particularly important for the weighted differences matrix, as without the standardization differences in length would overpower the other differences.

In the analyses above, clusters were compared to the raw data. To test how the clusters interacted with each other, chi-squared tests were carried out. Many of the chi-squared tables contain cells with structural zeroes. For this reason, the chi-squared tests are taken to be an indication of correlation. An expansion of data to include more swords so that the tables include no structural zeroes is needed to confirm correlation using chi-squared tests. The results of those tests can be seen in table 9.10. The table for six location clusters, 12 blade clusters, and 10 hilt clusters compared to style and find type can be found in Appendix B. Blade and hilt groups were also compared between each other using Chi-squared testing. No significant correlation was found between hilt and blade profiles or between blade profiles and cross sections. The p values from those tests can be seen in table 9.11.

Table 9.10: Chi-squared values for clusters compared to style, find type, and location.

Cluster	Style	Find Type	Lat/Lon
Style		0.0085	<.0001
Find Type	0.0085		<.0001
6 Location Clusters	<.0001	<.0001	
10 Location Clusters	<.0001	<.0001	
7 Blade Clusters	0.0018	0.7551	0.0439
12 Blade Clusters	0.0014	0.7024	0.1810
8 Cross Section Clusters	0.0025	0.7747	0.0650
12 Cross Section Clusters	0.0048	0.5356	0.2119
6 Hilt Clusters	<.0001	0.0014	0.0004
10 Hilt Clusters	<.0001	0.0041	<.0001
15 Rivet Clusters	0.0133	0.3728	0.0002

Table 9.11: Chi-squared values for blade groups compared to hilt and cross section groups.

Chi-Squared test for Blades and Hilts				
	Hilt6	Hilt10	CS8	CS12
Blade7	0.3067	0.0801	0.4072	0.5726
Blade12	0.6161	0.3405	0.5726	0.3111

The relationship between profiles and location was used for regression analysis. While blade profile does not significantly correlate to location, hilt profile does. Due to this correlation, I used the known locations to create a regression formula which can be used to estimate the location of a blade with an unknown find spot. This estimation does not take into account the likelihood of a long distance trade. It does, however, use all of the swords with known locations to develop a formula that will create a best guess of coordinates for swords with unknown location. Long distance trade is only accounted for by the amount that it is reflected within the formula. The likelihood of the sword being a product of long distance trade should be determined based on stylistic similarities. For purposes of this dissertation, I used the estimated latitude and longitude only for displaying the swords on a map. If the artifact did not have a known find spot, it was not included in the location clusters or any other analysis that used latitude and longitude.

The formula is presented below. To use it on a new blade, you will need a side and top profile of the hilt. Each profile should go through a Fourier transform with 20 harmonics. All of the variables from both profiles should be transformed using PCA. The first 11 principle components are what are used in this formula and represented by HPrin1-HPrin11. When re-creating swords with known locations, latitude has an average error of .9661(+/-1.0474) degrees and longitude has an average error of 2.5634(+/-2.1428) degrees.

Lat=48.31197-3.13234*HPrin1+8.63701*HPrin2-10.03307*HPrin3+2.88708*HPrin4-7.02584*HPrin5+4.62069*HPrin6+14.51688*HPrin7-9.39206*HPrin8+24.01061*HPrin9-12.70149*Hprin10+7.26966*HPrin11

Lon2=13.78801+9.35802*HPrin1-21.78429*HPrin2+18.06027*HPrin3+26.10363*HPrin4-27.50622*HPrin5+3.90810*HPrin6+14.97578*HPrin7-53.59689*HPrin8-33.28697*HPrin9+23.31321*HPrin10-4.56811*HPrin11;

CONCLUSIONS

This chapter has outlined the various analyses performed on the data. I have used a set of 4 sword clusterings as an example for each step. As noted throughout the section, the relevant charts and matrices which were used to determine different variables throughout the process can be found in Appendix B. Network graphs based on the nodes and links presented in these data and a discussion of their significance can be found in the following chapters. The networks presented in the next are only as strong as the inferences we are able to make based on the data gathered and the methods used. Since these data are used to create both the nodes and the links, the inferences drawn from the networks relies heavily on the methods above.

Chapter 10: Hypothesis Testing

The categories and variables were chosen to question how different aspects of shape interact with style, final use, and each other. This chapter will present the hypotheses and conclusions tested using the above methods as well as a discussion of the networks that were formed in the last step of data analysis. Each section of this chapter starts with a larger hypothesis and then breaks down into smaller hypotheses, which are examined via the data and discussed. Throughout these analyses, the null hypothesis is that there is no difference between groups. If the p-value comparing groups is lower than .05, this suggests that there is a correlation between the shape data and the group. In the presentation of data, green boxes represent significant correlation, a yellow box represents potential significance that is tempered by small sample for that group, and a white box indicates no significant correlation between groups. Refer to Table 9.4 for a graphical depiction of the key.

Before discussing specific hypotheses, it is necessary to address a few assumptions and limitations of the data. While the total count of 111 swords is respectable, I am dubious of the ability to identify the work of a single craft person in the record given the geographic and temporal span of the artifacts at this sample size. This issue becomes compounded as no single analysis can take advantage of every item in the scanned collection. For this reason, I have come to think of these groups as representatives of smaller networks that are interacting with each other. The various clustering methods also present limitations. The location clusters obscure the impact of long distance trade on the network. Since the clustering is based on location of the final destination, a blade that was traded over a long distance would not reflect its place of origination, but rather its place of deposition. The clusters based on shape data are less likely to obscure trade, and in some cases show individual swords that appear out of the geographic range where others of their type appear. In some cases, even though the location data are significant, it is difficult to see how the spread is interacting on a map due to the overlapping of groups. Finally, one of the most interesting groups for me is the decorative data. Unfortunately, most of the analyses done here result in small group comparisons. While there is statistical significance between group means, the size of the groups is too small for that significance to be interpreted as meaningful.

Each hypothesis in this chapter is presented as follows:

- Hypothesis: Null hypothesis.
- P values related to the hypothesis.
- Conclusion (accept or reject the null hypothesis).

The null hypothesis is that there is no interaction between the category being tested and the shape data. A standard α value for this type of test is .05. When the p-value is less than the α value, the null hypothesis is rejected. The p-value represents the chance that the sample could have been chosen randomly. When the null hypothesis is rejected, it means that there is a significant difference between at least two of the groups by that measurement; therefore, that measurement correlates to the group being tested. The correlation is not necessarily meaningful, and the discussion section of each hypothesis presents an interpretation of why the null hypothesis may or may not have been rejected.

HYPOTHESIS 1: TECHNICAL CHOICES ARE MADE INDEPENDENTLY OF STYLE.

Hypothesis 1a: Style does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
Style	<.0001	0.4207	0.0858	<.0001	0.2376

Conclusion: The null hypothesis is rejected for concentric circles and parallel straights.

Hypothesis 1b: Style does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
Style	0.0316	0.846	0.0043	0.0006	0.1286

Conclusion: The null hypothesis is rejected for standard deviation of concentric circles, parallel curves, and parallel straight lines.

Hypothesis 1c: Style does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
Style	<.0001	0.0002	<.0001	0.9143	0.0001	0.3758

Conclusion: The null hypothesis is rejected for blade profile, cross section, hilt profile, and rivet placement.

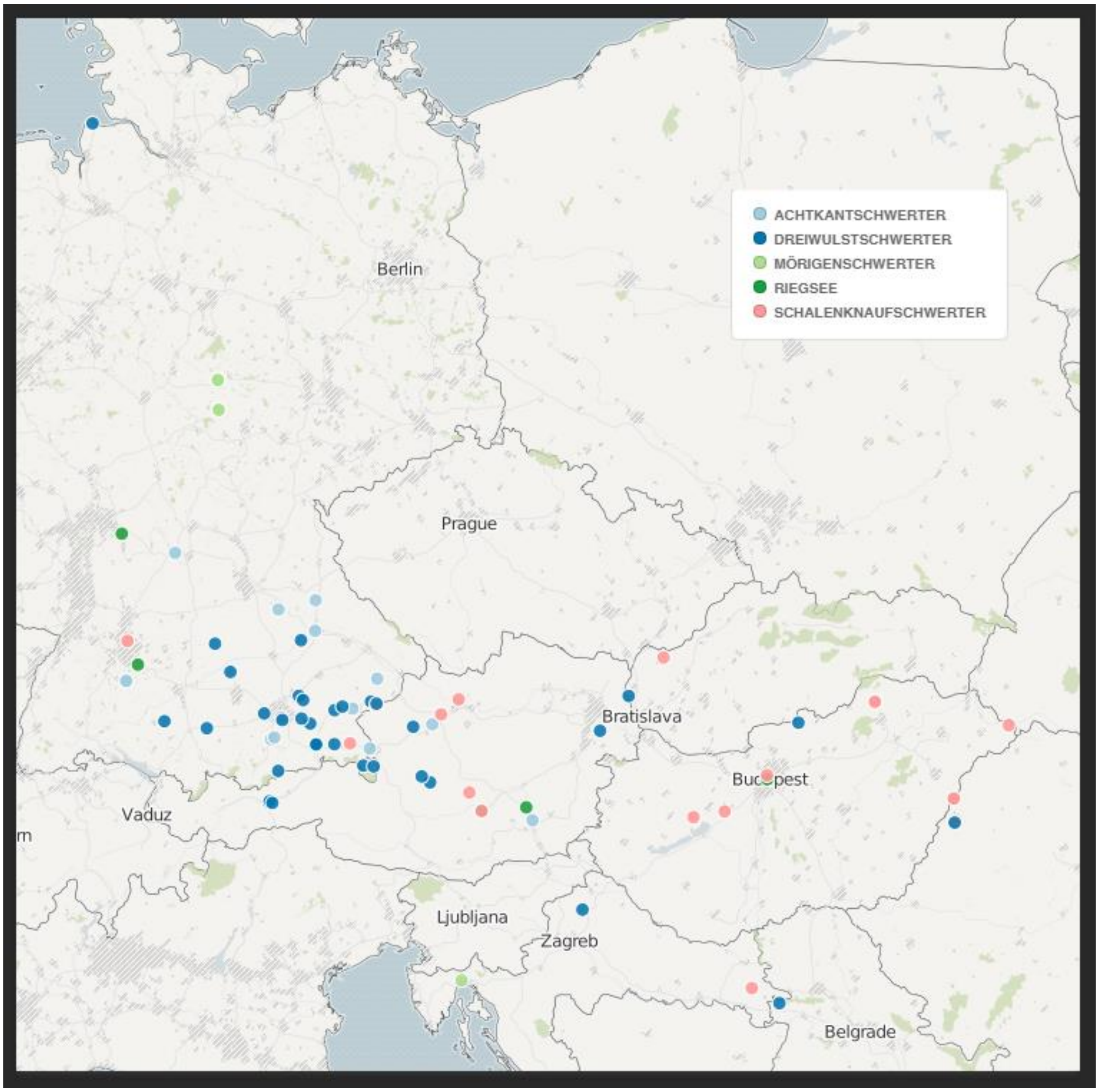


Figure 10.1: Sword distribution by style. Base map data ©2016 CartoDB

DISCUSSION

This hypothesis was developed to ask the question of whether or not individuals or people with the same shape repertoire (suggestive of closely knit networks) would be making swords that span across multiple style categories or if they primarily made swords of the same style.

The style of a sword is based on its visible attributes. It is not surprising, then, to see that hilt, blade, and profile correlate significantly with style. What is more interesting is the correlation of distances between parallel straight lines, concentric circles, and the correlation of standard deviation. This suggests that the consistency of shapes, and the need for them to be consistent in the particular ways, may change dependent on the style of blade. It is possible that this may also indicate differing levels of skill and ability to keep shapes consistent between the areas where different styles are expressed.

Swords are often discussed in terms of style due to the variety of stylistic expression and ability to tie those expressions to certain areas. However, a reliance on style creates a grouping that is determined based on attributes that are easily visible. The profile data collected show a wider range of variability than is able to be expressed through the style groups. The correlation of shape based clusters to the styles indicates that these blades can be broken down into groups based on a higher resolution of data. Furthermore, while those clusters tend to correlate with particular styles, there are clusters that are found outside of the typical associated style (see Table 9.10 for the chi-squared matrix.) For example, swords from hilt cluster two can be found in the *Dreiwulstschwerter*, *Achtkantschwerter*, and *Schalenknaufschwerter* groups. This shows a shared knowledge of hilt shape between those groups.

HYPOTHESIS 2: FINAL USE OF THE BLADE DOES NOT RELATE TO TECHNICAL CHOICES.

Hypothesis 2a: Final deposition does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
Find Type	0.1533	0.7188	0.0601	0.1628	0.4014

Conclusion: The null hypothesis cannot be rejected.

Hypothesis 2b: Final deposition does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
Find Type	0.9768	0.549	0.0085	0.3316	0.7339

Conclusion: The null hypothesis is rejected for the standard deviation of parallel curves.

Hypothesis 2c: Final deposition does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
Find Type	0.0684	0.0787	0.0447	0.2552	0.525	0.0827

Conclusion: The null hypothesis is rejected for hilt profiles.

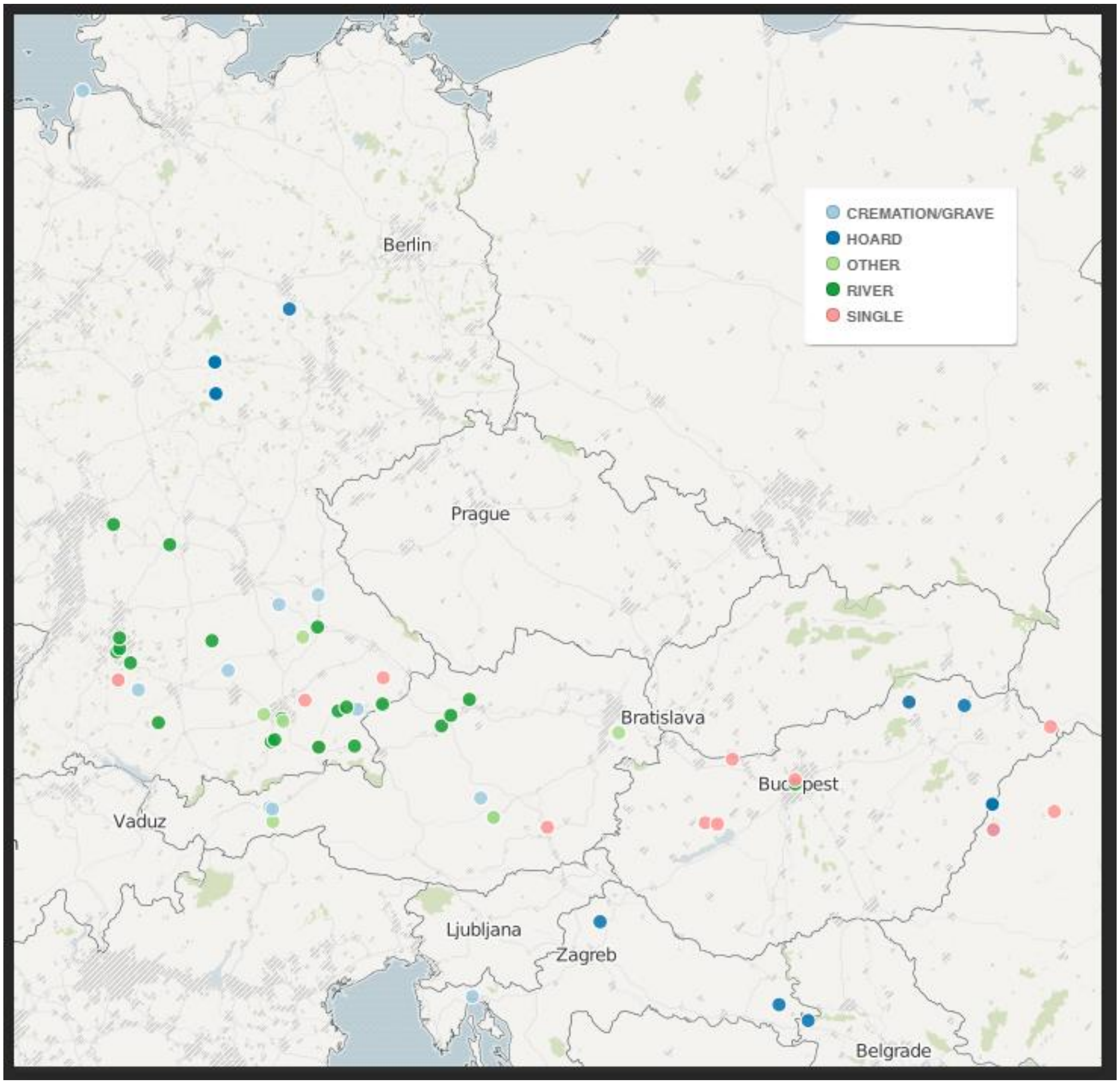


Figure 10.2: Sword distribution find type. Base map data ©2016 CartoDB

DISCUSSION

I chose to examine find type to examine the relationship between final use of the sword and manufacture. It is not clear if the final use was the intended use during production. However, an association between find type and manufacture choice may show cases where the swords were made with a particular purpose in mind.

As with style, there are some interesting correlations that are being expressed in find type. Since find type appears to be correlated with style, I suspect the correlation to find type and profiles is being driven by the style association. Based on where the significant difference in means appear in the ANOVA test, hilt profile mainly separates out hoard finds from other finds, which are made up primarily of *Schalenknaufschwerter* and *Mörigenschwerter*. Additionally, *Mörigenschwerter* from this sample were only found in hoards.

The correlation between river finds, single finds, and parallel curve shape is distinct form the patterns that occur across styles. It is possible this difference in the manufacture of parallel curves on the hilt reflects a difference in how the curves are made dependent on the use of the blade. This is a tenuous conclusion at best, as it assumes a conscious choice on the part of the maker and knowledge of the final deposition of the blade. However, it is worth considering the possibility of conscious choice in how the shape is changing, particularly regarding deposits that are less likely to be removed at a later time.

Hypothesis 3: Location plays a significant role in how shapes are expressed across blades.

Hypothesis 3a: Location does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
6 Location Clusters	0.1880	0.0083	0.4130	0.8025	0.1601
10 Location Clusters	0.1878	0.1713	0.4524	0.7849	0.3337

Conclusion: The null hypothesis is rejected for dashes at the six location cluster level.

Hypothesis 3b: Location does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
6 Location Clusters	0.1998	0.2850	0.0845	0.8619	0.0465*
10 Location Clusters	0.4389	0.3286	0.1094	0.9417	0.2620

Conclusion: The null hypothesis cannot be rejected. There are too few swords per group for the standard deviation of wave shape, but the results here suggest that a larger sample size might show a rejected null hypothesis for the standard deviation of waves.

Hypothesis 3c: Location does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
6 Location Clusters	0.0321	0.0260	<.0001	0.0575	0.0003	0.7206
10 Location Clusters	0.0723	0.0346	<.0001	0.1179	0.0081	0.0719

Conclusion: The null hypothesis is rejected for blade profiles and rivets at the six location cluster level. It is also rejected for cross section and hilt at both the six and 10 location cluster levels.

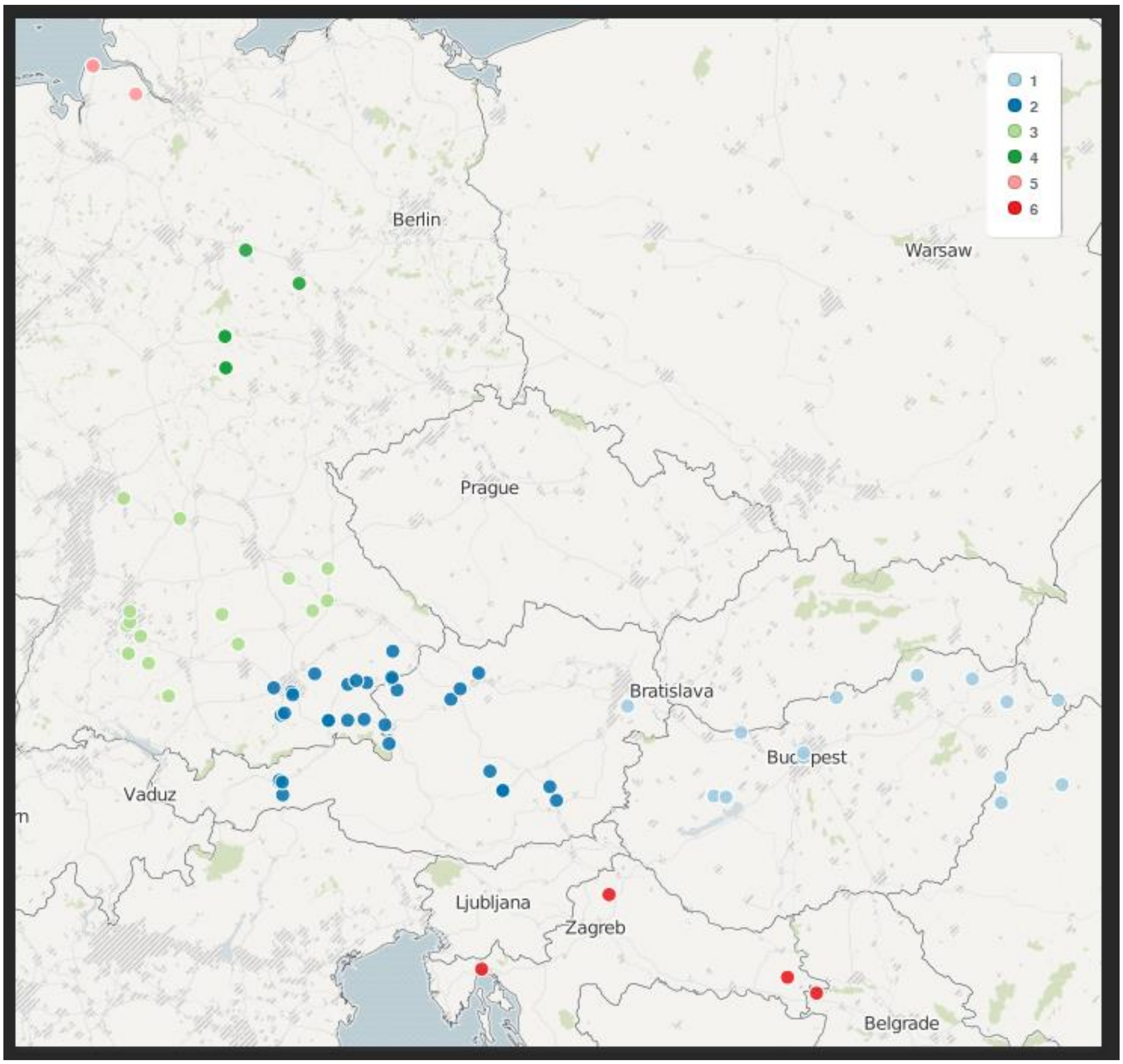


Figure 10.3: Sword distribution by location cluster. Base map data ©2016 CartoDB

DISCUSSION

There are correlations in the non-decorative data of the swords. Some of this correlation is due to style, but these correlations go beyond style as at 10 location clusters there are more groups than there are styles. There are enough differences in this group to compare the network based purely on geography. The clustering of objects by location is significant beyond style grouping and provides a way to look at networks based on local similarities between groups. However, some of the significance is lost at the 10 cluster level. This indicates that as the switch from six to 10 locations is made, the change in blade profile and rivet placement can no longer be detected between groups. For this reason, I chose to use the six cluster level for network analysis in the next chapter.

HYPOTHESIS 4: BLADE PROFILES CLUSTER IN MEANINGFUL WAYS THAT CORRELATE WITH OTHER TECHNICAL CHOICES

Hypothesis 4a: Blade profile does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
7 Blade Clusters	0.5922	0.0479*	0.5023	0.0366	0.4726
12 Blade Clusters	0.1009	0.0479*	0.6380	0.0686	0.0682

Conclusion: The null hypothesis is rejected for parallel straight lines at the seven blade cluster level. It is possible that the null hypothesis is rejected at both levels for the dashes, but a larger sample size is required to confirm this.

Hypothesis 4b: Blade profile does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights
7 Blade Clusters	0.394	0.0958	0.2704	0.046
12 Blade Clusters	0.1661	0.0958	0.0286*	0.1462

Conclusion: The null hypothesis is rejected for the standard deviation of parallel straight lines at the seven blade cluster level. While it is possible that there is a correlation between the standard deviation of parallel curves at the 12 blade cluster level, it is unlikely. Most of the groups end up with one or two specimens, and likely the correlation seen here is that one or two of the blades are significantly different than the other blades.

Hypothesis 4c: Blade profile does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
7 Blade Clusters		0.0631	0.2743	0.0009	0.4632	0.0007
12 Blade Clusters		0.0153	0.2133	0.0016	0.3931	0.0185

Conclusion: The null hypothesis is rejected for length and tang height at the seven and 12 blade cluster level. It is also rejected for cross section at the 12 blade cluster level. Note that the blade clusters are not compared to blade profile, since those were the variables that defined the clusters.

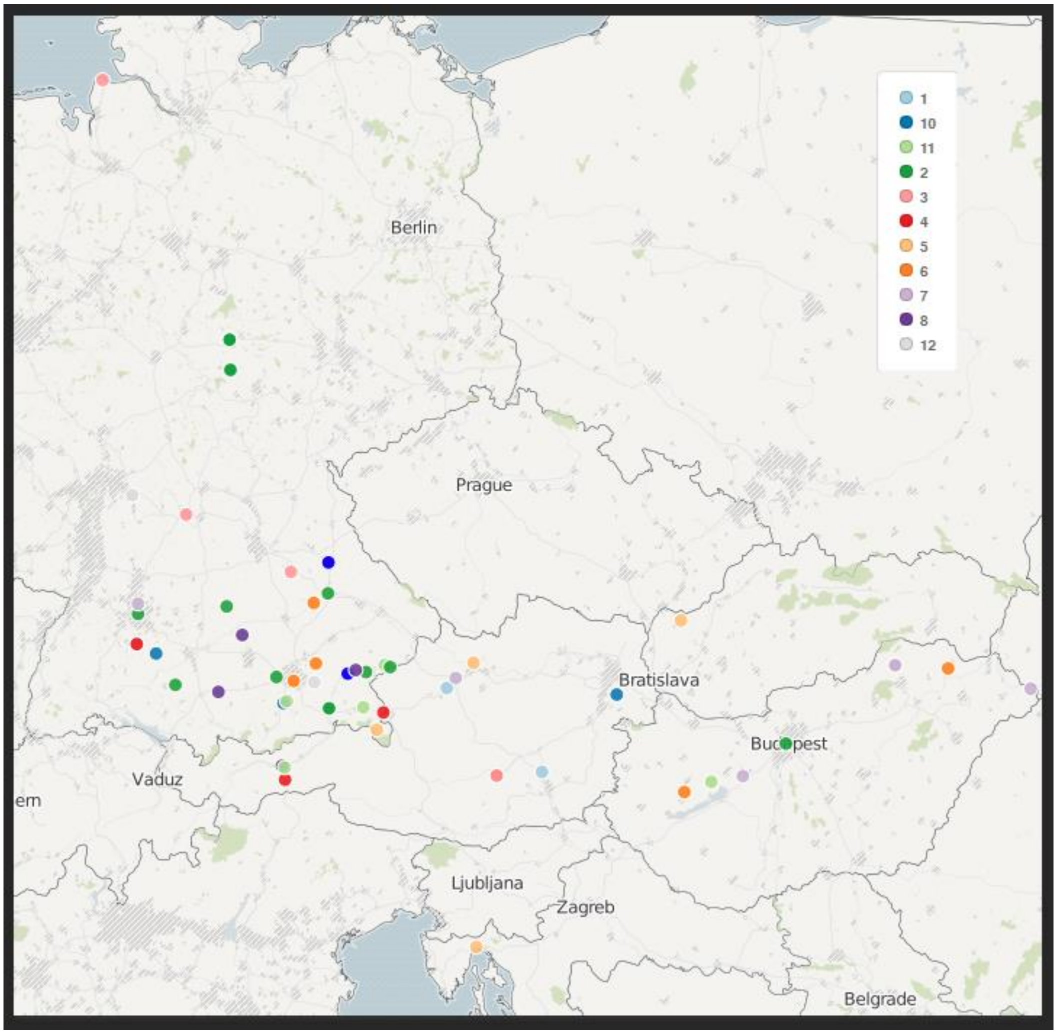


Figure 10.4: Sword distribution by hilt cluster. Base map data ©2016 CartoDB

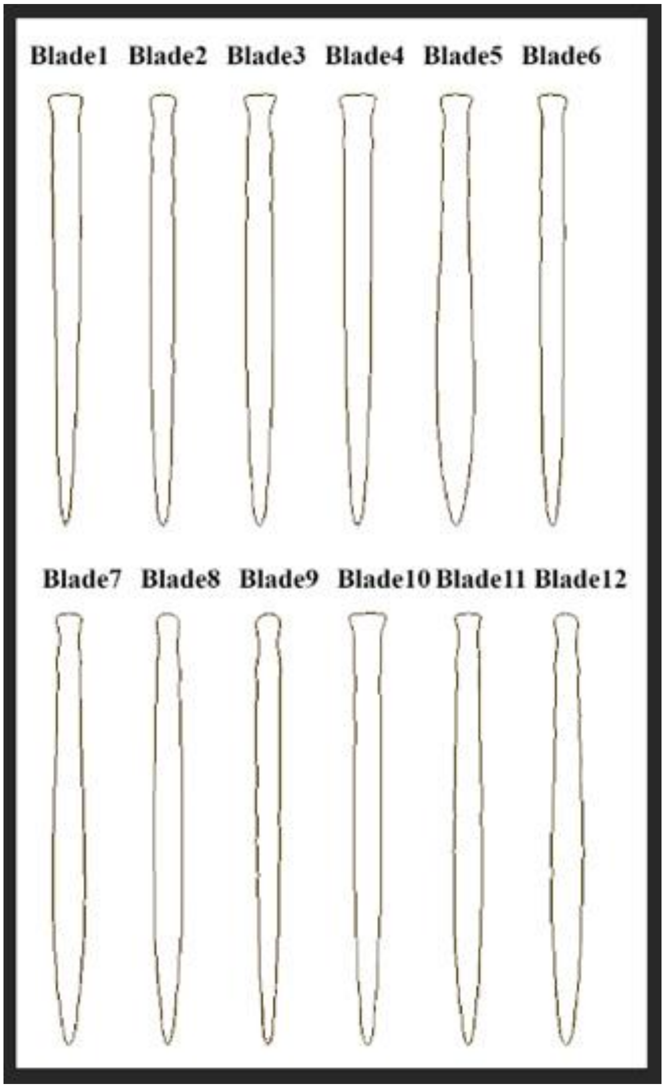


Figure 10.5: Average hilt profiles by cluster

DISCUSSION

There are a variety of correlations between non-decorative data and blade type, particularly at the 12 cluster break. Most of these are in groups that have less than 20 blades per group. It is useful to note here that there is significant difference between blade groups when looking at hilt profiles. This difference suggests that changes in blade shape are not tied to changes in hilt shape, an idea that I will come back to later in this dissertation.

Hypothesis 5: Cross sections cluster in meaningful ways that correlate with other technical choices.

Hypothesis 5a: Cross section does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
8 Cross Section Clusters	0.0183*	0.5573	0.3363	0.4878	0.3415
12 Cross Section Clusters	0.0288*	0.5573	0.3363	0.8538	0.5347

Conclusion: The null hypothesis cannot be rejected. More specimens would be necessary to reject the null hypothesis for concentric circle shape data.

Hypothesis 5b: Cross section does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
8 Cross Section Clusters	0.6081	0.9901	0.3013	0.4361	0.8266
12 Cross Section Clusters	0.6081	0.9901	0.3013	0.8156	0.3120

Conclusion: The null hypothesis cannot be rejected.

Hypothesis 5c: Cross section does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
8 Cross Section Clusters	0.0018		0.1948	0.2164	0.0245	0.4577
12 Cross Section Clusters	<.0001		0.3833	0.0002	0.1481	0.8182

Conclusion: The null hypothesis is rejected for blade profiles of both levels. At the eight cross section cluster level, the null hypothesis is rejected for rivet placement. At the twelve cross section level, it is rejected for length.

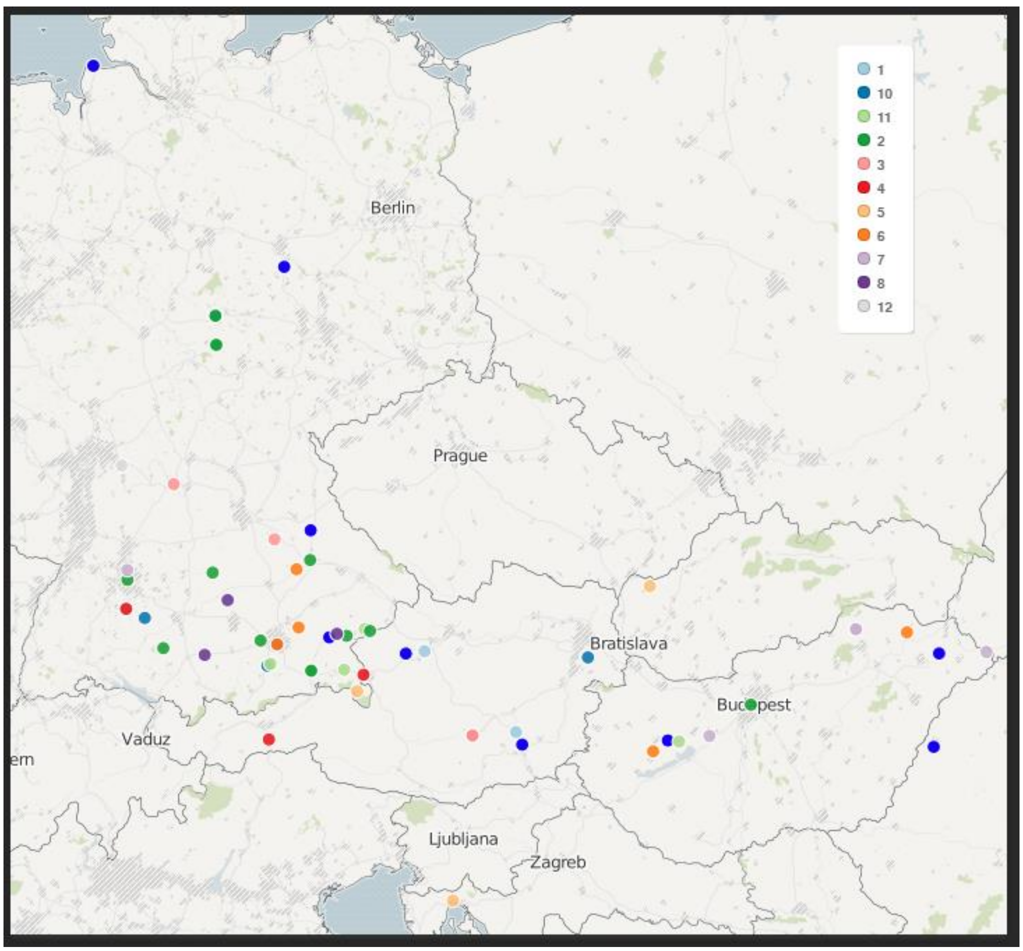


Figure 10.6: Sword distribution by cross section cluster. Base map data ©2016 CartoDB

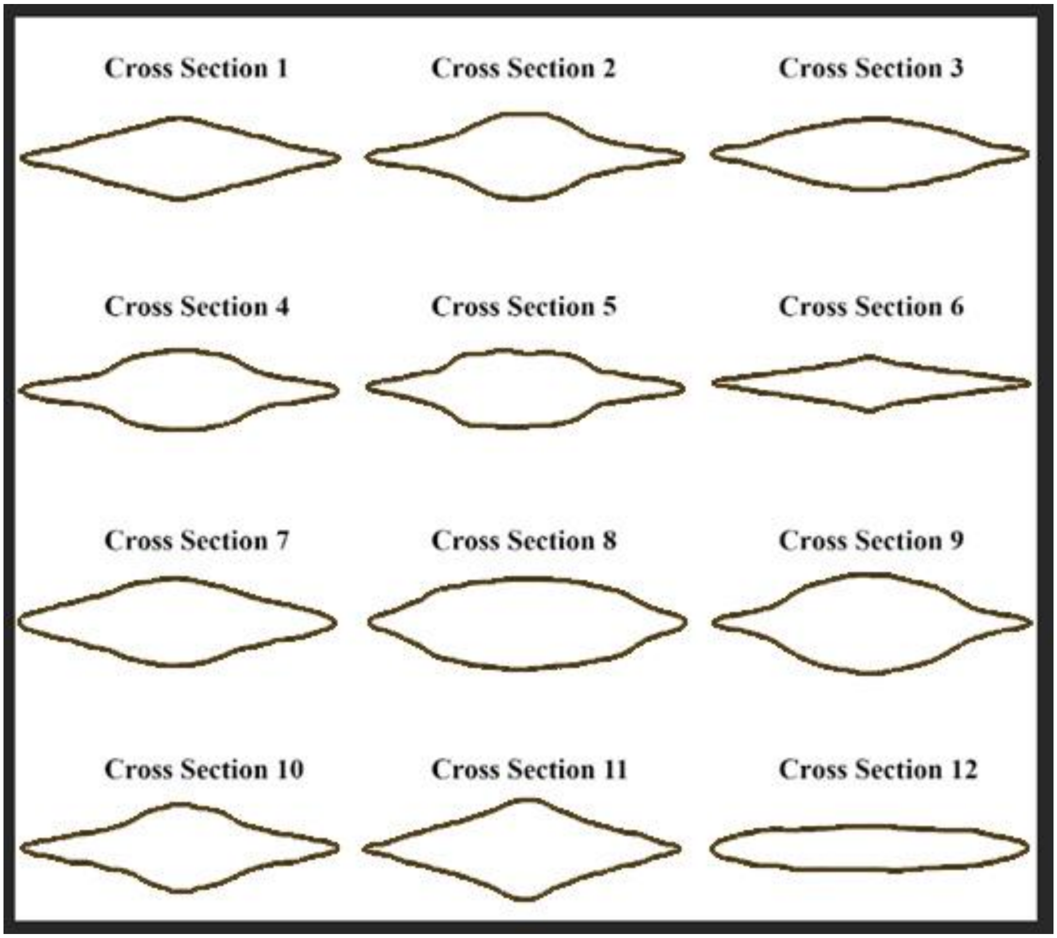


Figure 10.7: Average cross section shape by cluster

DISCUSSION

The cross section of the blade does vary with the profile of the blade, but not with other aspects. Closer inspection of the data shows that there are only three variables at eight clusters and one variable at 12 clusters where there is a significant difference between groups. This variation is not sufficient to examine a network analysis of cross sections. Based on the chi-squared tests (see Table 9.10), there is no correlation between cross section clusters and hilt clusters. This means that even though cross section groups are changing as blade shape does, that change is not significant enough to be able estimate the cross section based on what the blade profile is.

HYPOTHESIS 6: HILT PROFILES CLUSTER IN MEANINGFUL WAYS THAT CORRELATE WITH OTHER TECHNICAL CHOICES.

Hypothesis 6a: Hilt Profile does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
6 Hilt Clusters	0.0129	0.8243	0.0975	0.0254	0.3276
10 Hilt Clusters	0.0704	0.9259	0.3495	0.0157	0.6271

Conclusion: The null hypothesis is rejected for concentric circles at the six hilt cluster level and parallel straight lines at both the 6 and 10 hilt cluster level.

Hypothesis 6b: Hilt profile does not correlate with the consistency within decorative shapes.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
6 Hilt Clusters	0.3279	0.3529	0.3132	0.1480	0.3051
10 Hilt Clusters	0.2191	0.2533	0.0154	0.0967	0.6134

Conclusion: The null hypothesis cannot be rejected.

Hypothesis 6c: Hilt profile does not correlate with profiles or shape descriptors.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
6 Hilt Clusters	0.0004	0.3555		0.0837	0.0343	0.3792
10 Hilt Clusters	<.0001	0.4635		0.0065	<.0001	0.2238

Conclusion: The null hypothesis is rejected for blade profile and rivet placement for both levels. It is also rejected for length at the 10 hilt cluster level.

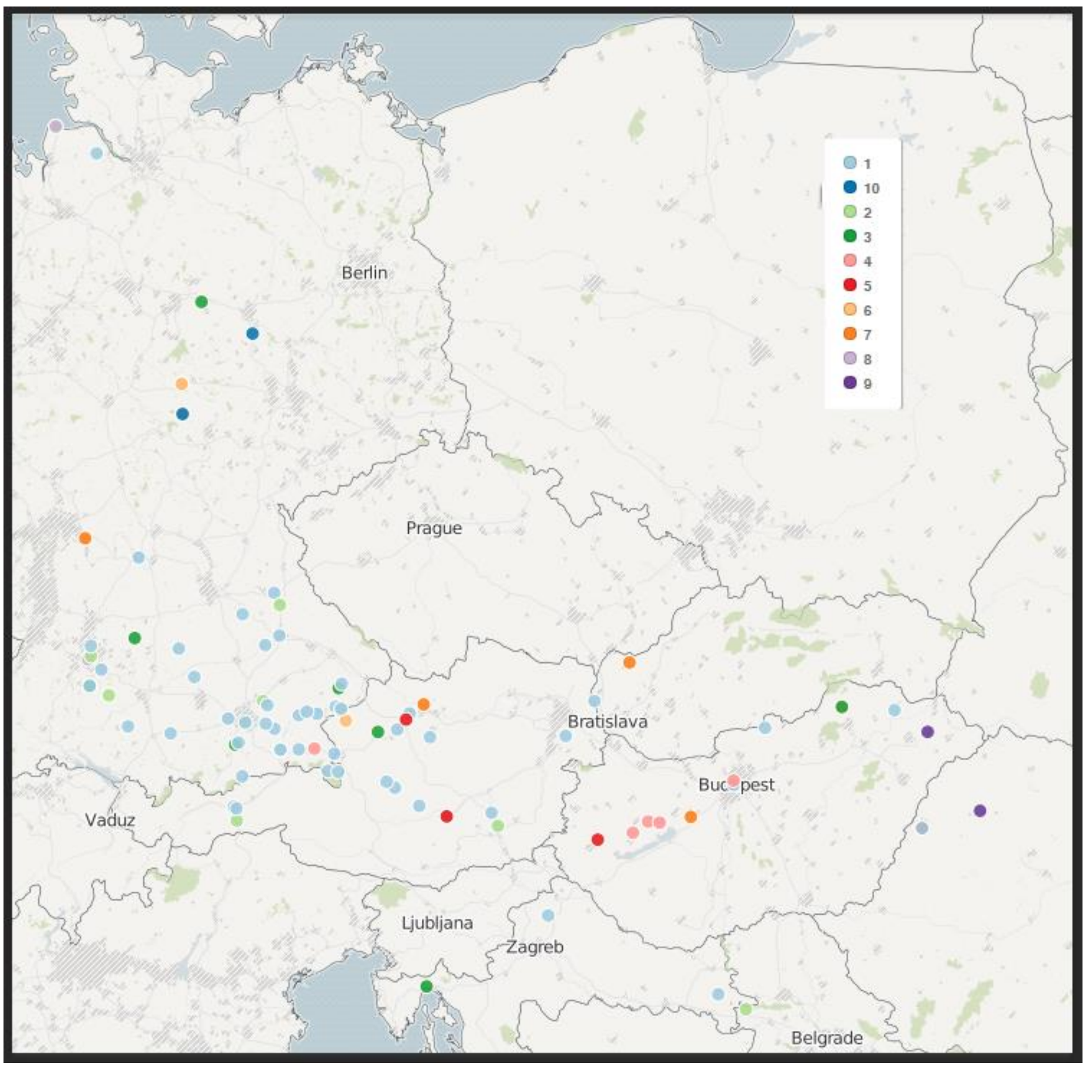


Figure 10.8: Sword distribution by hilt profile cluster. Base map data ©2016 CartoDB

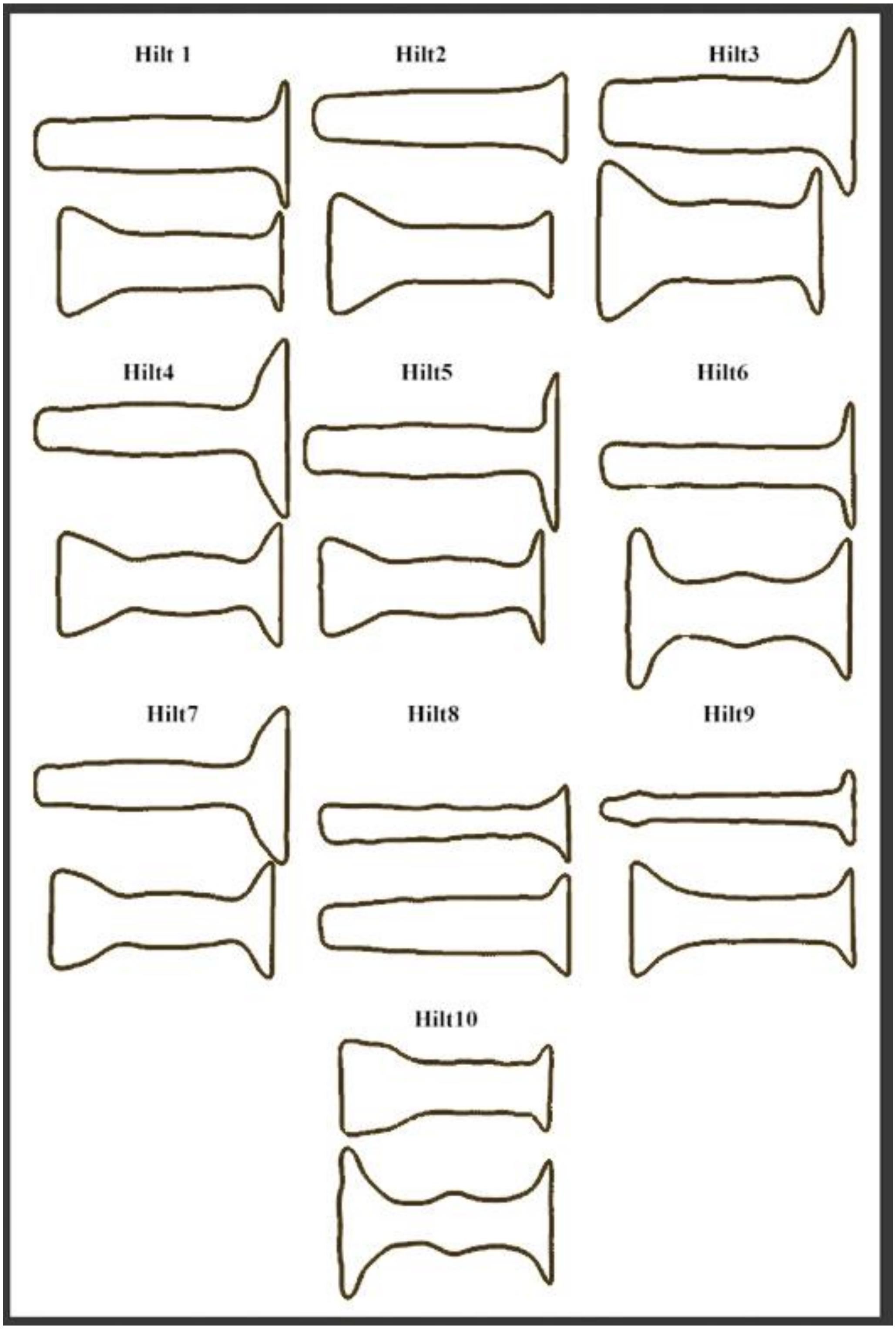


Figure 10.9: Average Hilt Profile by cluster.

DISCUSSION

Correlation between style and hilt profiles is more likely than any other non-decorative data type. It is the only group that shows a significant correlation with decoration and has a large group size. Hilts correlate significantly with the other non-decorative data as well, except for cross section and tang height. These data are the most interesting in terms of how and where it changes, as there are the most opportunities to find similarities and differences between groups. The hilt clusters also show the highest potential for examining the decorative data in further detail, were the sample size larger. Hilt cluster one is a particularly large cluster, containing 56 blades from all styles. When the cluster analysis was done originally, there were two major outliers, but no large groups like this one. Removing the outliers showed that these hilts were more similar than at first. While I opted not to break down the clusters beyond those suggested by the charts found in Appendix B, it might be worth re-running the analysis at a higher cluster level to see if that nets clusters that continue to show significance. This would also allow the hilt clusters to represent more of the variation in the hilts, as the current variation captured by hilt clusters is ~75%. Alternatively, the large cluster could be analyzed separately to determine how that cluster is grouping. This type of analysis is potential for further work.

Hypothesis 7: Rivet placement clusters in meaningful ways that correlate with other technical choices.

Hypothesis 7a: Rivet placement does not correlate with decorative shape data.

	Circles	Dashes	Parallel Curves	Parallel Straights	Waves
15 Rivet Clusters	0.0888	0.6351	0.0951	0.0059	0.3561

Conclusion: The null hypothesis is rejected for parallel straight lines.

Hypothesis 7b: Rivet placement does not correlate with profiles or shape descriptors.

	St. Dev. Circles	St. Dev. Dashes	St. Dev. Parallel Curves	St. Dev. Parallel Straights	St. Dev. Waves
15 Rivet Clusters	0.3125	0.429	0.7573	0.3340	0.0798

Conclusion: The null hypothesis cannot be rejected.

Hypothesis 7c: Rivet placement is related to other non-decorative data types.

	Blade	Cross Section	Hilt	Length	Rivets	Tang Height
15 Rivet Clusters	0.27	0.5451	<.0001	0.711	[redacted]	0.1935

Conclusion: The null hypothesis is rejected for hilt profile.

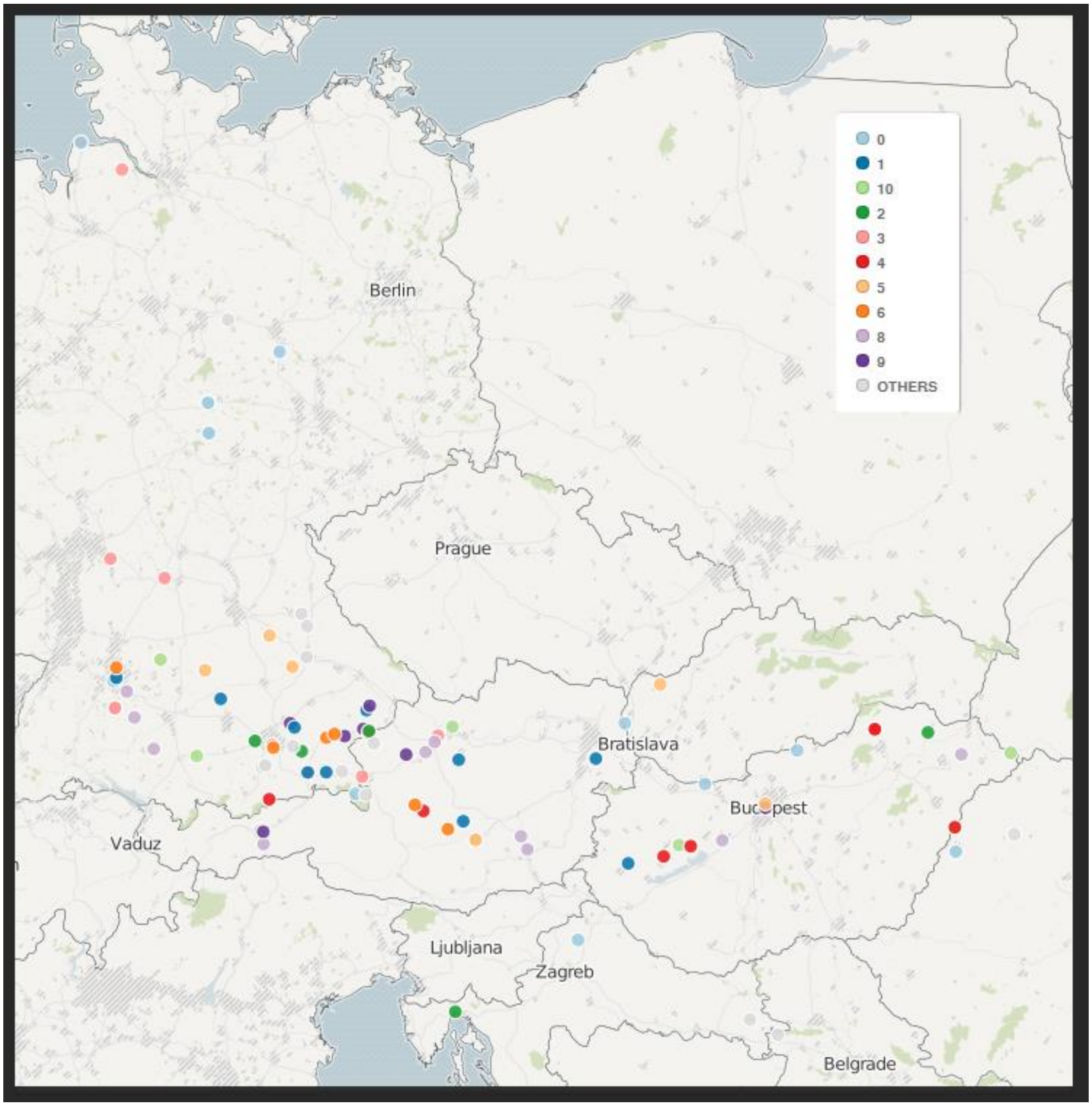


Figure 10.10: Sword distribution by rivet placement distribution. Base map data ©2016 CartoDB

DISCUSSION

Despite the correlation between rivets and hilts, there do not appear to be significant correlations between types of data to suggest a network analysis would add anything beyond one of hilt profiles. When looking at how rivet placement varies in comparison to hilt profiles, only two of the principle components show differences between groups. The correlation between rivet placement and the distance between straight lines is an interesting one. While it is beyond the scope of this dissertation, it would be interesting to examine how the relationships between hilt profiles, rivet placement, and distance between parallel lines were interacting.

Chapter Conclusions

All of the categories that were compared for hypothesis testing were seen to show significant differences in at least one set of variables. Style of the sword had the largest series of significant differences followed by location, and then hilts. Blade profiles and hilt profiles do not correlate in a chi-squared testing, though the hilt category does show differences in how the blade profiles are expressed between those categories. Rivet placement and cross section profiles show little difference between groups, and where that difference occurs it is based on hilt and blade profiles respectively. Using this information, network graphs were created based on style, location, hilt profile, and blade profile. Clusters for hilt and blade profiles were used alongside decoration profiles to create links between individual swords, given the differences shown between the groups.

CHAPTER 11: COMPARISONS OF NETWORKS

The networks presented in this chapter represent the morphological similarities between swords grouped by find location, style category, hilt shape, and blade profile. Each of these networks reflects a part of the overarching network which connected people during the Late Bronze Age. They are depicted either on a map placing the cluster or sword by latitude and longitude measurements or using a force atlas. The latitude and longitude measurements are either from the original find spots of the artifact, estimated using the regression formula presented in Chapter 9, or the average of the swords that made up a particular cluster. In the case of clusters, the average is taken only from items with known find locations. A force atlas is a method of displaying a network such that links that are more related are closer together and those that are different are further apart. Additionally, groups that are highly connected and cluster pull together towards each other and push away from other points that are not in the cluster. This presents a visual representation of similarities and differences both spatially as well as through the placement and strength of the lines connecting them.

Figure 11.1 shows an overlay of the clustered networks on a map of Central Europe to represent how these networks are overlapping and interconnected. Bear in mind that the points for each of these groups were calculated using the average of the sword for that type. In all cases except the blade profiles, the cluster groups appear to be correlated with the location. The geographic outliers in the study do affect the mean, but I chose to go with the mean so that it better represented the distribution and included those outliers.

For the most part, connections between location clusters are more closely linked to other locations that are near them, except for the link that swings down from Southern Germany into Croatia. This point skips over the location in central Austria. It is possible that this divergence is the result of a trade route. It could also be the result of random

Figure 11.1: Minimum spanning trees superimposed over a map of central Europe. Base map data ©2016 CartoDB. Network maps created in GEPHI 0.8.2.

similarities between styles unrelated to trade. This second idea is strengthened by the relatively weak relationship between southern Germany and Austria. Despite their geographic proximity, this location link is the weakest. Viewing the map of geographic dispersion of style (Figure 10.1) shows that the *Schalenknaufschwerter* are found in both Austria and Hungary. The spread of this style type is indicative of trade across this area, and likely the reason that particular link is a strong one.

The construction of each of the hilt, location, and style networks has a central point from which most of the other clusters branch out. This shape is reminiscent of a hub network. The central point of similarity for the hilt and style similarities is not the geographic center of the sword locations, rather it is further north. The weight of the lines is also telling. Stronger lines mean greater similarities – or stronger connections. The hilt and style groups all have strong connections, and seem to distribute in a similar manner. Given the similarities in network dispersion and the chi-squared correlation, the network of the hilt profiles most likely represents a more finely tuned expression of the style network. Figure 11.2 shows the hilt and style networks using a force network. Each set of clusters is mapped as an unconnected group. They are not shown to scale here. The style cluster has been enlarged, but the relationship between the size of the dots and the thickness of the links is roughly the same between the hilt and style matrices.

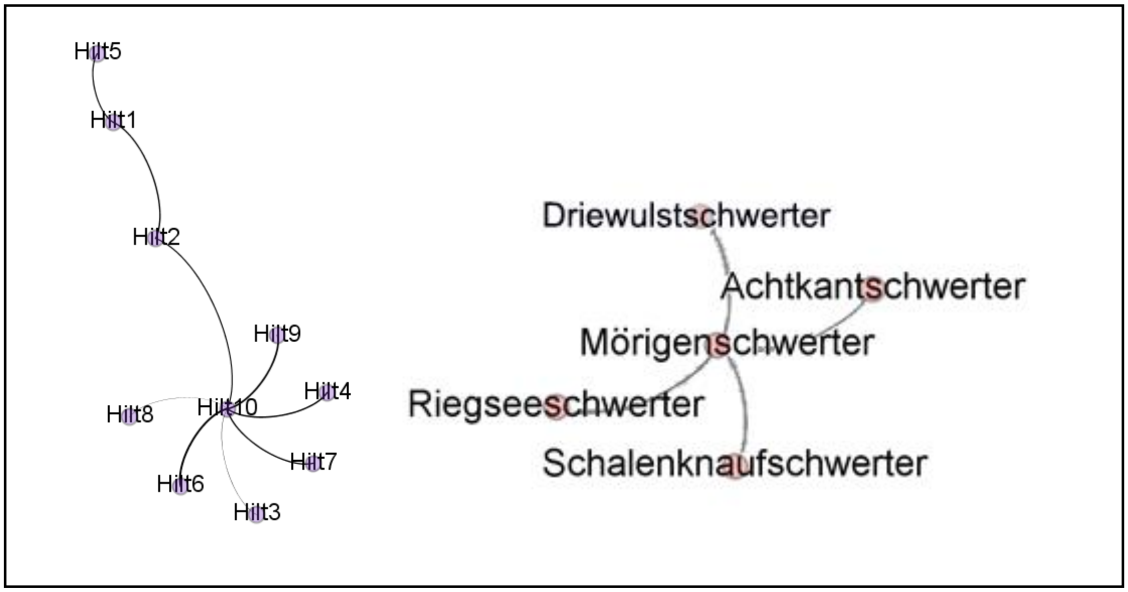


Figure 11.2: Minimum spanning trees for style and hilt clusters mapped using a force atlas. Network maps created in GEPHI 0.8.2.

The blade network has a very different expression. The blade profiles do not correlate significantly with location, so their placement on the map is not a representation of how the blades are expressed geographically. Rather, the network is placed there to compare its shape and strength to the other networks. In GEPHI, the links between the nodes are thinner than those in the style and hilt networks. This difference in link weight indicates a more loosely connected network. They have been thickened here for visualization purposes. There is also no central point from which the other nodes branch out. Rather, the blade profile network is a weakly connected sprawling network. This is reflected in the network viewed in a force atlas perspective, instead of a geographic perspective.

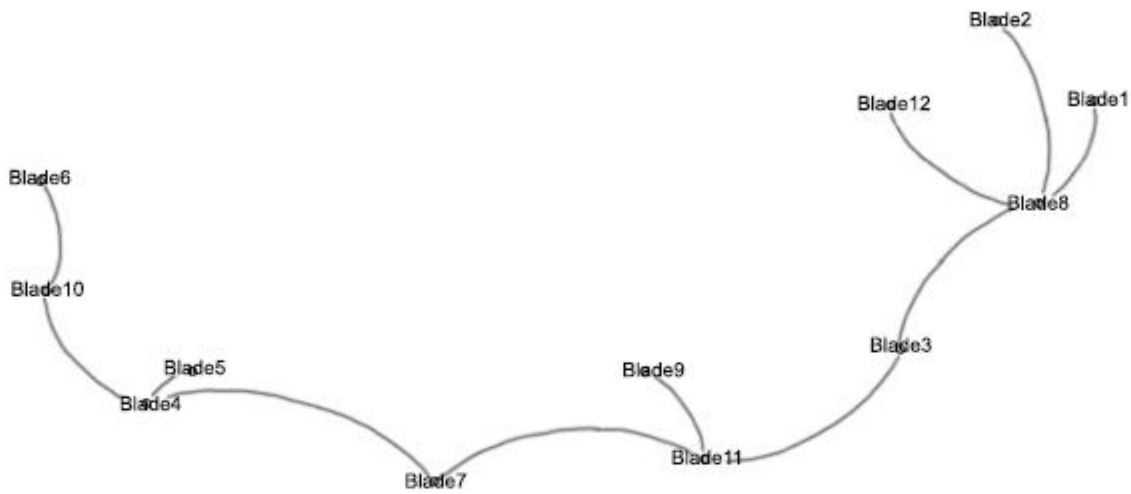


Figure 11.3: Blade cluster minimum spanning tree mapped using a force atlas. Network map created in GEPHI 0.8.2.

BLADE VS. HILT NETWORK SHAPES

A further examination of the blade and hilt networks reveals some more similarities and differences between the two networks. Both of the networks exhibit a central grouping with one cluster that is weakly connected, but the blade network is more spread out on the same force network than the hilts, as seen in Figure 11.4. While each group does have an outlier, that outlier is found in a different geographic area, see Figure 11.5. The areas of the network that disperse are not the same. This comparison is tempered by the fact that blade profile clusters do not correlate significantly with location, and so the geographic comparison is limited.

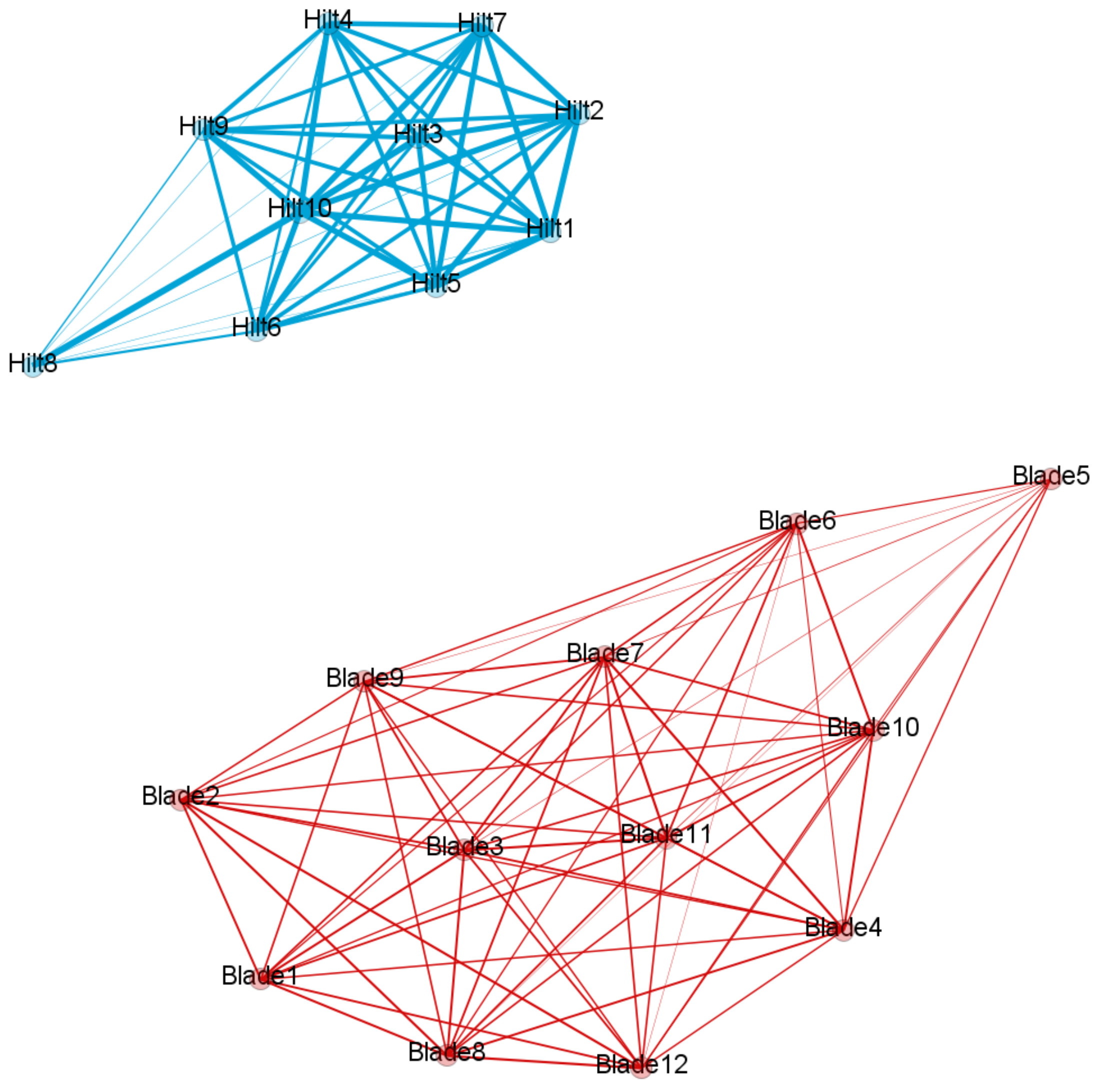


Figure 11.4: Entire network for blade and hilt clusters mapped using a force atlas. Network maps created in GEPHI 0.8.2.

These divergences in the hilt and the blade network suggest that they are being utilized very differently. I suggest that different craft workers were involved in the making of the blades and the hilts. The cultural implications of this will be discussed in Chapter 12.

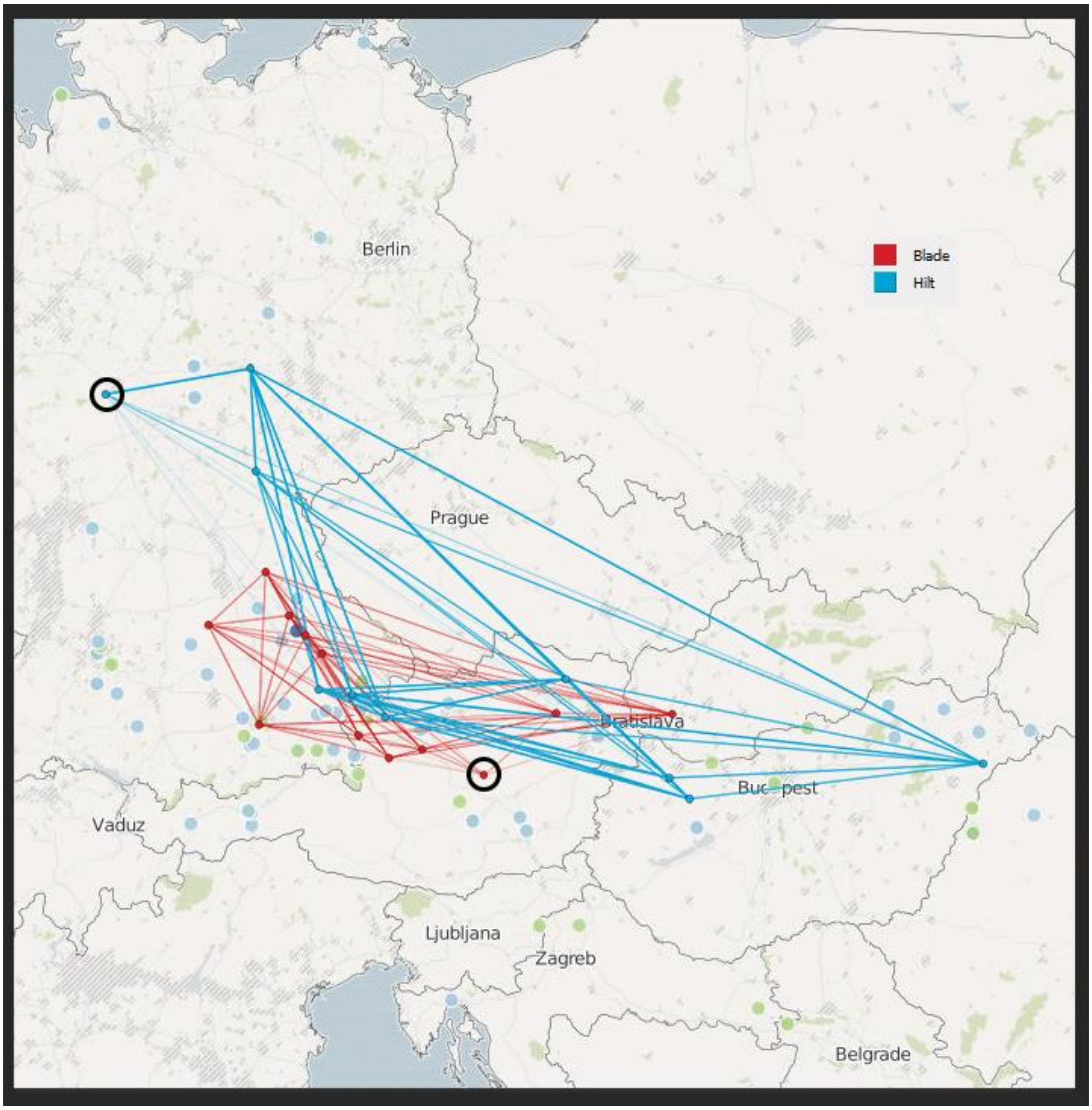


Figure 11.5: Complete blade and hilt networks mapped geographically. Base map data ©2016 CartoDB. Network maps created in GEPHI 0.8.2.

Treating Individual Swords as the Nodes

Up until this point, I have been treating the clusters as the nodes. Each cluster was assumed to have some measure of similarity to the other clusters, as defined by the distances between the clusters of different significant variables. For this last section, I want to take a moment to consider the swords themselves as nodes. Links were created based on whether or not they belonged to the same cluster. Blade clusters, hilt clusters, and decorative clusters were all considered. Every sword that shared a cluster was given a link of one, and those links were added up to create a network graph.

The first two graphs presented are the networks created by blade and hilt clusters. Since the first two clusters do not take into account any shared clusters, they both appear as a series of unconnected networks. However, this presentation of the different networks demonstrates the difference in how the blades are clustering. Notice the large cluster apparent in the hilt network (Figure 11.6) in comparison to the blades (Figure 11.7). The second thing that these images provide is a graphical depiction of how style separates out between these groups. With a few notable exceptions, the majority of the clusters contain more than one style. The inclusion of multiple styles across a cluster indicates shared knowledge between individuals making the hilts or blades for that style.

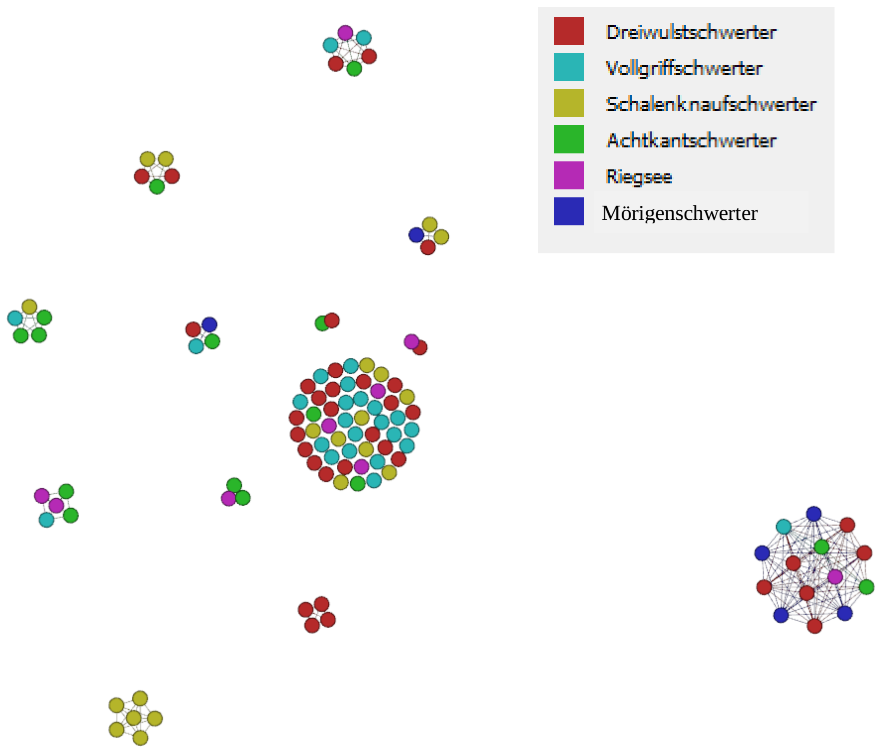


Figure 11.6: Individual sword networks with links defined by shared blade clusters. Network maps created in GEPHI 0.8.2.

The *Schalenknaufschwerter* are the exception to styles not clustering together. In both the hilt clusters as well as the blade clusters, *Schalenknaufschwerter* cluster separately from other styles. There is one main blade cluster consisting of *Schalenknaufschwerter* and three unique hilt clusters. Additionally, these objects share several decorative aspects, but for the most part do not share the same hilt and blade network. This could indicate that the hilts grouped together were made in different workshops, accounting for the difference between those hilt shapes. Alternatively, the hilts could differ due to the preference of the individuals or groups for which the blades were made.

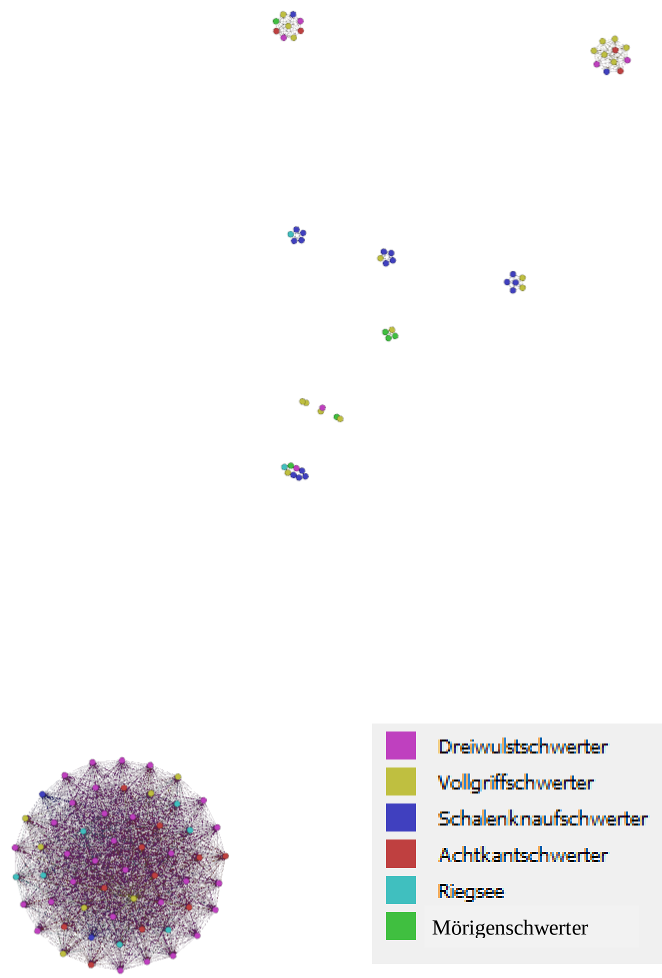


Figure 11.7: Individual sword networks with links defined by shared hilt clusters. Network maps created in GEPHI 0.8.2.

Combining the blade and hilt network shows a few blades that share both clusters. The most notable of those is the large cluster containing *Dreiwulstschwerter*, *Achtkantschwerter*, and one *Riegseeschwert*. Figure 11.9 shows the location of blades that share both clusters. Most of the large group clusters around Munich. The swords that share clusters but have traveled further includes group F and group B. These nodes are more likely to have the same group manufacture the hilt and the sword at the same time than different people making the blade and the hilt. The networks creating these groups has also been mapped in Figure 11.10.

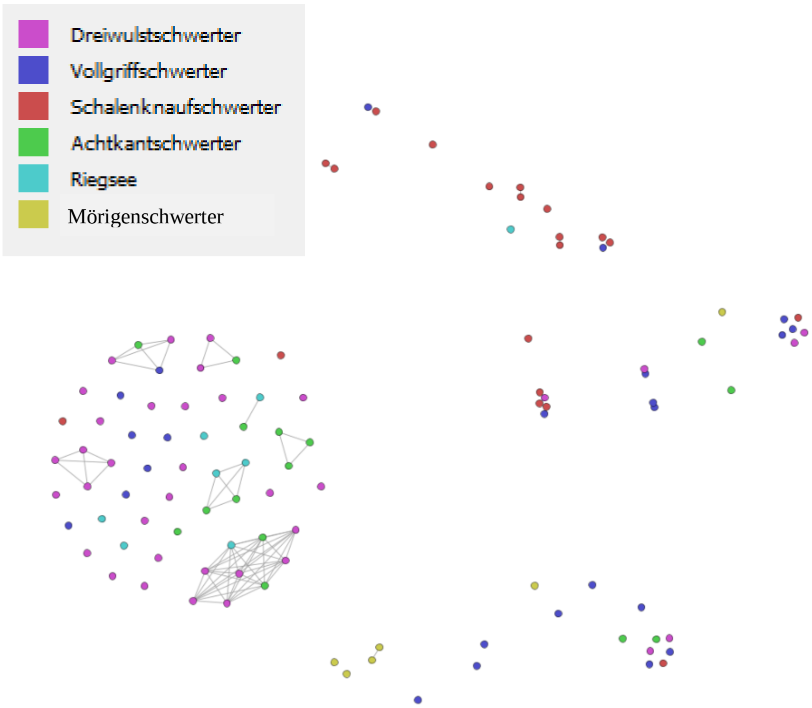


Figure 11.8: Individual blade network with links defined by both shared blade and hilt clusters. Network maps created in GEPHI 0.8.2.

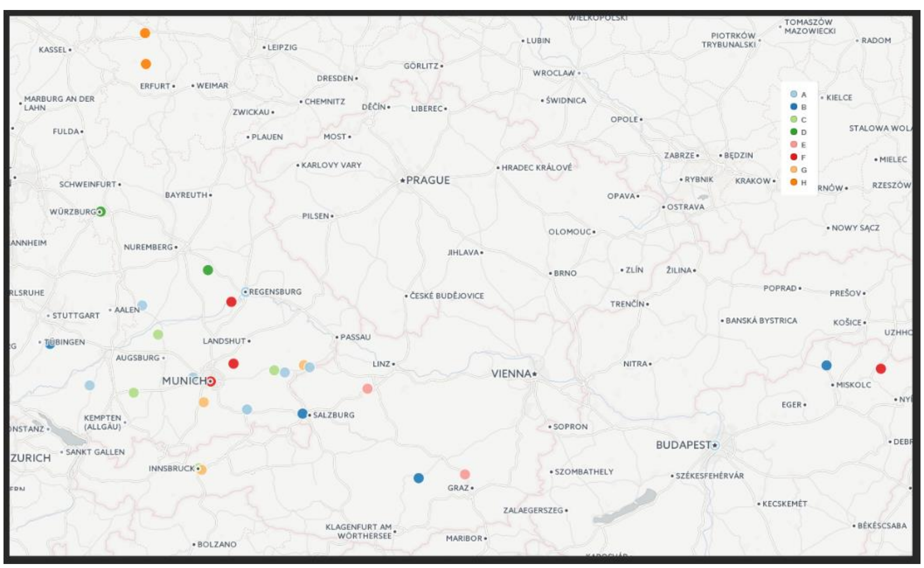


Figure 11.9: Blades that share hilt and blade clusters mapped geographically. The color key is based on swords in the same network. Base map data ©2016 CartoDB

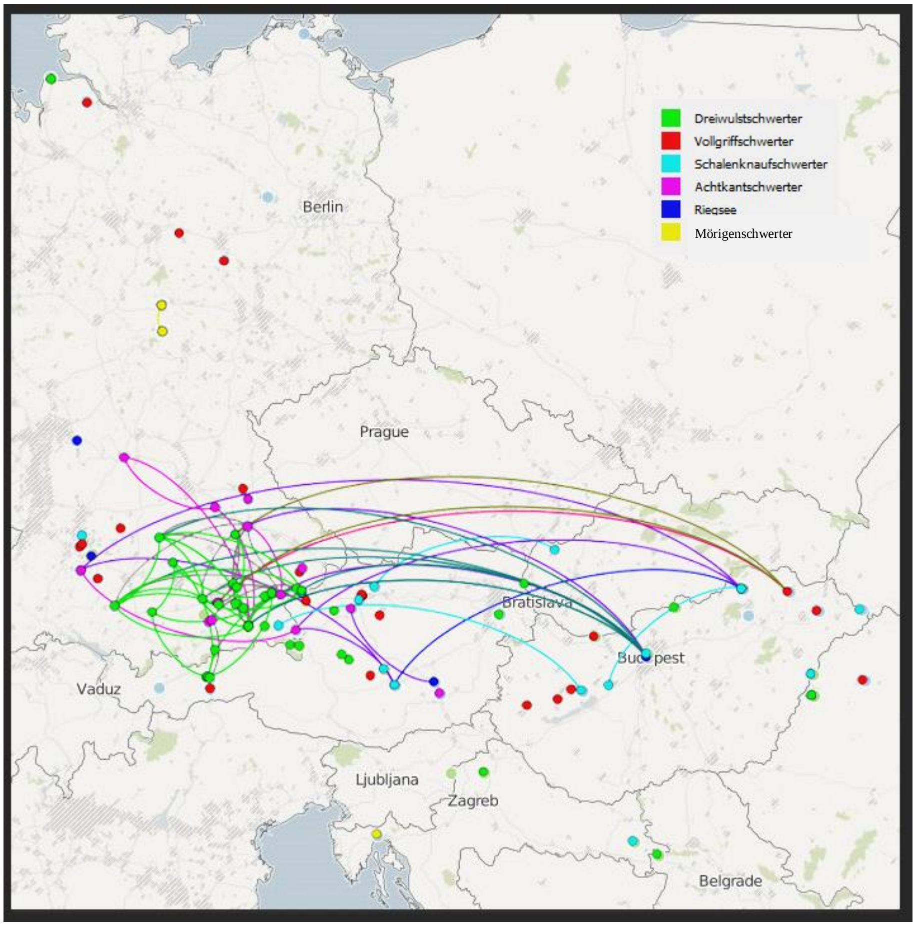


Figure 11.10: Individual blades that share both hilt and blade clusters. The color key in this map is based on style. Base map data ©2016 CartoDB. Network maps created in GEPHI 0.8.2.

Relationships between swords can also be shown by looking at the shared decorative clusters. In Figure 11.11, the network is mapped out based on shared decorative clusters. The original force atlas was applied using any number of shared clusters. After the force atlas placed the nodes, I applied a filter to show only those links which included two or more shared clusters. Groups that appear clustered, but have no nodes, are a cluster that share only one type of clustered group. The *Schalenknaufschwerter* swords appear in this network as having a stronger connection than other blades. The thick lines here indicate three shared clusters between the groups, with one pair sharing four cluster groups. Swords that have more than three decorative links are mapped out in image 11.12. Artifacts 10.098 and 9.223 are marked on the map, as they share a total of four decorative clusters. I find it particularly interesting that these swords are relatively spread out geographically, yet continue to share such a strong correlation between each other. While style certainly contributes to this, the links between this heavily connected group to *Vollgriffschwerter*, *Riegseeschwerter*, and *Achtkantschwerter* can be interpreted as shared knowledge.

Swords that are closely related can be further defined by combining the decorative, hilt, and blade profile clusters. While the remaining connections are few, they are indicative of strong similarities between the swords. In particular, 11.040 and 11.042 share the same blade cluster, hilt cluster, and two decorative clusters (concentric circles and parallel straight lines). These two swords are the most likely to have come from the same workshop, and are as close as I can come to saying they might have been made by the same individual. They do not, however, share the same location cluster. The geographic distance between them can be used to infer long distance trade of these particular swords.

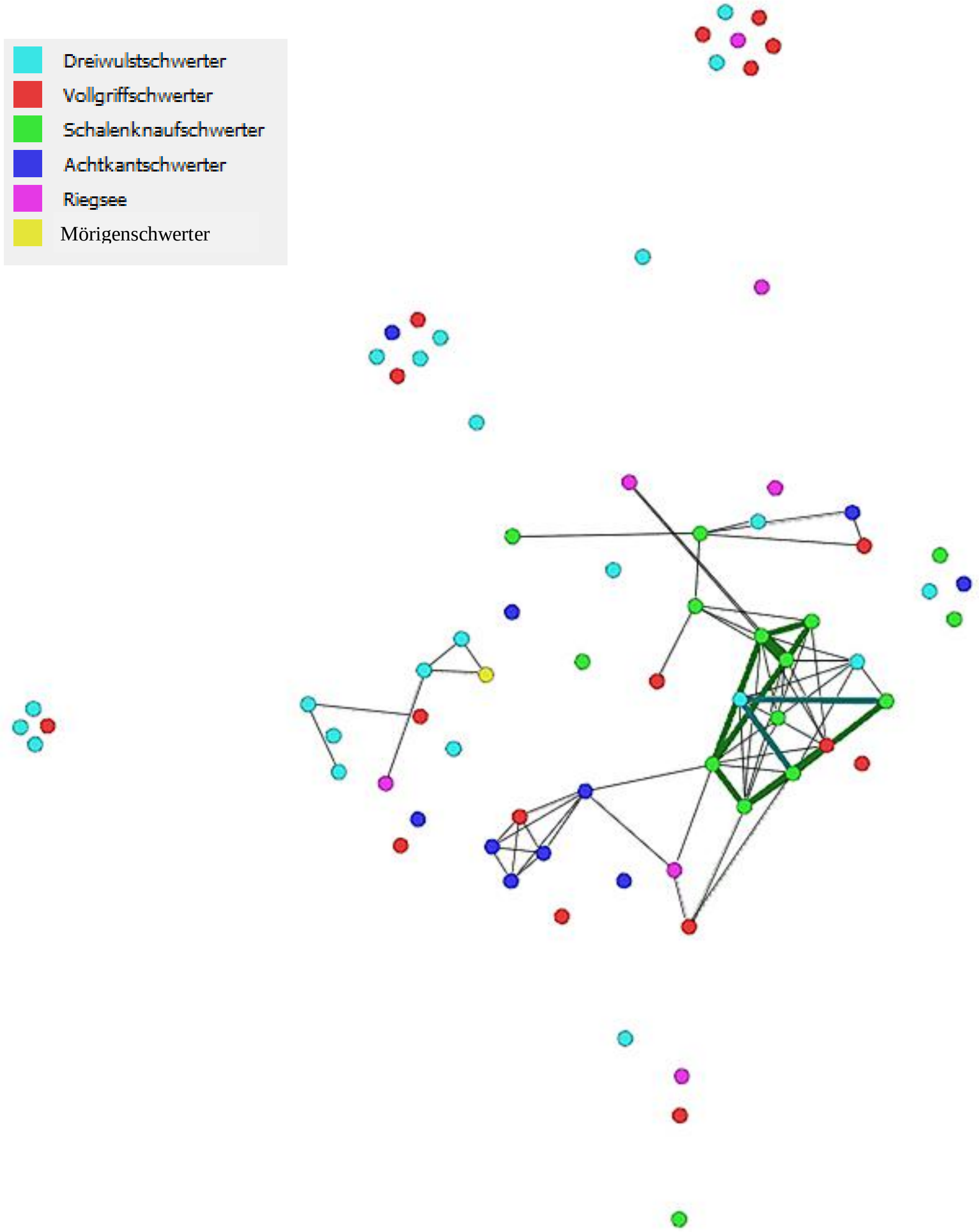


Figure 11.11: Force atlas projection of individual blades connected by shared decorative data clusters. Network map created in GEPHI 0.8.2.

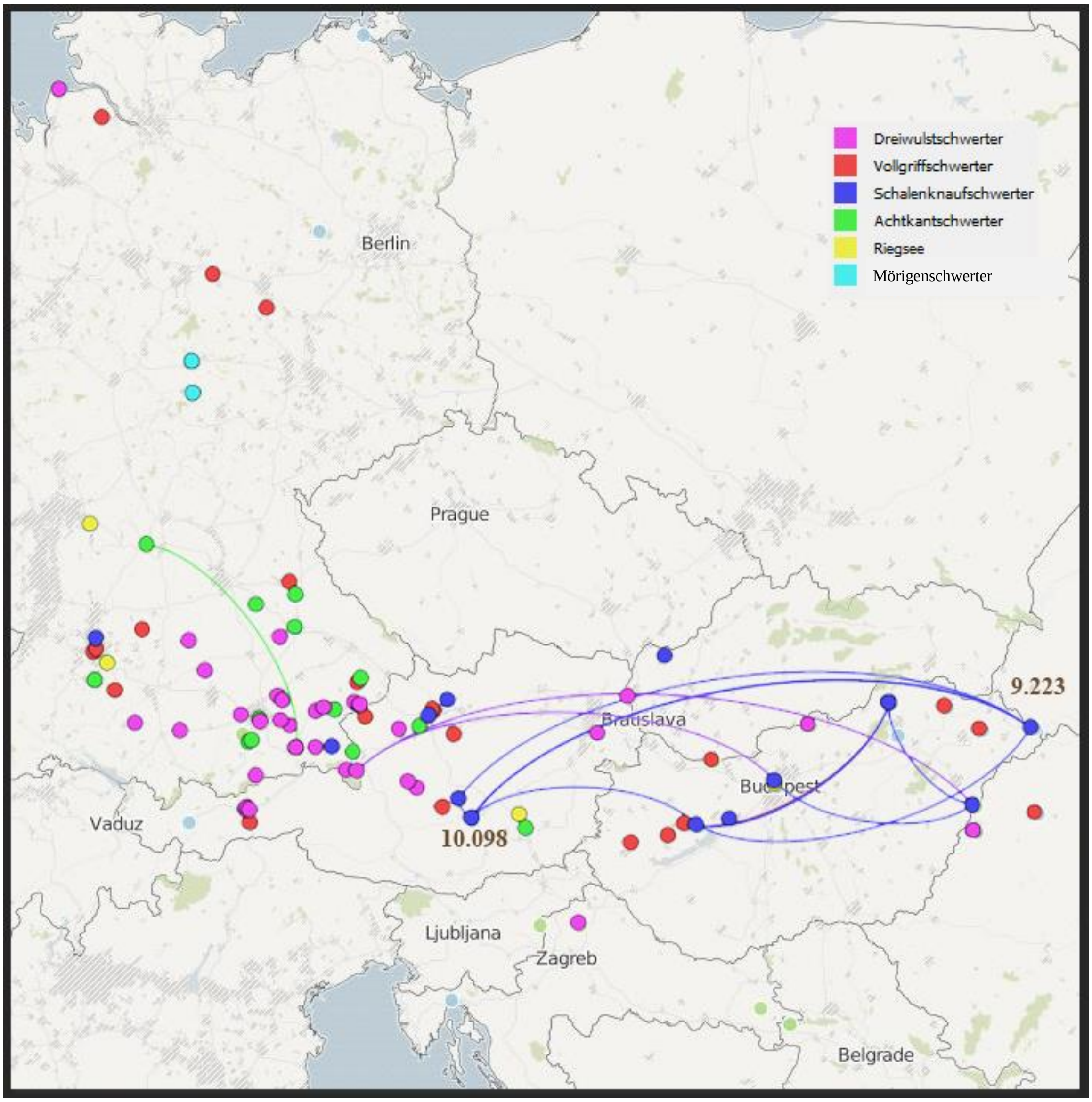


Figure 11.12: Map of individual blades that share three or four decorative clusters. Base map data ©2016 CartoDB. Network maps created in GEPHI 0.8.2.

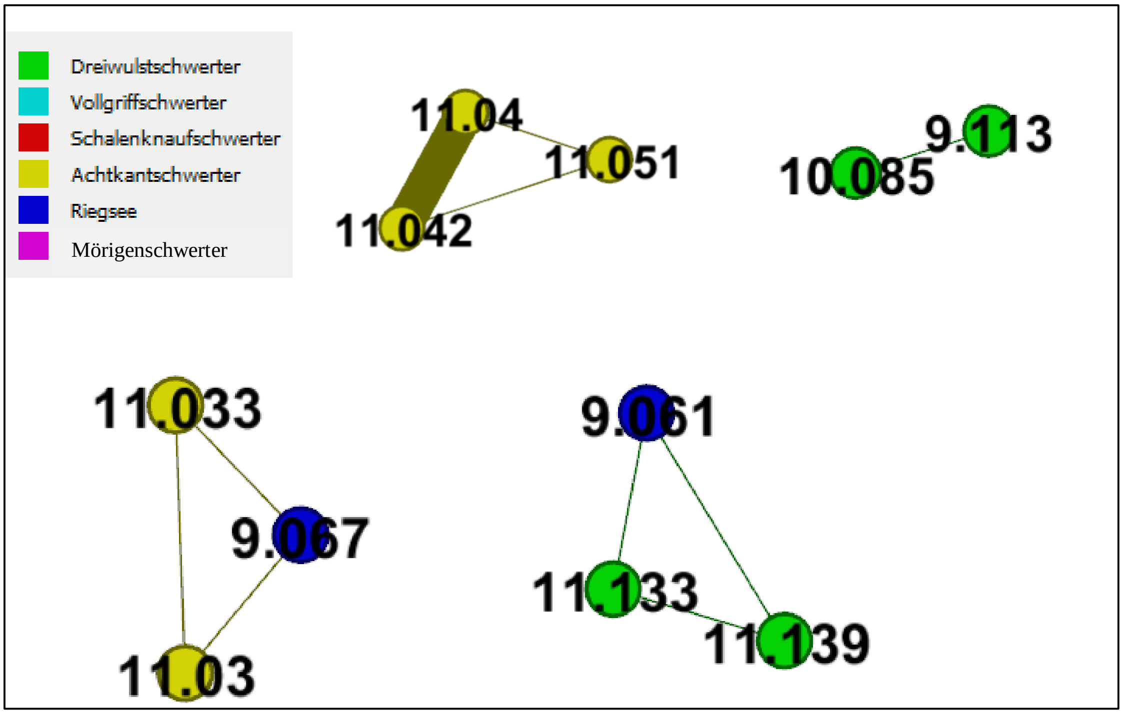


Figure 11.13: Blades that share both blade and hilt clusters as well as at least one decorative data cluster. Network map created in GEPHI 0.8.2.

Figure 11.14: Swords 11.040 ©Archäologishe Staatssammlung München and 11.042 ©Landesmuseum Württemberg.

Community Detection

Above, I discussed the structure of network by examining how the swords were clustering based on manufacture related choices. Network analysis statistics also provides a way to detect communities within the networks. This is known as **network modularity** (Blondel *et al.* 2008). For this analysis, I chose to incorporate all of the different types of clusters except location. These include the non-decorative clusters (blade profile, hilt profile, and cross section profiles) as well as clusters based on the decorative shape data (circles, dashes, curved parallel lines, and straight parallel lines). While location does correlate to differences in shape (see p. 180), I wanted to focus on the decisions made during manufacture. Removing location as an edge weight also allows for long distance trade to be more visible, since weighting by location cluster strengthens links between objects that are closer together. The modularity also integrates a resolution. A typical resolution is one, but the resolution can be smaller (.05) to show smaller networks, or larger to view large scale networks; however, the ability to detect networks breaks down as the resolution becomes smaller (Lambiotte, Delvenne, and Barhona 2009).

For this analysis, each node is an individual sword and each link is made up of a shared cluster. The link weights range from zero to five. The highest theoretical link weight is eight, if all clusters were shared, but the highest actual weight is five. Specimens that share five clusters can be seen in Figure 11.15. Much like swords 11.040 and 11.042, these objects share a significant number of clusters and are more likely to have come from the same smaller community of smiths, potentially even the same smith.

Blade 9.006 is the only blade that does not share any clusters with any other blade, making it an outlier to the network (see Figure 11.16).

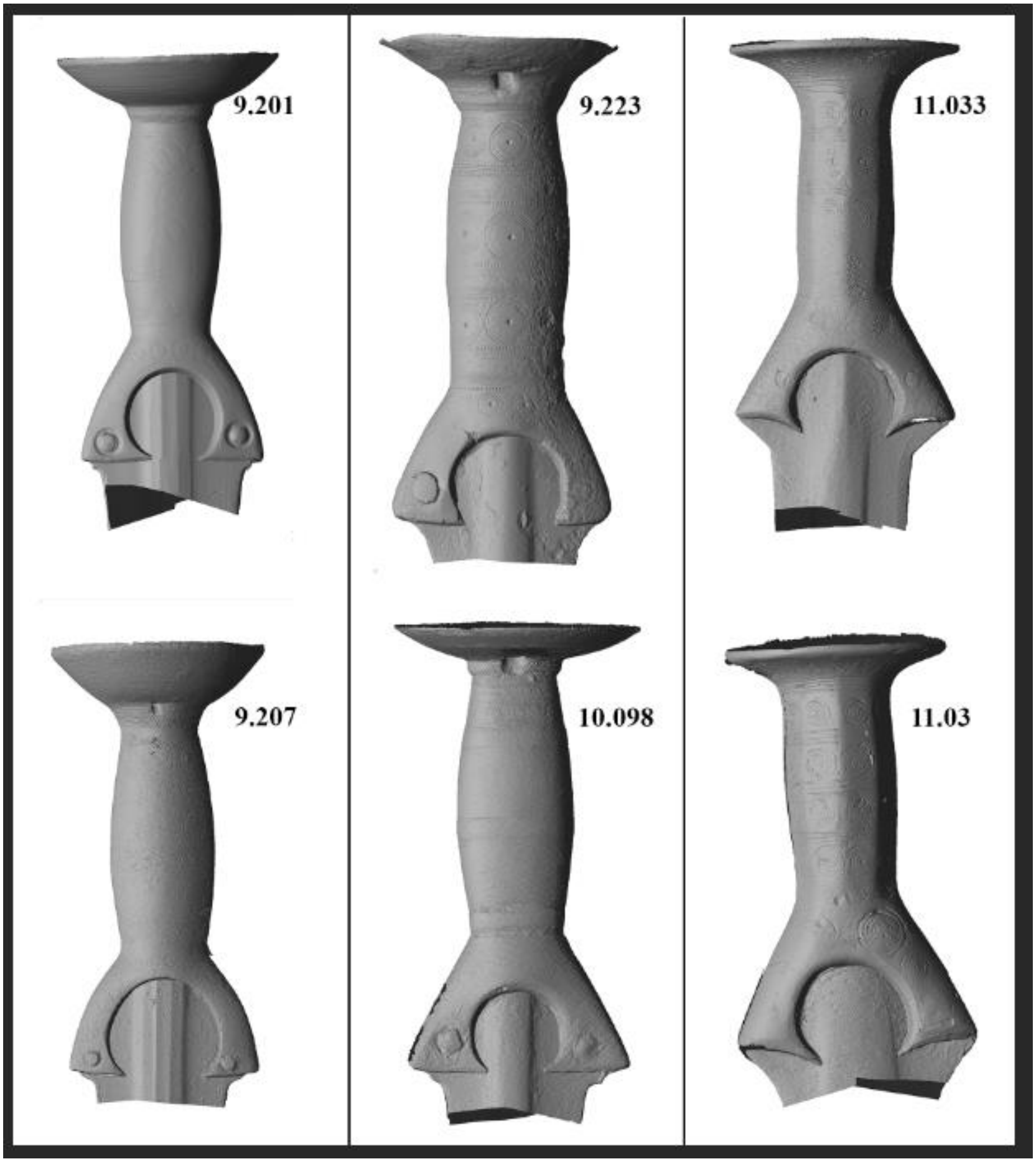


Figure 11.15: Swords which contain five shared manufacture based clusters. Each vertical box contains one pair with shared clusters. 9.210, 9.207., 9.223 ©Hungarian National Museum. 10.098 ©Archaeology Museum Scholl Eggenberg. 11.033 ©Archäologische Staatssammlung München. 11.030 ©Landesmuseum Württemberg.

Figure 11.16: Sword 9.006 is an outlier, with no shared manufacture traits with any other sword in the study. Sword image ©Hungarian National Museum.

Figure 11.17 shows the breakdown of network modules using a force atlas for the shape of the network. At a resolution of one, four modules (or communities) are detected in the network, with the unconnected blade making a fifth group. When the resolution is decreased, to show smaller groups, 8 communities are detected (see Figure 11.18). Groups one and two from the original set remain mostly intact (as two and six in the new breakdown), and the additional four communities are composed of subsets of the original groups three and four. This shows that groups one and two are more strongly connected than groups three and four when using a resolution of one, since they maintain their structure at a tighter group resolution. Group one stretches across modern day Hungary. Group two is composed mostly of *Achtkantschwerter*. It is likely that group one indicates a sub community of smiths making swords of different typological styles across a wider geographic area but using similar shape repertoires. In contrast, group two is likely composed of smiths who are using both the same style and the same shape repertoire, but whose blades have spread geographically, likely through trade.

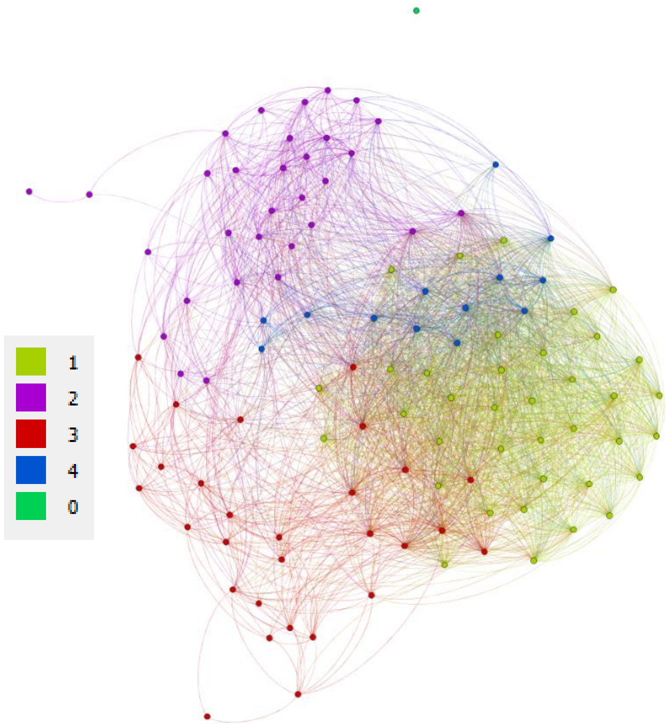


Figure 11.17: Communities in the network detected using a resolution of 1. Network map created in GEPHI 0.8.2.

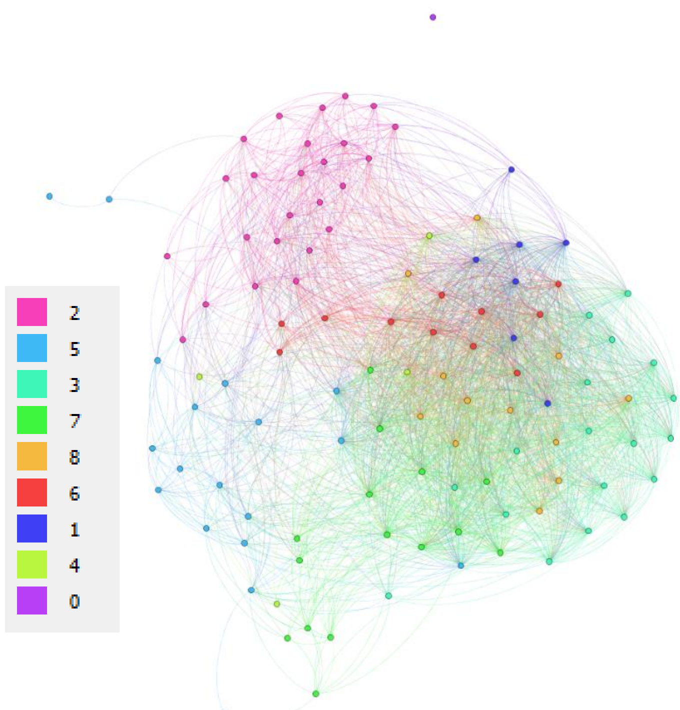


Figure 11.18: Communities in the network detected using a resolution of .8. Network map created in GEPHI 0.8.2.

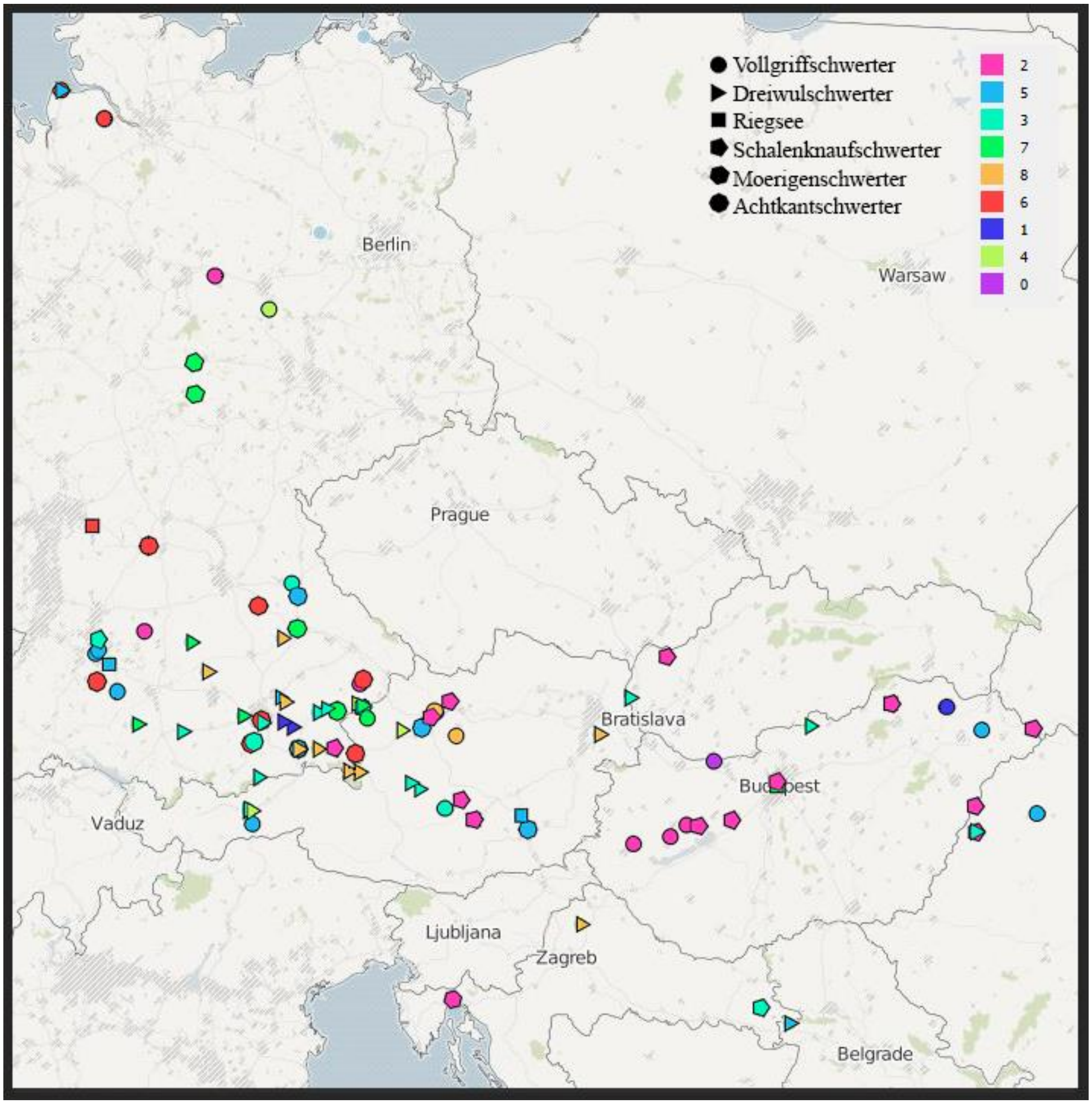


Figure 11.19: Communities mapped geographically. Colors represent the sub community in the network and shapes represent style groups. Base map data ©2016 CartoDB. Network map created in GEPHI 0.8.2.

Table 11.1: List of swords by community, using a resolution of .8.

Group 0	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
0.008	9.006	9.076	9.113	0.002	9.015	0.001	9.061	0.006
0.009		9.136	9.175	0.007	9.15	0.004	10.147	9.019
9.026		9.145	15.49	9.005	9.49	9.062	11.052	10.048
9.079		10.032		9.027	10.003	9.067	11.072	10.067
9.16		10.081		9.199	10.021	11.03	11.133	11.142
9.17		11.031		9.201	10.023	11.033	11.136	11.151
9.174				9.202	10.034	11.036	11.139	11.154
9.523				9.206	10.065	11.037	11.14	11.158
10.033				9.207	10.104	11.04	11.145	11.175
10.037				9.211	11.005	11.042	11.161	14.234
10.068				9.223	11.011	11.051	15.478	
10.071				9.232	11.017	11.206	15.479	
11.066				9.234	11.024	17.168	15.481	
11.175A				9.235	11.082	17.176	15.487	
11.185				9.244	11.083		15.489	
11.186				9.249	11.112			
11.188				9.524	14.231			
14.236				10.085	17.186			
				10.096				
				10.098				
				10.103				
				10.105				
				11.026				
				11.162				
				11.198				
				14.244				

Finally, Figure 11.19 shows the groups mapped geographically. The colors represent the different communities within the networks and the shapes represent the style. The communities are defined by shared manufacture choices through profile and curvature data as well as in the formation of decorative aspects, such as the concentric circles. The largest group, group two, is mostly located in modern day Hungary, but reaches over into Austria and Germany. It consists of *Vollgriffschwerter*, *Schalenknaufschwerter* and one *Achtkantschwert* found in Croatia. The grouping of certain styles within the communities shows that style does play a role in how these communities are formed; however, no one network module contains only one style. There are a mix of styles across the groups. Therefore, it is likely that the smiths who made the blades worked on blades of different stylistic types.

CHAPTER CONCLUSIONS

In this chapter, I have described several networks of swords smiths based on morphological data. These networks present possible ways that swords smiths may have been communicating based on different manufacture decisions. These connections change based on the type of manufacture data being compared. In particular, there are discrepancies between networks related to hilt and blade profiles, which may suggest two networks occurring: one based on the production of the hilt versus one based on the production of the blade. If there are indeed two networks, this structure has implications for cultural constructs that may have existed.

Chapter 12: Conclusions, Implications, and Further Study

LBA Network Scales

Communities in the Late Bronze Age were made up of multiple layers of networks between people and groups of people maintained over time. The presence of bronze across the continent requires the trade from the mountain ranges where it's found, primarily the Alps and the Carpathians, to coastal regions such as northern Germany. These trade links are also maintained through the exchange of exotic materials such as amber. Figure 12.1 shows the paths along which amber may have traveled (Harding 2013:376). Continuity of cremation deposition in urnfields throughout Central Europe is evidence of a shared belief concerning treatment of the dead. Genetic evidence from the so called Amesbury Archer show that he may have grown up in Central Europe (Harding 2013:380). This evidence, along with the frequent depictions of boats in Scandinavian rock art (Goldhahn and Ling 2013:277) provide evidence of connections to Great Britain. These links show a large scale network that connected communities within central Europe. This large scale network is integral to our understanding of the connections between cultures during the LBA.

On a smaller scale, the lack of distinct social stratification in settlement structure indicates that there was no overarching political structure. More likely, communities existed as small scale chiefdom-like groups. Smaller scale organization was required to organize activities such as ore extraction and the building of fortified sites such as Heunischenburg, Germany, or planned villages such as Zürich-Mozartstrasse. Trade occurred within settlements for everyday items.   Ceramic analysis has shown that the clay for pottery is often locally sourced, lacking evidence for frequent long distance trade (Sofaer 2010:187). These types of links create the small scale networks that keep communities connected.

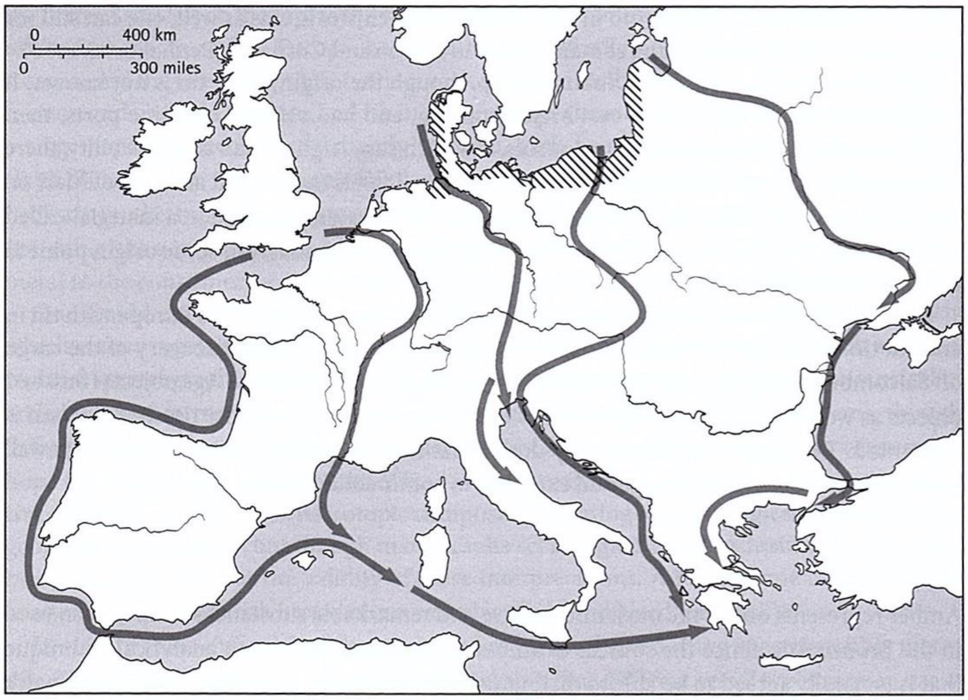


Figure 12.1: Proposed trade routes of amber trade (Harding 2013: 376) representing large scale LBA networks.

Individuals within communities would also have their own networks between each other to maintain. In a settlement of 60 to 100 people, the majority of people were likely farmers who had some basic craft skills in woodworking, ceramics, and stone tool making. These individuals would have primarily focused on managing their land and livestock. A few people, however, would have been skilled craft workers such as a potter, a woodworker, and a bronze smith among others.   In a small settlement, the local bronze smith most likely would have also maintained a farm and livestock, though perhaps a smaller homestead, practicing his or her craft part time. The majority of the smith's work would have been smaller, utilitarian items, such as cups and jewelry. These items would be produced as needed for the community and bartered for.

Not all smiths necessarily cast more complex objects, such as swords. In discussing specialized crafts, Kuipers (2008:33) and Kienlin (2013:420) suggest a two tiered system of smiths with those who produce primarily the types of everyday items being the lower tier. A second type of smith, or the higher tier in the two tier system, would be the smith who was able to spend more time working on his or her craft. These smiths were more likely based in larger settlements, with more resources to support the smith. These settlements would have been hubs for trade, where the smith could make items not only for the local community but also for people who were bringing in other goods. The site of Klinglberg, Austria was primarily a mining site and shows evidence of imported grains (Shennan 1998:197). The site would have been occupied year round by a community dedicated to mining and supported by people from other communities through trade of food and other goods. This type of trade is what I propose is occurring with individual bronze smiths on a community level as well as with bronze smiths of greater skill who produced items such as the so-called ritual bronze statuettes and swords.

Bronze smiths were likely not in isolation within their community. While a small scale cast can be done by an individual who gathered the materials, prepared the furnace, and tended the bellows prior to casting, they most likely had a small number of helpers. The helpers could have been individuals brought on in a type of apprenticeship or trained through kinship relationships. Kienlin (2013:432) extends the importance of kinship roles in communities to craft networks, suggesting that the organization of metalworkers need not be governed by political organization, rather, the connections between smiths and the networks they maintain could instead be maintained through kinship. Additionally, if kinship is the major link between smiths, specialized knowledge for higher quality items could be passed on through these lines. This type of knowledge production would support the presence of highly skilled part time craft workers in smaller communities.

Often lost in the discussion of trade across Central Europe are the in-between networks, or those that bridge local and long distance trading. This type of intermediate trade and contact is what my study targets. Individuals engaged in producing specialized craft inhabit a space in the overall network which connects local trade to communication beyond their immediate settlement area, but which does not necessarily need to stretch the breadth of the entire network. Studying these networks and defining them helps to bring the shape of the overall network into focus.

BRONZE SMITHS AS LINKS BETWEEN LARGE AND SMALL NETWORKS

Smiths existed within a small scale settlement community, and participated in the day to day activities of Bronze Age life. There was likely a reciprocal nature between support of the smith and the livelihood of the village. Bronze smiths engaged in a variety of casting activities which were not limited to the production of swords. Likely there was a system of exchange for materials such as wood for charcoal, sand and clay for molds, or food in return for cast bronze items. The smith was probably engaged in casting everyday items such as tools for working the field, jewelry, and bowls or jugs. Simple casts, using melted down bronze instead of alloying on the spot, could have been done by less skilled metal workers. Swords would have been a specialized item that were cast when needed. With the dearth of clearly defined workshops for large scale production of bronze and the lack of high status burials associated with bronze working materials, Kuijpers rejects the idea of the smith as a high status individual within the local community (Kuijpers 2007: 107), suggesting it unlikely that the smiths were amassing great wealth to produce these items.

While I agree that smiths themselves were neither spending all of their time casting nor amassing personal wealth, the skill to produce swords is beyond basic casting knowledge and would require an investment of time and specialized knowledge. A smith would need knowledge about proper alloying ratios, multi part molds and their preparation, and finishing techniques. While some of this knowledge can be taught through word of mouth, obtaining the skills would have required practice to acquire and master them. The swords in the archaeological record do not show signs of significant mistakes that would make the weapon unusable. Likely, a smith spent time practicing his or her craft and re-casting objects that were unsuitable for their purposes. Bronze was, and still is, a valuable enough material that there is little economic sense in retaining a bad cast. This need for practice to create the necessary shapes indicates that the bronze smiths were spending time learning their craft, time that could not have been spent on subsistence. It is unlikely that the smiths were casting full time, but the time they spent working on, practicing, and refining the skills of the craft would require some level of community investment. The smiths may have also held other social roles supporting the settlement. In the case of the Benin people of South Africa, iron smiths played a ritual role in the community (Dark 1973:55). The inclusion of a ritual element to bronze smithing would have provided a way to embed knowledge through repeated actions between smiths (Budd and Taylor 1995:140) while obscuring that knowledge to outsiders (Apel 2008: 109), reinforcing the networks between smiths.

Bronze smiths would have been part of the larger scale networks. Acquisition of copper and tin required access to the long distance trade networks operating during the LBA. The production of swords was a major factor in the relationship between settlements. Just as trade connects settlements, evidence of warfare divides those same settlements. Fortified sites, evidence of skeletal trauma, the presence of weapons, and rock art depicting the use of those weapons all point to warfare and dissent as part of the reality of Bronze Age life. Bronze smiths, particularly those involved in the casting of swords, would have played an integral role in navigating both the trade bonds that connected communities as well as the presence of violence that separated them.

Organizing bronze manufacture and the "in between" networks

Bronze working requires significant amounts of pre-planning. The acquisition of ore, conditioning wood to be used as fuel through drying and burning, mold making, casting, and the finishing of items all require a component of time as well as access to the appropriate materials. Bronze has the desirable attribute that it can be melted down and re-used, but the wood and clay or sand molds are not likewise re-usable. Each casting would require effort to obtain those items. Ethnographic examples of Awka iron smiths in Africa and other modern groups support the idea of larger casting events. The Awka iron smiths are frequently compared to LBA bronze smiths given the small settlement sizes of their Sub-Saharan African culture as an example of how itinerant smiths might exist within neighboring communities and how knowledge sharing is structured. The structure of the Awka smiths consists of a mix of sedentary smiths and itinerant smiths, who switch positions every year (Neaher 1979:356). These events take advantages of economies of scale, where producing more has a lower cost in terms of time and materials per object. The types of events that brought smiths together were likely the acquisition of raw materials and larger casting events, where economies of scale would be beneficial to the group as a whole.

Bronze smith communities likely consisted of individuals from different villages that met up on occasion, but spent the majority of their time working alone or in small groups. This type of **fission-fusion community**, where individuals spend most of their time apart (fission) but come together on certain occasions (fusion), is supported through ethnographic research of modern day metal workers, such as the Awka iron workers (Neaher 1979:357. Similar to the proposed network for Bronze Age smiths, the Awka iron workers spend most of their time alone in small settlements unable to support more than one smith. They come together for larger iron casts and to trade craft knowledge. This structure of working primarily alone and then coming together for periods of time is necessitated, in part, by the limited ability of the community to support a small number of dedicated craftsman.

Gathering of ore could have been a community event where non smiths helped to obtain the ore while the smiths themselves extracted the metals from the ore. Production of charcoal would have been another such event, with individuals gathering together for the multi day event of smoking the wood. In terms of casting, smaller casts could have been completed individually on an as needed basis, perhaps for those everyday items such as cups and bowls, while more elaborate casts may have occurred in a larger gathering, similar to the modern day experimental castings of the *Umha Aois*, based in Ireland. The *Umha Aois* group is suggested here as an example of a bronze casting community. The group uses traditional casting methods, but it's individual members are geographically separated. Thus, the *Umha Aois* group represents a fission-fusion community whose connection is through the shared knowledge of ancient bronze casting. These larger events would reinforce existing networks by providing an environment for bronze smiths to trade tips, share ideas, and share the labor of alloying and casting bronze. Group casts would also be a more efficient way to use materials by melting a larger amount of bronze at one point in time. These types of group activities that bring smiths together allow for the maintenance of networks over time.

The networks observed in the previous chapter are a representation of the larger groups that would have gathered for these events (Figures 11.17 and 11.18). These communities existed in overlapping geographic areas and span stylistic groups. Figure 12.2 depicts the links between different communities with each spoke representing a different community of sword smiths. Those blades with more links between communities have been placed on the outside of that community's spoke to emphasize inter-community relationships. This depiction of communities is based on the community detection detailed in Chapter 11 and represents communities based on the manufacture decisions examined in this project. Though the communities would have stronger influences within each group, the overlapping geographic nature of these groups of smiths, as depicted in Figure 11.19, facilitates the so-called weak connections between those groups. Swords that appear geographically distant from other blades in the community are indicators of the long distance trade network of the LBA.

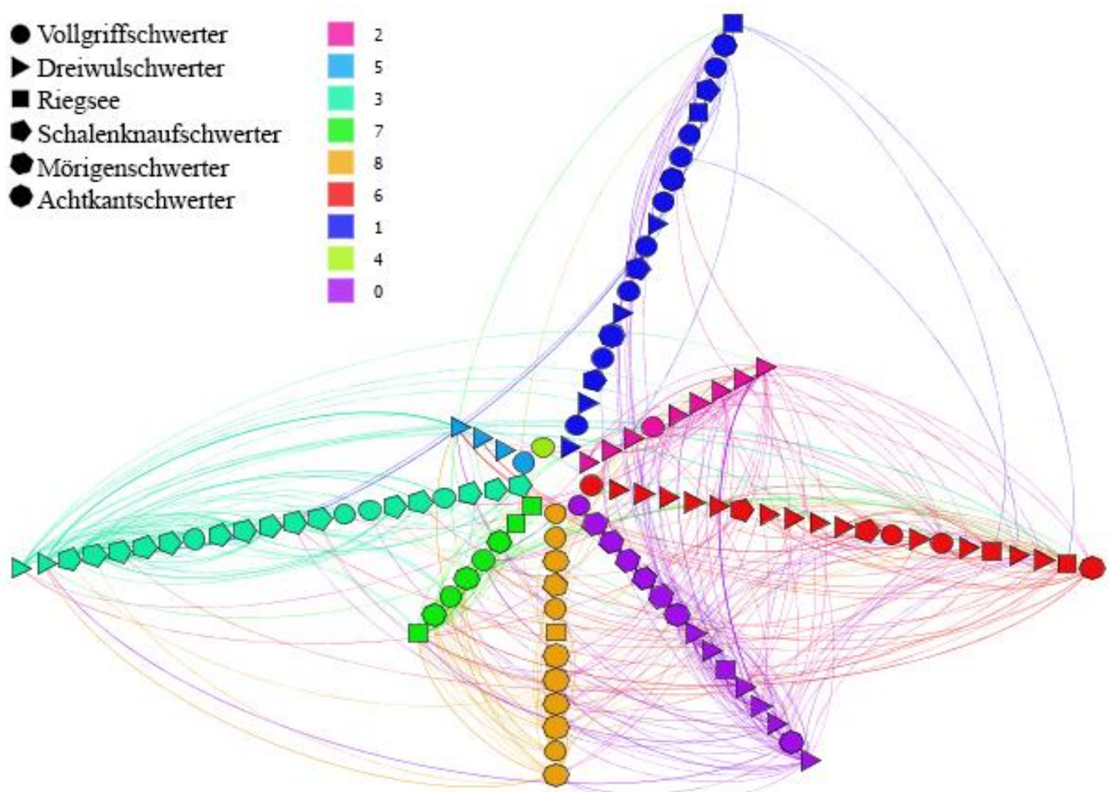


Figure 12.2: Links maintained between communities within the network of bronze smiths. Blades with more connections between groups are on the outside of the spoke, emphasizing inter community links. Network map created in GEPHI 0.8.2.

Maintenance of multiple networks simultaneously

Through group activities, multiple networks were maintained. In particular, the divergence between hilt and blade networks can be interpreted as an indication that different groups were making these aspects of the swords. Of the two parts of the sword, the blade is easier to reproduce, because a well-made stone mold can be used over and over again to cast a blade. While there is a general dearth of stone molds, clay molds could also be formed around an existing blade and then replicated several times before the cast. It is not unlikely that multiple items were cast in a single session when the materials were available as described above. Manufacture of the hilts would have been more time consuming, due to the detail found on many swords. These details are more often found on the hilts than the blades. It is possible that certain smiths specialized in making the hilts, but were not as involved in casting the blades themselves.

Another explanation is that blades may have been cast in small batches, such as the blades found in the Tapolnica Hoard discussion in Chapter Five. These blades could have been used at a later date and had the hilts added. Perhaps a group of individuals, such as a village or a group of smiths, accumulated enough wealth to cast a few blades and then store them. An alternative scenario is that blades which originally had organic hilts were repurposed to include metal hilts. This type of re-use would account for the lack of geographic correlation to blade profiles. If the blades were part of a trade circle with more time depth, changing social structures would muddle the relationship between maker and community.

Organic hilted swords had been circulating around Central Europe for the past 300 years or more. Bronze, and by extension items made from bronze, were difficult to obtain. It is not hard to imagine a sword that was passed down through familial or political networks as a valuable item. Since hilts can be cast on to existing blades, it would not be out of the realm of possibility for individuals to request their blade be made into a *Vollgriffschwert*.

Bronze smith networks as indicators of inter community LBA networks

The networks maintained by bronze smiths during the LBA create inter-community links which would have been reinforced by other types of community interactions. For example, a smith that lived on existing trade routes would be a more favorable contact that one in a warring settlement. Figure 12.1 depicts a very large scale network suggesting routes for amber trade. In contrast, Figure 12.3 illustrates potential trade routes based on the communities of bronze smiths in Central Europe. The ovals encompass the main body of swords included in each of the four main communities detected using network analysis in Chapter 11. The black dot in the center is where the four ovals overlap. The lines follow the general orientation of the ovals to show how those communities could have all had a similar point of contact.

The point indicated is also the area of the site of Hallstatt, a salt mine site that becomes particularly important to our understanding of the Early Iron Age. The site does show activity during the Late Bronze Age, and its placement at the intersection between the four larger communities of bronze smiths may point to its importance in bringing the various communities together. In particular, it is likely that this site was a trade hub through which items from the different groups of smiths were passed along to other communities. Notice, for example, that there are swords from group 4 (the purple group) far to the west of the main body of swords. These blades probably went through the Hallstatt area as a trade item. The same can be said of the group 2 blade (in blue) found in northern Germany. Thus, the examination of networks maintained by bronze smiths as seen through the manufacture choices in swords can be used to illustrated how interaction occurred between communities, eventually creating the long distance networks observed through the trade of exotic materials.

FURTHER WORK

The networks and correlations shown here would benefit from a variety of improvements to the study. First and foremost, a larger sample size of decorated swords would provide higher group numbers and therefore higher fidelity when comparing overall shape to decorative shape. The data set can also be expanded and improved by obtaining reliable 3D scans of the blades. The flat nature of the blades proved problematic in the post processing phase of this study, but scanning a flat blade is not impossible. There is also potential in the scan data already taken to recover some of those data. A number of hilts and blades were scanned but not included in this study due to problems with combining the individual scans into an entire object. The inclusion of these data would introduce blade profiles and cross section profiles for blades where that information is not available through the PBF. Extracting these profiles from the 3D data would also remove some of the uncertainty of using drawings and allow for a measure of control on where the cross section is taken from. This increase in fidelity of the data may result in correlations between the cross section and aspects of manufacture beyond just blade shapes.

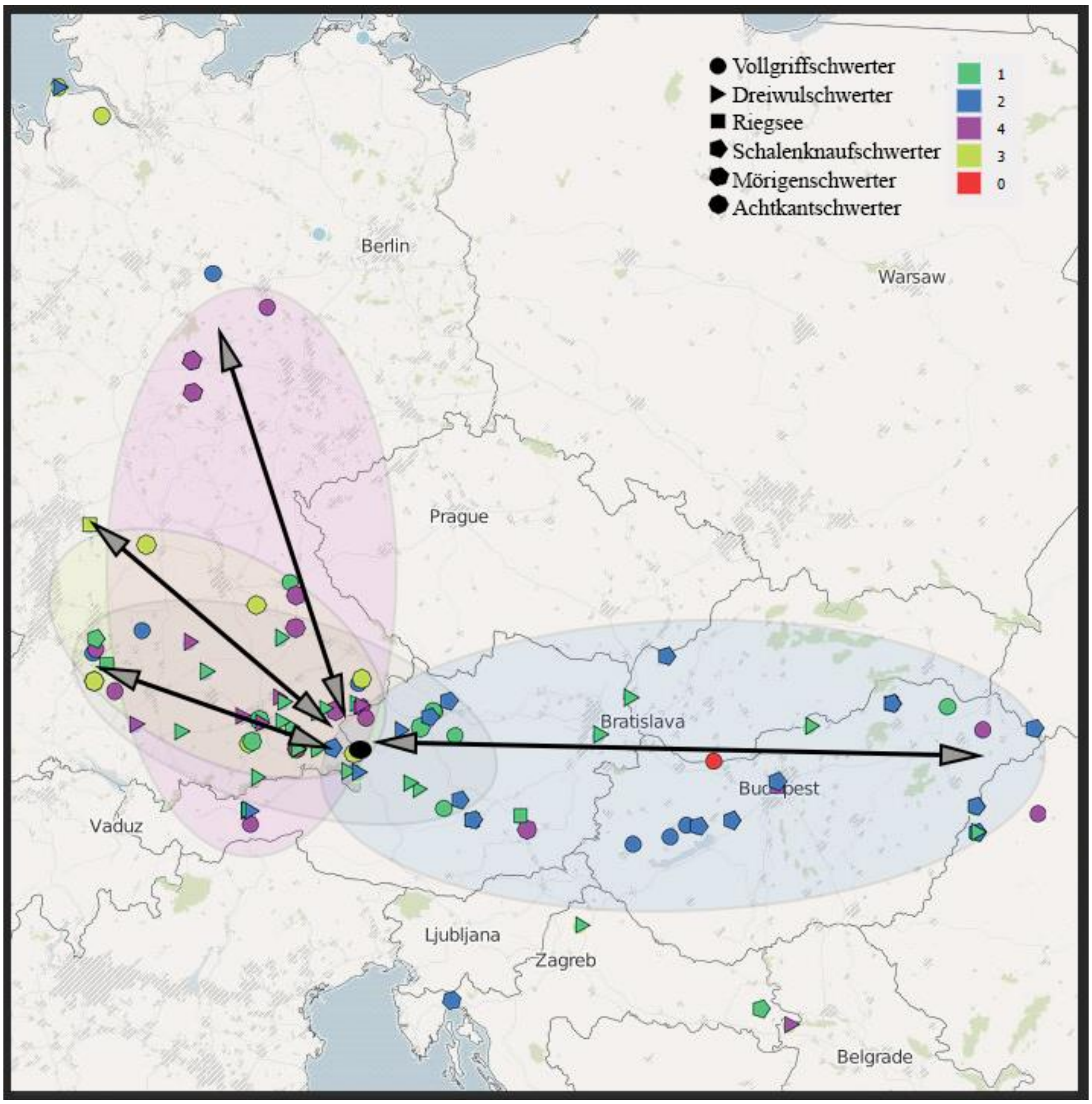


Figure 12.3: Proposed trade routes based on the four main groups of smith communities. Base map data ©2016 CartoDB. Network map created in GEPHI 0.8.2.

Even within the data presented here, there is room for more interpretation and analysis. It would be interesting to parse apart the interaction between blades and cross sections alongside the interaction between hilts and decorative data to see if the divergence of networks continues as seen above, or if a more nuanced reading of the data suggests that they are following a similar network. This type of analysis could strengthen the argument that blades and hilts are made by different groups, or by filling the blanks it could provide key data that are missing from the analysis.

Another area for expansion of this type of analysis would be to include blades that do not have metal hilts, the organic hilted blades. Inclusion of these blades would help fill in geographic areas missing in the data and extend the temporal range of the analysis. If the networks remain constant when comparing between different subdivisions of the Bronze Age, that would show network maintenance over time. It may also lead to a better understanding of how LBA networks formed. This type of analysis could also be extended in the Early Iron Age to examine how well these networks hold up as technology changes in the area.

Furthermore, the focus of this dissertation has been on network formation, but there are also some interesting differences occurring in terms of decorative shape formation and consistency within those shapes. These ideas are not examined here as they are presented as a step on the way to network formations and often not backed by a large enough group for analysis, but they provide an interesting place for further exploration into why these differences are occurring and what they might suggest about how style, find type, and manufacture are connected. Many of these connections are tenuous due to small group size, but an increase in the overall sample size, specifically swords that contain these types of decoration, could be done to bring those group sizes up.

CONCLUSIONS

Presented in this dissertation is a method of shape analysis rooted in material culture theory and network theory. The dissertation begins with networks, examines the archaeological record from a network analysis perspective, explains the theoretical link between shape, manufacture knowledge, and communication. From there, I use this theoretical bridge to take shape data associated with LBA swords and reconstruct networks between LBA bronze smiths.

The methods presented here are not valid only for LBA swords. This project was developed and carried out as a case study for studying specialized craft items to better understand the networks of the craft workers. These methods can be expanded to work with other artifact types and time periods. While the intention of this dissertation was to use 3D scan data in a novel way, network analysis is not limited to this type of data, as is shown in Blake's treatment of network analysis (2004). The combination of 3D shape data, limitations of inferences made from those data, and developing meaningful links for network analysis is a promising method for reconstructing connections based on shared knowledge of specialized production techniques.

PART IV:
APPENDICES, GLOSSARY, AND BIBLIOGRAPHY

GLOSSARY

Active style – Style choices that are made consciously by the individual exhibiting that style in question. These types of style often project knowledge about the person, such as an affiliation to one's university.

Affective mode– Making choices based on the emotional feedback those choices afford the individual.

Agency – The ability to affect changes in other people, objects, or environments.

Banks and ditches – A fortification method wherein alternating dips in the landscape (the ditches) and mounded earthworks (the banks) are used.

Chi-squared testing – A method of comparing two categorical variables and determine if those variables are found in a predictable manner.

Cluster – Data points that are grouped together based on proximity.

Communication – Methods of transferring information from one individual to another.

Connection – A unit that connects to nodes in a network analysis. Synonyms: link, edge.

Continuous – Data that is on a sliding numerical scale, such as height or weight.

Decimated – A form of 3D data processing where points are removed to create a less dense mesh. Decimation can be done at multiple levels, and does not need to leave only 10% of the data remaining.

Directional connection – A connection between two nodes in a network that only goes one way between the nodes. For example, in a phone tree you would only call the next person down the line. You would not also call the person who called you. Because you're only enacting the connection in one direction, the link is a directional connection.

Emblematic style – an image or style that is representative of something. For example, the University of Minnesota has a stylized M that is emblematic of the university.

Enculturation – The gradual and unconscious learning of behaviors and cultural expectations.

Fortification – A site that has a barrier. During the Late Bronze Age barriers can be fences or bank and ditch enclosures.

F-test – A statistical test to determine if two populations are part of the same population. The null hypothesis is that they are. A p value of $<.05$ indicates that the groups might not be equal.

Habitual mode – choices that are taken unconsciously.

Hierarchical network – A cascading network with layers that grow in size.

Household – Individuals who cohabitate. These individuals are not necessarily related, though they could be. A household does not indicate a modern nuclear family.

Hub and spoke network – A network that has a small number of highly connected nodes and a large number of nodes with fewer connections. To be connected from the weakly connected nodes, the path goes through one or more of the highly connected nodes. Airport traffic is a good example of a hub and spoke network.

Isochrestic variation – Variation that does not affect the function of an object. This type of variation includes both active and passive style variation.

Multiplexity – The ability of nodes to have multiple types of connections. For example, a person can be part of a network of coworkers and a network of family members simultaneously.

Network – The way in which things are connected.

Node – A point on a network. The node can be a person, a city, or any other object that is being connected to another.

Non-continuous – Data that is not on a sliding numerical scale. This type of data is often categorical. An example of non-continuous data would be whether someone's pet was a dog or a cat.

Non-directional connection – A connection that can be initiated or traveled down from either node. For example, a family connection would be non-directional since both individuals are family with each other.

Normal distribution – A distribution that has a bell curve shape.

Passive style – Style that expressed unconsciously. This includes decisions that are made through habitus and habitual mode.

Point cloud – A large series of x, y, z points that describe an object in three dimensional space. A point cloud does not have any edges connecting the points.

Post-processing – All the editing that occurs after 3D scans are obtained.

Power law distribution – A network that is exponentially increasing.

Random network – A network whose links do not follow any particular pattern.

Reflective mode – When an individual thinks about the choices they make as they make them.

Six degrees of separation – The theory in network analysis that all people are within six connections of all other people.

Slit scanning / laser scanning – A type of laser scanning based on a single line of light. As the line shines on the object and warps, the camera captures the image and the software extrapolates how the line is warping to create 3D points for the object.

Strong ties – Links in a network that are reinforced by other nearby links.

Structured white light scanning – A type of 3D scanning based on projecting patterns of white light onto an object. A camera captures the warping of the pattern to determine where the object is and create a point cloud.

Time of flight – A type of 3D scanning based on sending a signal (usually light or sound) to the object being scanned and timing how long it takes for that signal to travel to the object and reflect back.

T-test – A test to see if the means of two groups are different.

Weak ties – A tie that connects two groups that are clustered. The term weak refers to the fact that it is not reinforced by other similar ties nearby. However, weak ties allow information to move from one clustered group to another.

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Appendix A: Protocols

Scanning Protocol

3D scans were collected using a David SLS2 (structured light scanner 2). See Figure A.2 for an example of setup. The hilts were scanned using the 30mm calibration plate and the blades were scanned using the 60mm calibration plate. If there was no decoration on the hilt, only the top of the hilt was scanned with the 30mm calibration plate. This was to ensure coverage of the pommel on the side towards the blade. The pommel was also scanned from the other direction. Figure A.3 shows a selection of perspectives scanned.

All scans were taken using the highest quality setting with both horizontal and vertical patterns. A total of 58 patterns were used per scan. Quality, smoothing, and outlier removal options were all set to 0. The swords were placed on a series of Styrofoam blocks, an example of which can be seen in Figure A.2, and rotated forward approximately 30 degrees with each rotation until a full 360 degree rotation was completed. Scans were taken along the length of the hilt or blade as necessary with an overlap of approximately 20-30%. A series of coins was placed on the table to help with alignment. A minimum of 18 scans were taken per hilt, with some swords containing as many as 50 scans per hilt. This number does not include any blade scans, as they were not used in this study.

Figure A.1: propped up blade

Figure A.2: Basic work setup

Figure A.3: Example of some of the angles the sword is scanned from.

Post Processing Protocol

The following text describes the protocol used to process the raw scan data into a complete hilt. Both David 3d Scanner Pro v4.3.5 and Geomagic Design X build version 2015.2.0 were used. While it is possible to do all of the processing in one program, I have found that each program has strengths over the other. David 3d Scanner produces faster auto aligns between scan shells, while Geomagic Design X provides a better fine alignment. Both programs have features which allow for removing extraneous data from multiple scans at the same time, but Geomagic Design X provides more options with greater control to the user. Finally, I prefer the final merge results from David. Both programs were available for use at the University of Minnesota Anthropology Labs. I developed this protocol to process the scans quickly while still retaining an accurate alignment and final product. I did not do any auto alignment during scanning, and so this protocol assumes extraneous data, such as from the table, as well as original scans that are not aligned. The images shown below are taken from the example sword 10.048. Each blade has the following file structure:

- Blade Number
  - Blade
  - Hilt
    - Original
    - Cleaned
    - Align1
    - Aligned

Extraneous data was removed in Geomagic using the "Data Editing" stage of the Mesh Buildup wizard. I used a series of alternating "Find Noisy Cluster" and "Find

Boundary" removals, shown in the screenshots below. Any remaining extraneous data was removed by hand.

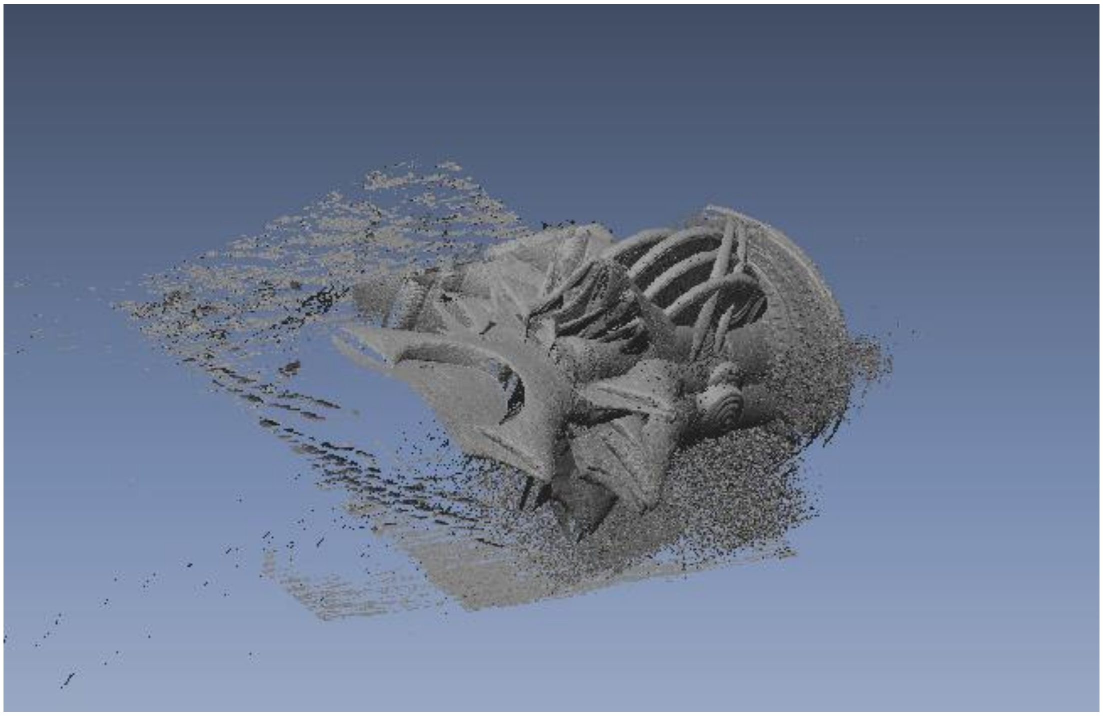


Figure A.4: All hilt data from sword 10.048.

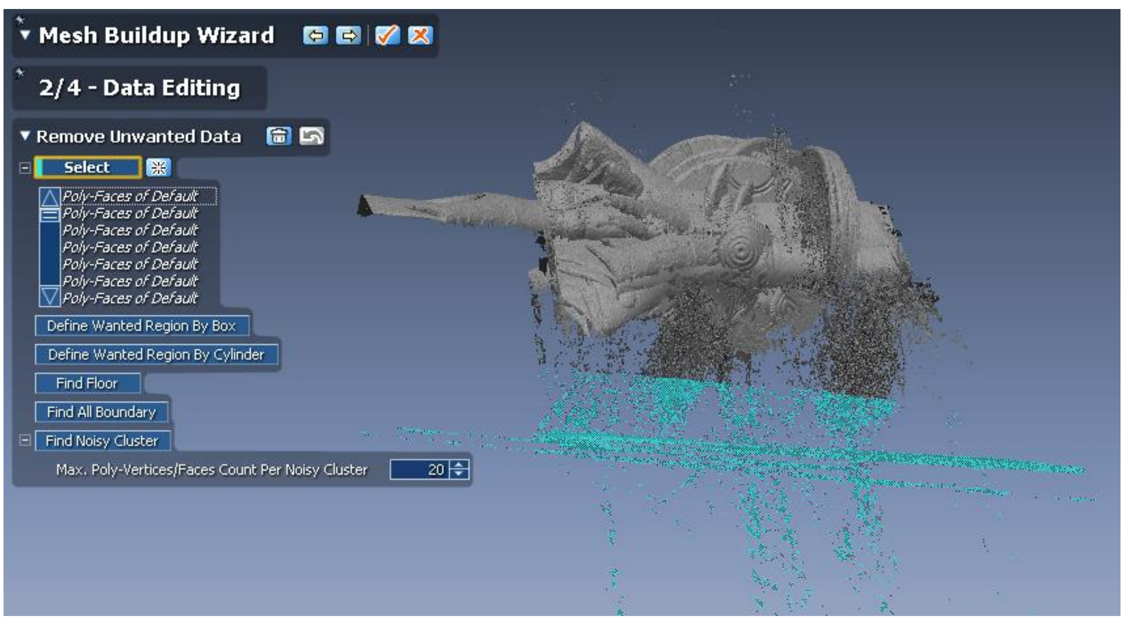


Figure A.5: Hand removal of edits from sword 10.048.

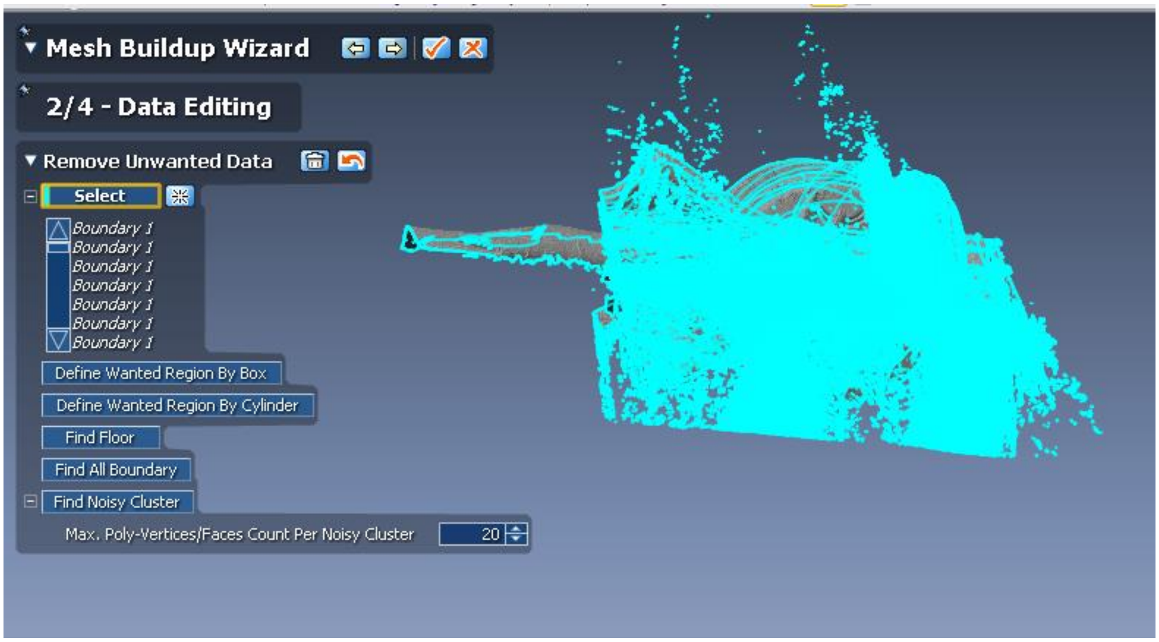


Figure A.6: Edge removal for sword 10.048.

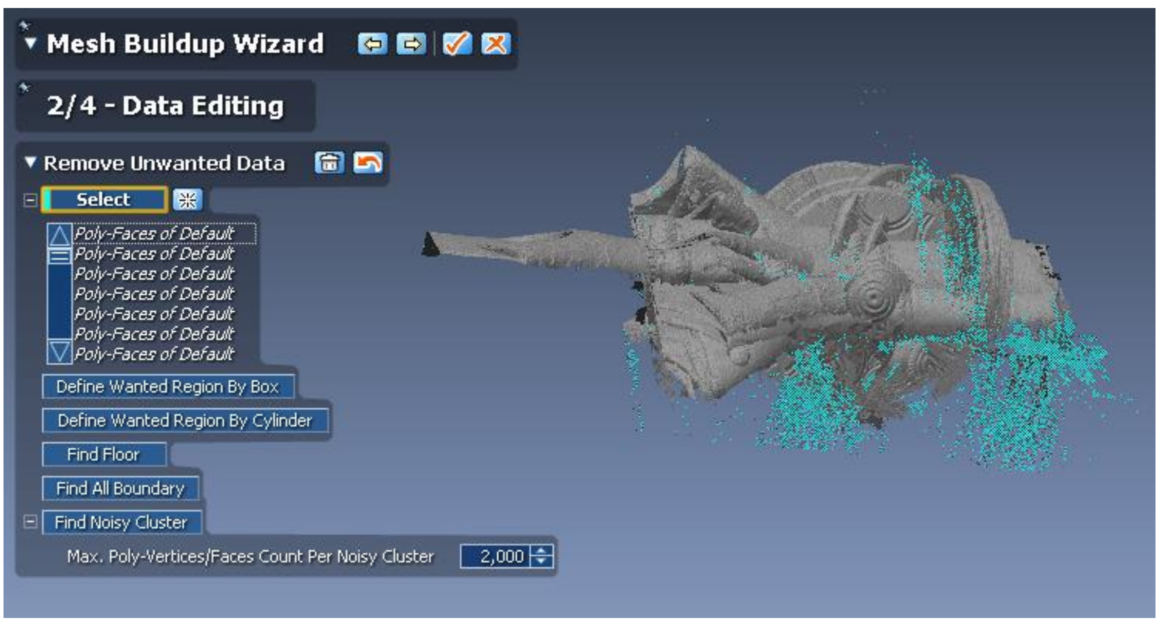


Figure A.7: Noisy cluster removal for sword 10.048.

Figure A.8: Removal of remaining extraneous data for sword 10.048.

Once any extraneous data were removed, the scans were exported and re-imported into the David software. From there, each scan was aligned to the previous scan. For example, if there were 4 scans, the alignment process would go like so: Scan 2 – Scan 1, Scan 3 – Scan 2, Scan 4 – Scan 3. This provides a quick rough align. In some cases, scans were not able to be aligned to one of the scans directly next to it. In almost all cases every scan would align with at least 1 other scans. The roughly aligned scans were exported out of David and back into Geomagic for the final alignment.

Any remaining scans out of alignment were placed using the picked point option of Geomagic. This process requires user input as to which points on the scans meet up. Groups of pre-aligned scans as well as individual scans were aligned using this process. A minimum of 3 points were used. More points were used as needed. Finally, a global fine alignment was performed with the option to minimize scan movement checked. In some cases, the picked point option was used again to refine the scan alignment further.

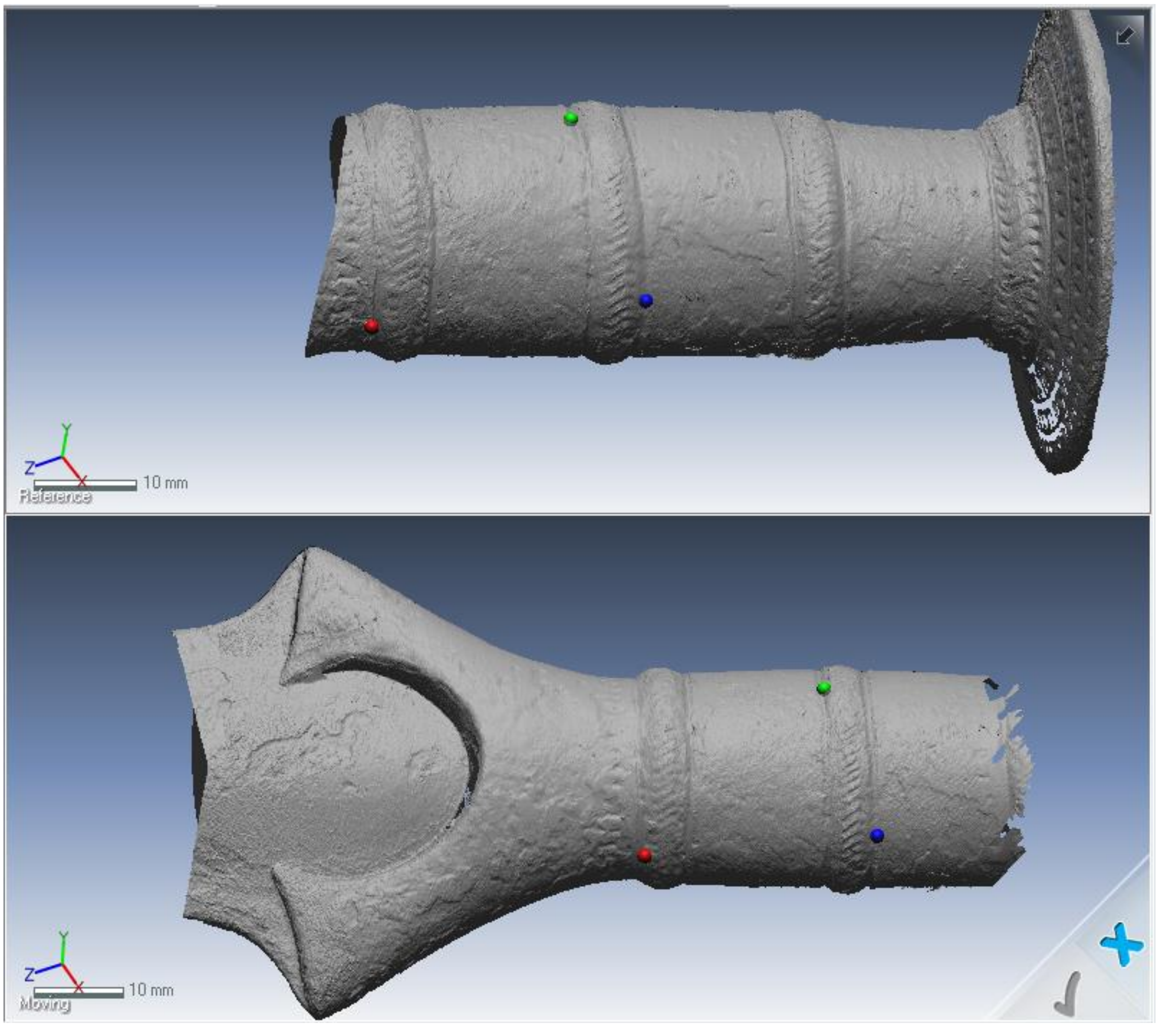


Figure A.9: Picked point alignment for sword 10.048.

The final step of post processing is to merge the individual scans together to create a single 3D file. To do this, the various scans that make up the hilt were exported from Geomagic and imported back into David scanner, where they were merged at a quality of 700. The image below shows the scans once they have been merged into a single object.

Figure A.10: Aligned, cleaned, and merged hilt for sword 10.048.

The scans associated with this dissertation are not available with the other data files stored on the University of Minnesota DRUM server in accordance with copyright. If you are interested in obtaining any of the scans, please contact the museum where the sword you are interested in is housed. The curators in those institutions hold the rights to provide access for the 3D files.

MEASUREMENT PROTOCOLS

For this series of protocols, sword 09.201 will be used to show examples. This particular object has all of the different types of decoration used for this study, which makes it a good sword to use for demonstration. The first step that must be taken before measurements can be taken is to align the blades to the global origin in a consistent manner. There are 3 planes that matter for this: The X, Y, and Z planes. I aligned each sword so that the Z plane lined up as best as possible where the hilt met the blade. The blade was then rotated so that the X and Y planes dissected the center of the hilt when looking down the pommel end.

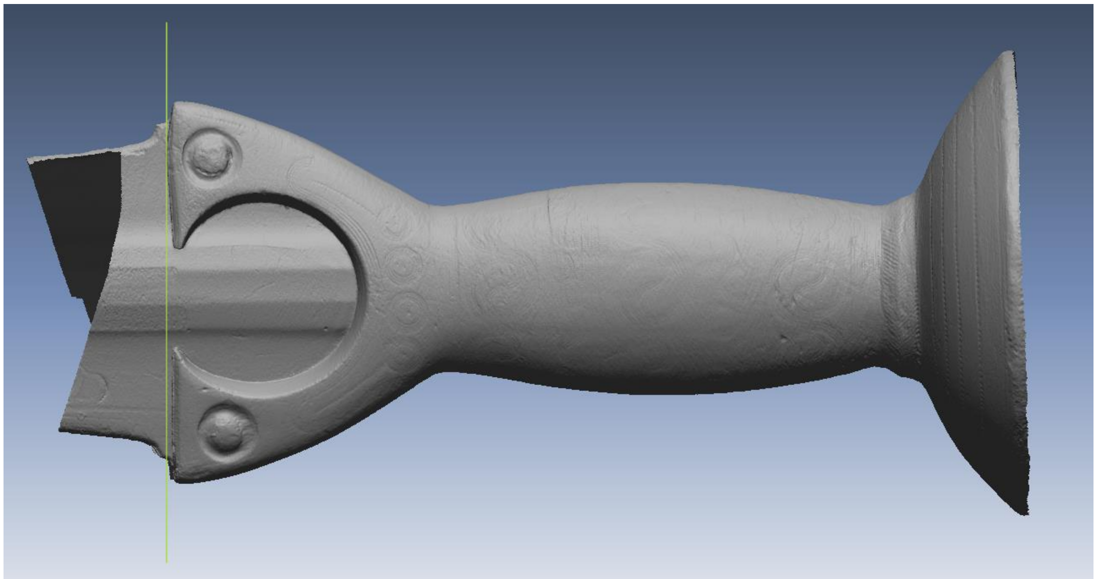


Figure A.11: Alignment of hilt 9.201 to the Z plane.

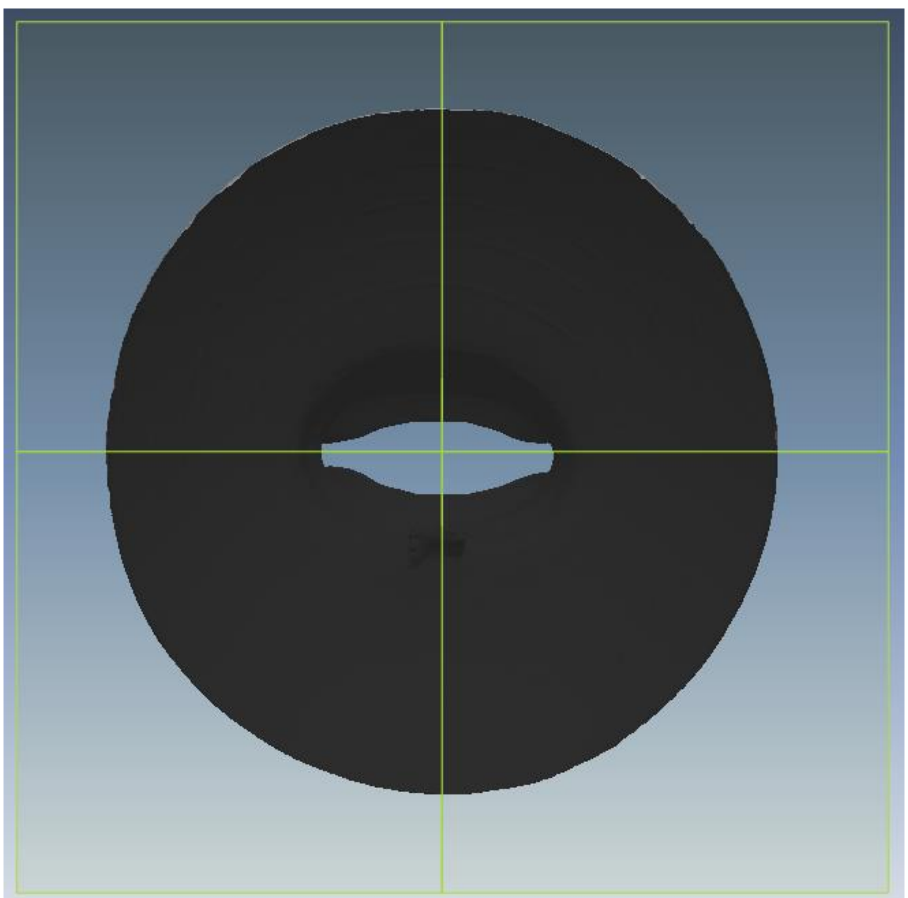


Figure A.12: Alignment to the X and Y planes for hilt 9.201.

The X plane provided an appropriate division for a side profile, but the blades are not perfectly symmetrical along a perpendicular plane. In order to get a cross section from a plane, I create a plane using the option to base a plane on points. Points were chosen along both sides of the hilts where the point of inflection indicated a switch from one side of the hilt to the other.

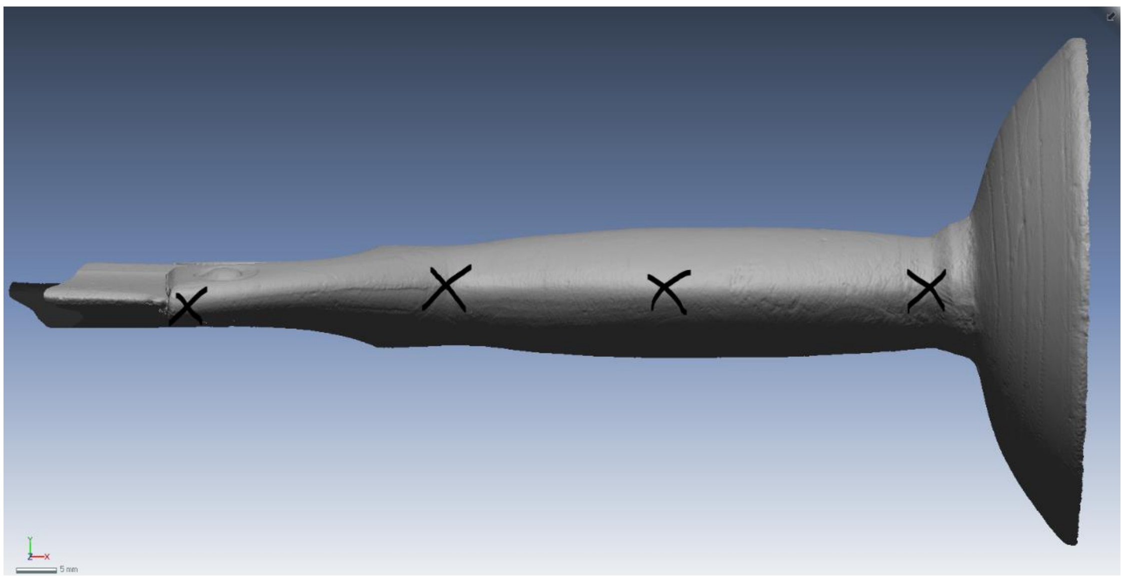


Figure A.13: Points for top profile extraction on hilt 9.201.

Profiles were extracted from the hilts based on these planes. Where small holes existed, they were filled in with straight lines connected the two points. The intersection of the hilt and the blade was closed using a straight line, as was the pommel end. The pommel was closed at it is widest point. The images below show the original hilt profile alongside the edited hilt profile, which was used for a Fourier transform as discussed in Chapter 9.

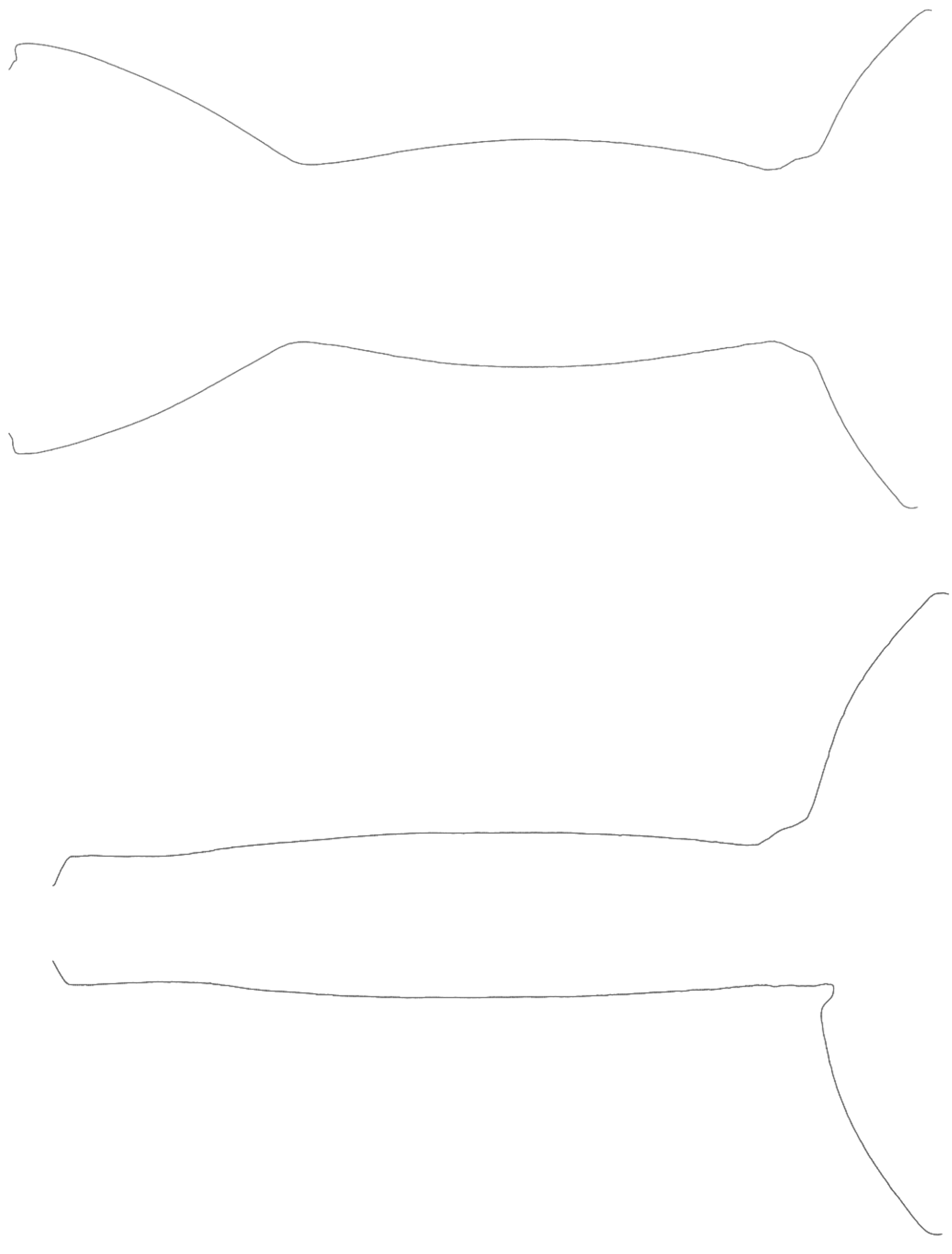


Figure A.14: Top and side profiles for hilt 9.201.

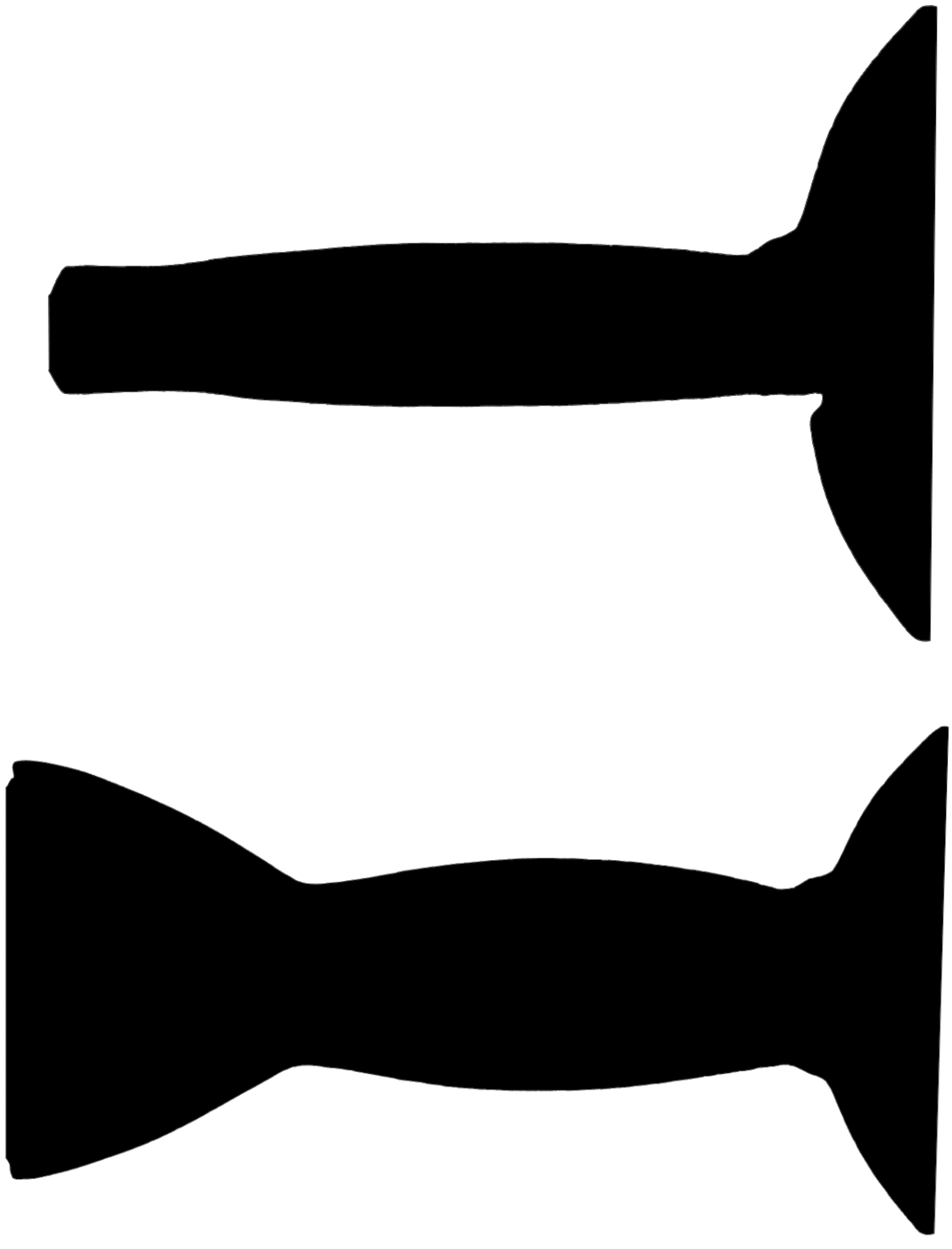


Figure A.15: Filled in top and side profiles for hilt 9.201.

Once the planes were defined, points were defined. Most blades had rivets 1 and 2. The center of the rivets was taken by using the extract method to create a reference point. This works by selecting all the relevant faces. Geomagic calculates the center of those points and creates a single point to represent those faces. This process was also done to determine the center point of concentric circles. The tang points were defined by the intersection of the X plane, the blade, and the hilt on each side.

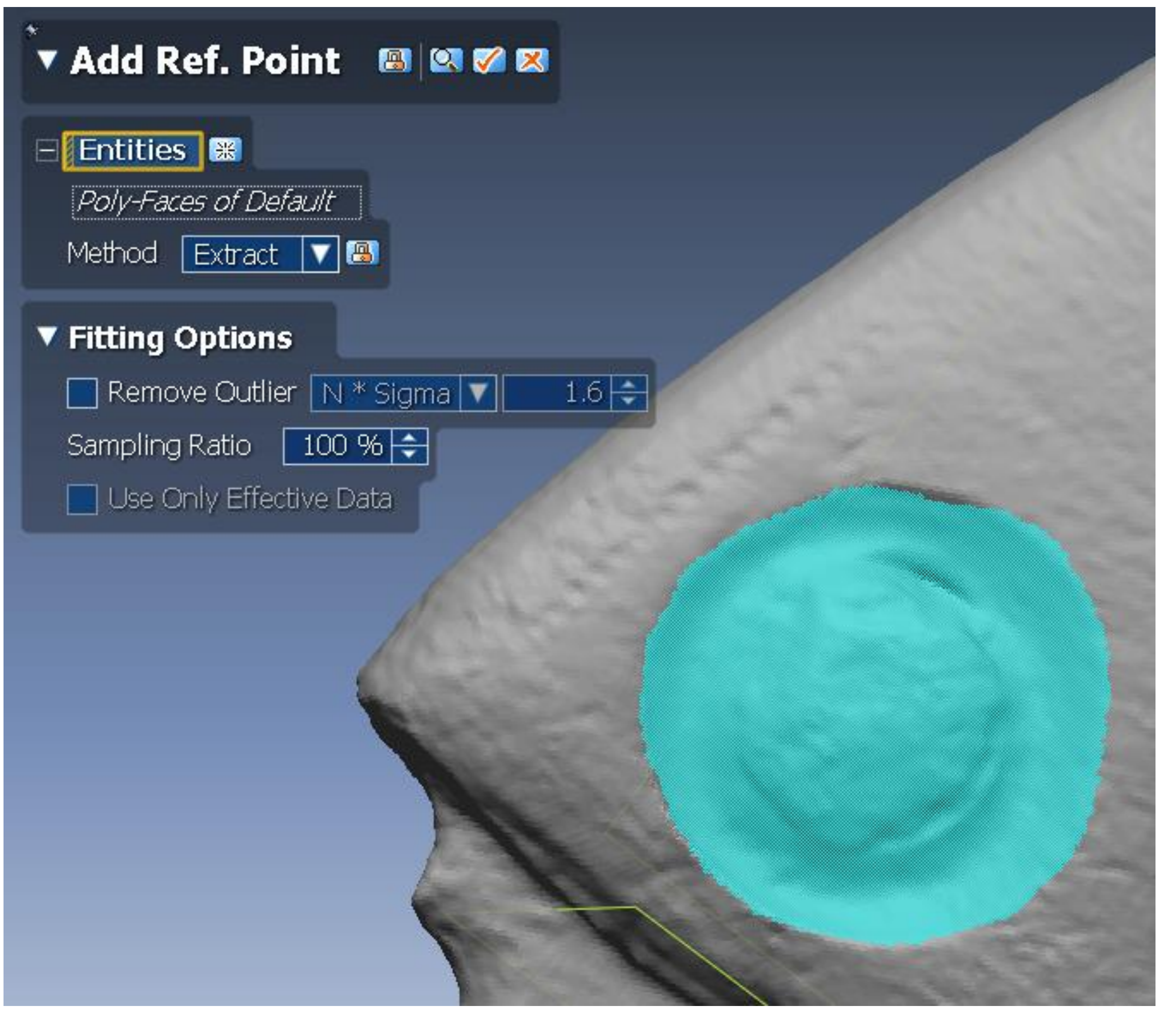


Figure A.16: Selection of faces for rivet point extraction on hilt 9.201.

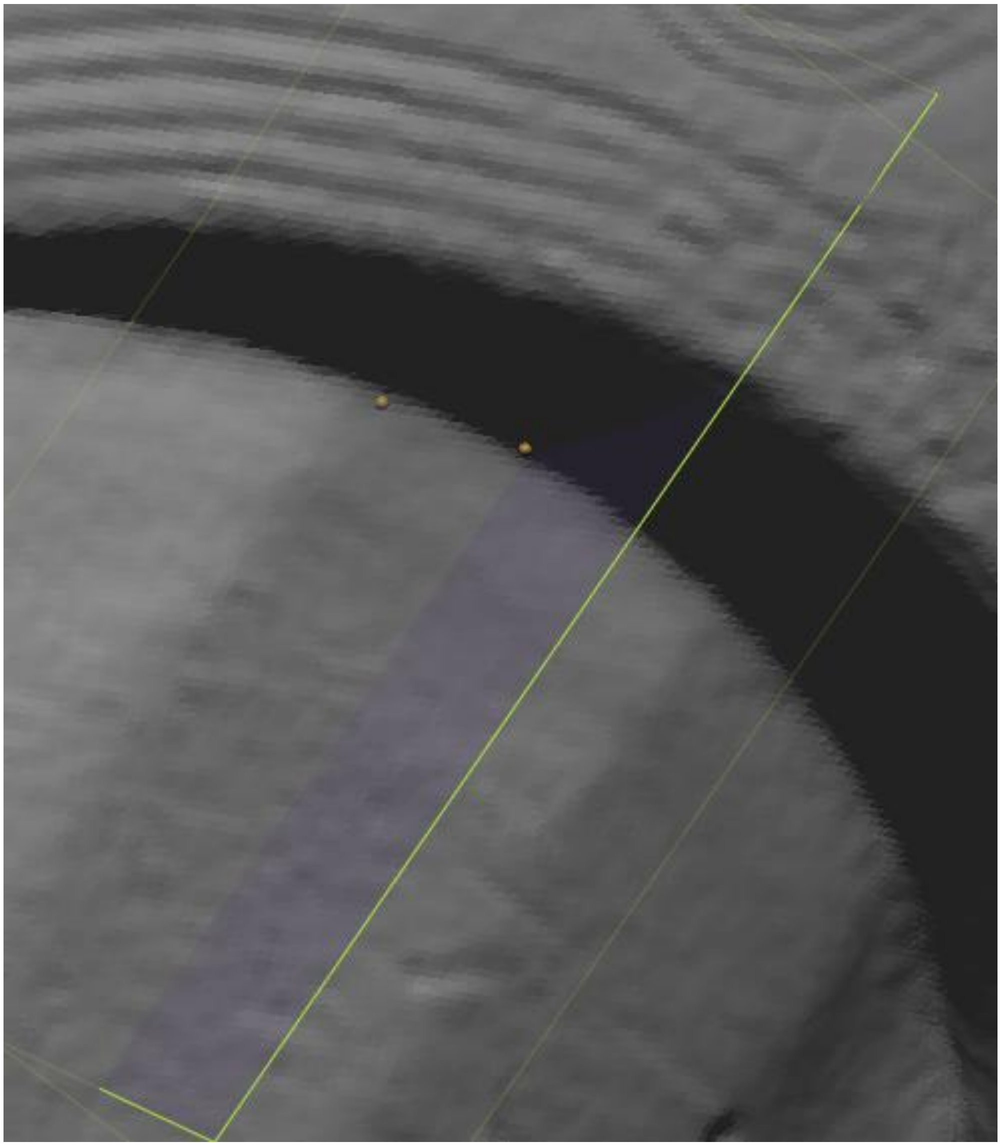


Figure A.17: Points for tang width on hilt 9.201.

After the points were defined, measurements were taken between the defined points. The remaining measurements were taken with the aid of the curvature display. The images below show the difference between a regular view and the curvature view. The colors in the curvature view are defined by points of inflection – high and low points showing where the faces of the scan are curving. This view aids in determining where the deep points which define the shapes are found. The amount the color enhances can be modified as needed for different observations.

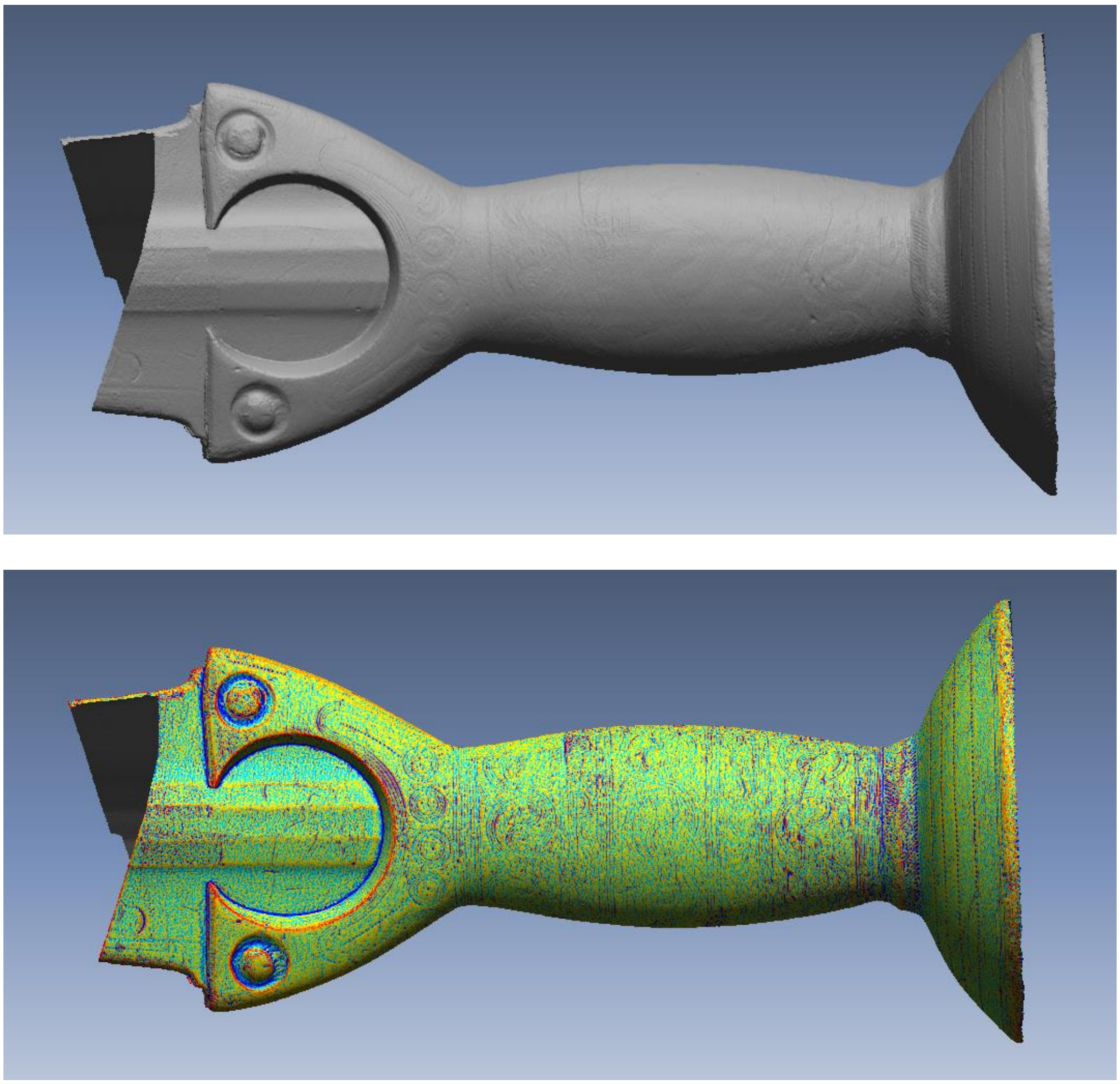


Figure A.18: Difference between material view and curvature view in Geomagic for hilt 9.201.

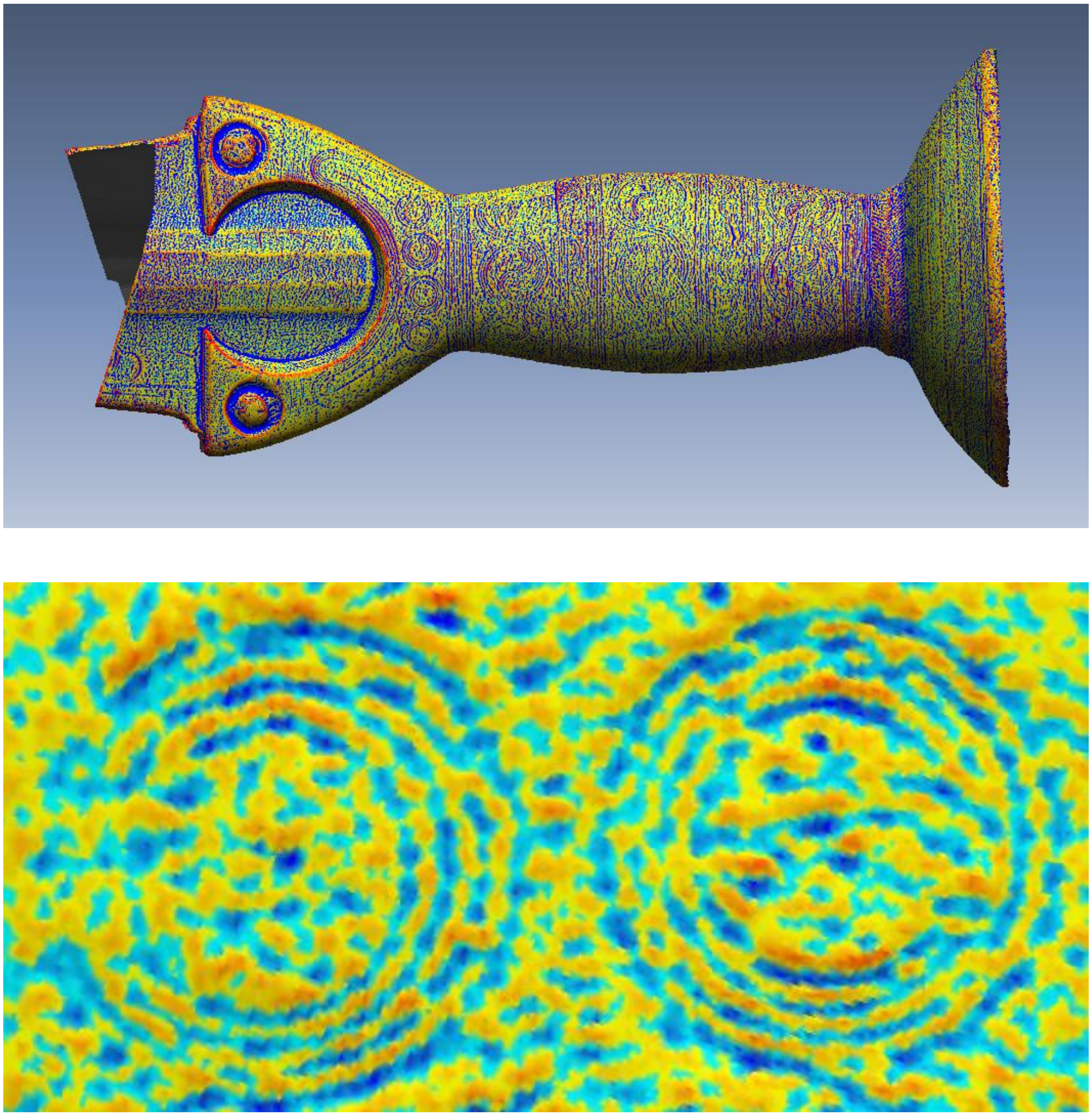


Figure A.19: Upper: Exaggeration of curvature view to enhance visibility of decorative marks. Lower: Close up of two of the concentric circles on hilt 9.201 .

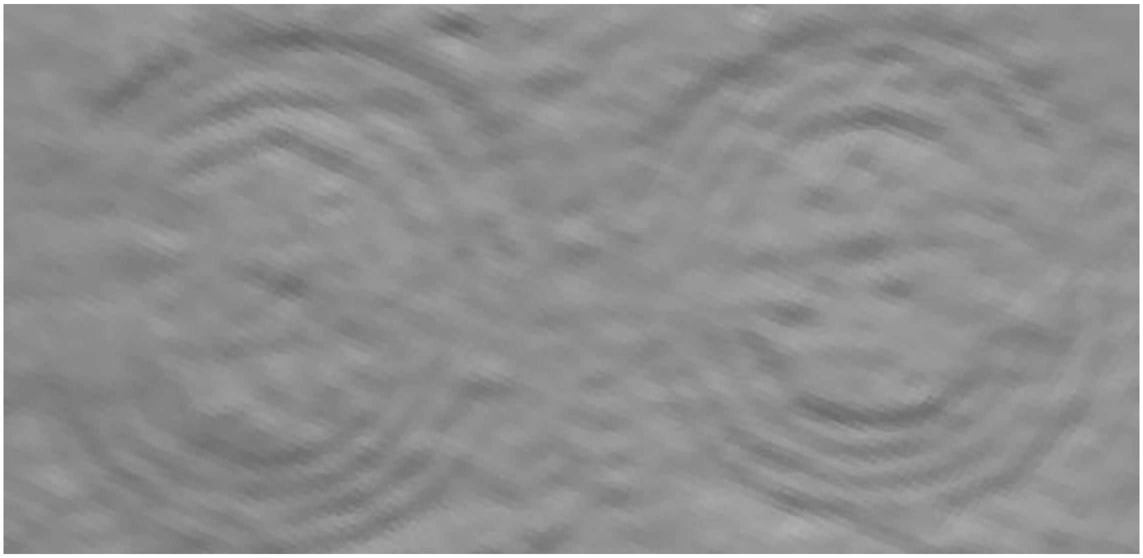


Figure A.20: Close up of the same two concentric circles in A.19, but without curvature view on.

Using the curvature mode, measurements were taken for the shape data as follows. The example is shown up closing using the curvature mode to demonstrate the power of being able to examine the geometry better, but examples of the measurements themselves are shown with the grey mesh so that the measurements can be observed. Concentric circles were defined by their outer most radius (as defined by three points on the circle), the distance between their center points along the width of the hilt, and the distance between the concentric circles taken at four positions.

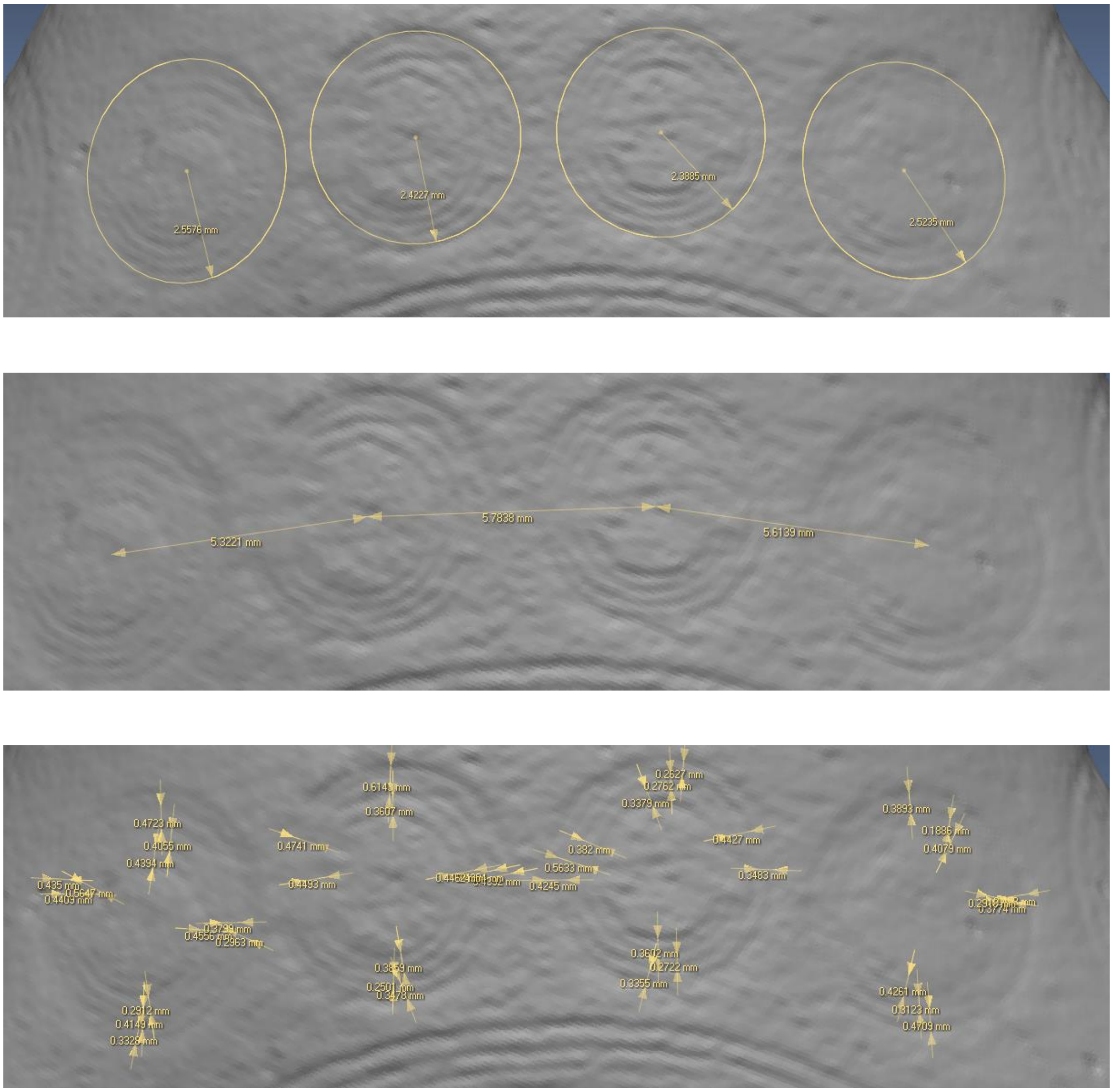
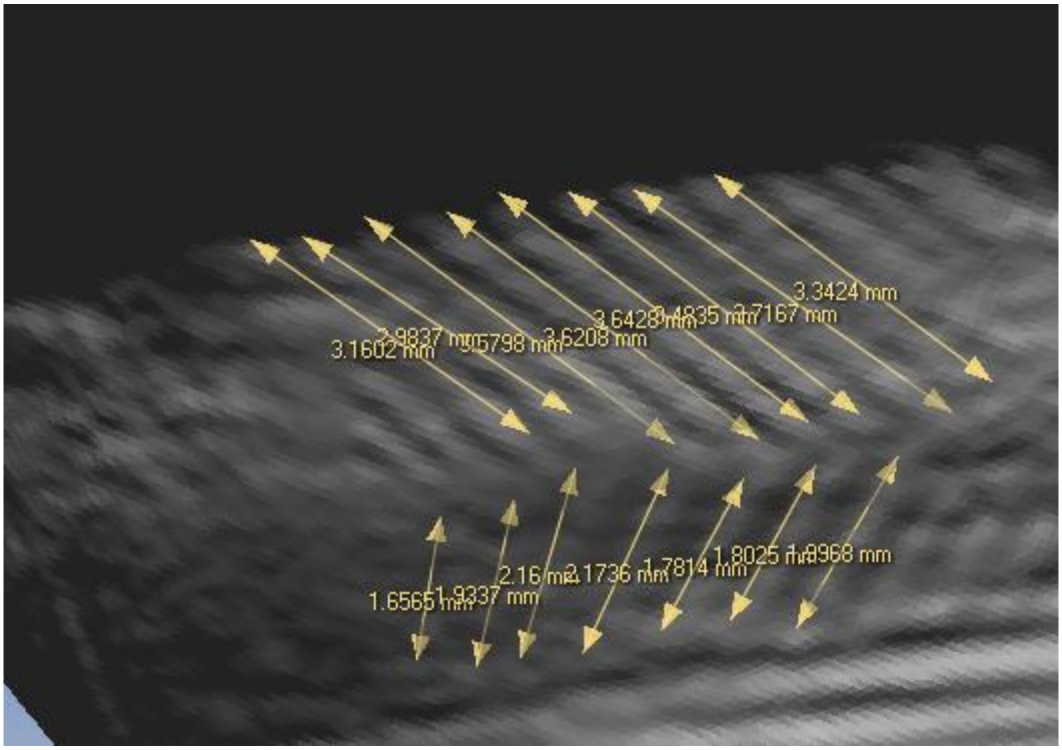


Figure A.21: Diameter, distance between centers, and distance between circles for concentric circle measurements on hilt 9.201.

Dashes were measured both by the length of the dash as well as the distance between each dash.



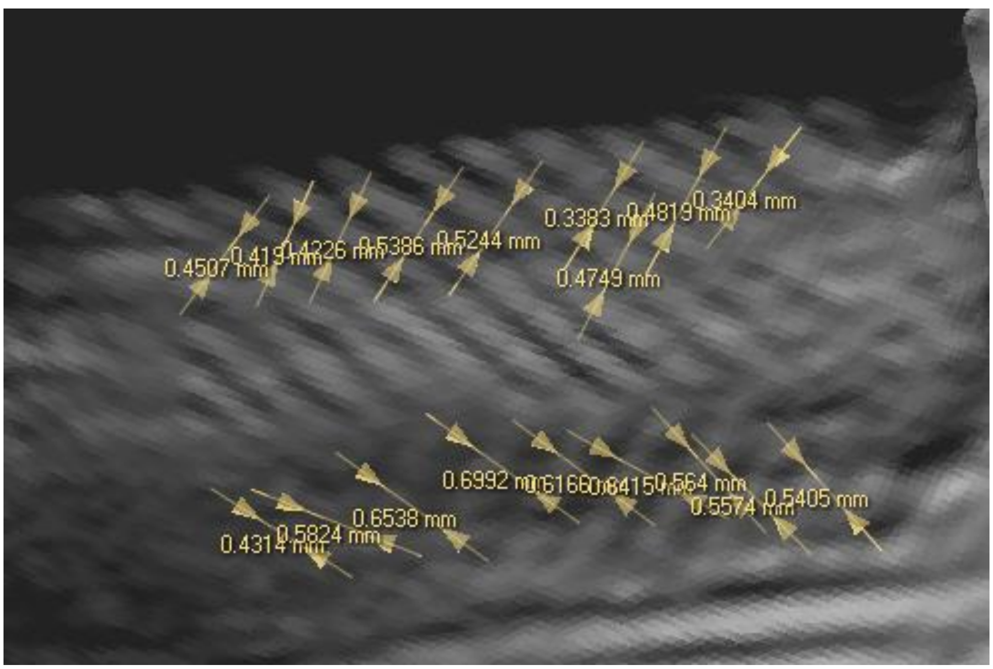


Figure A.22: Dash measurements on hilt 9.201.

Parallel curves are found at the bottom of the hilt, near the blade. The distance between the curves was measured along the length of the curve as possible.

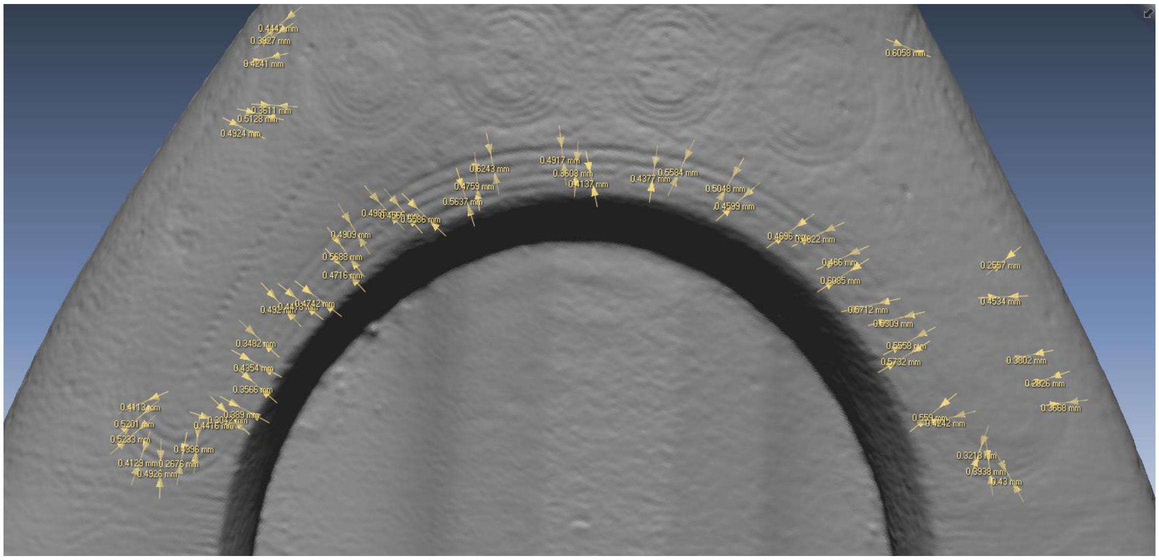


Figure A.23: Parallel curve measurements for hilt 9.201.

Parallel straights were measured along the X plane for each set of straight lines.

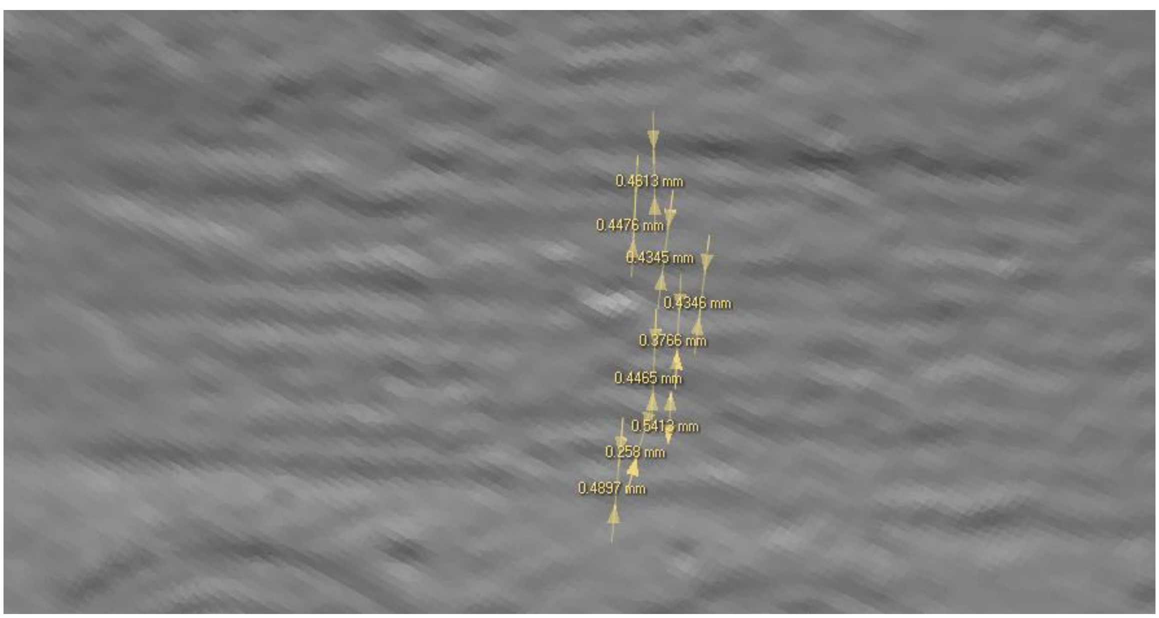


Figure A.24: Parallel straight line measurements for hilt 9.201.

Waves were given three measurements: width, height, and distance between the centers. This measurement was the most subjective of all, as it is difficult to determine where these points may exist, even with the help of the curvature feature.

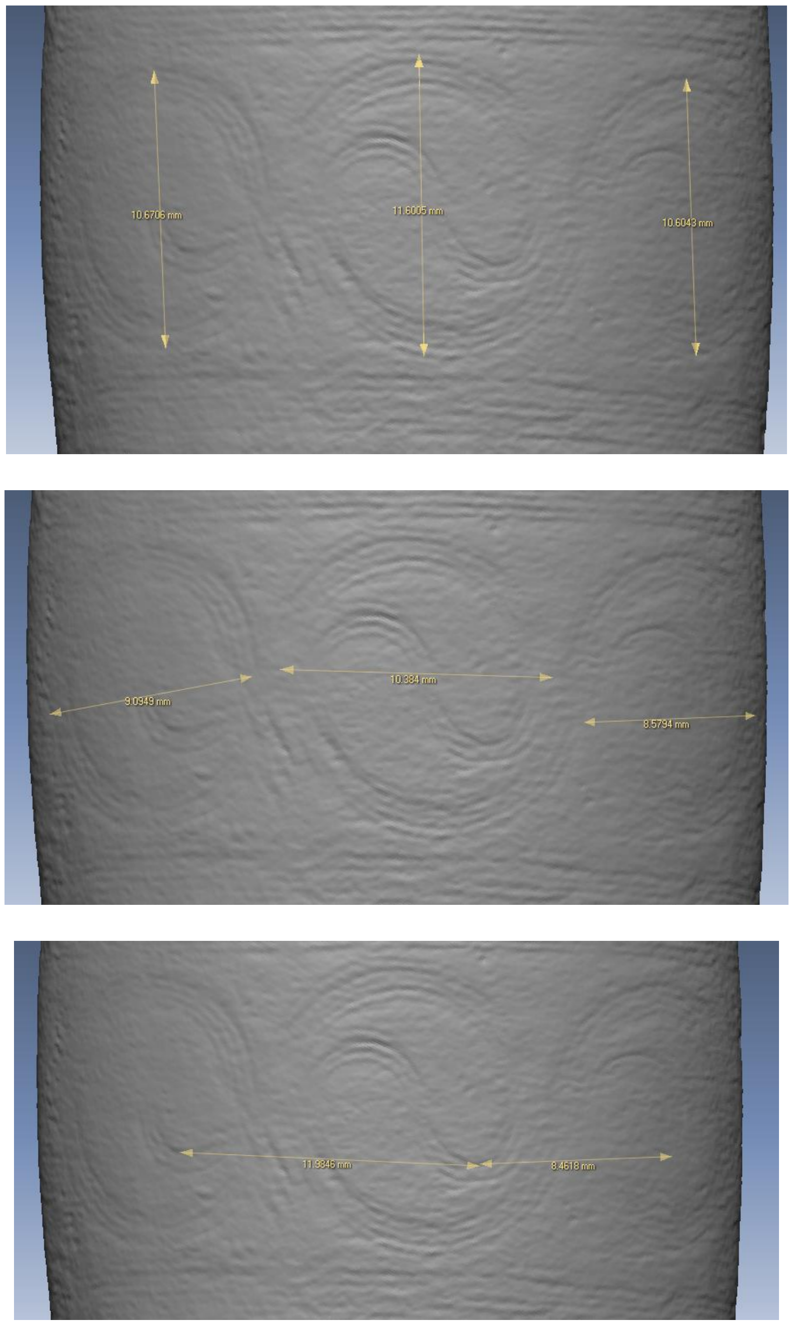


Figure A.25: Wave measurements for hilt 9.201.

The goal of these measurements was to find a way to quantify the decorative shapes. While these measurements are not perfect, the give a sense of the variation within a blade. Because it is not possible to take the same number of measurements per sword (in part due to differential preservation, and in part due to differing numbers of decorations), each of these measurements was averaged across the blade. The average and standard deviations were the values used in the final calculations. The individual measurements made for each item can be found in the University of Minnesota DRUM files at http://hdl.handle.net/11299/180367.

Appendix B: Charts and Matrices for Statistical Analysis

Cluster Analysis Graphs

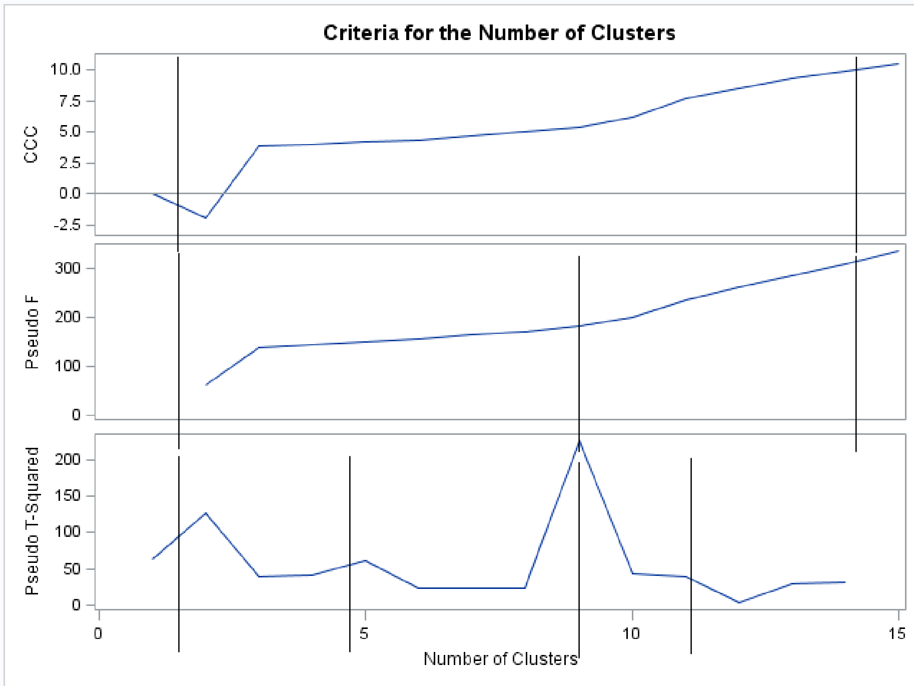
The following pages contain the graphs used to determine the number of clusters for each cluster group. The first graph shows plots of the Cubic Clustering Criterion (CCC), pseudo F (PSF), and t-squared (PST2) statistics for each cluster analysis as output by the SAS software. These plots are used to determine the number of clusters for each set of variables. Useful clustering points on each type of graph are as follows:

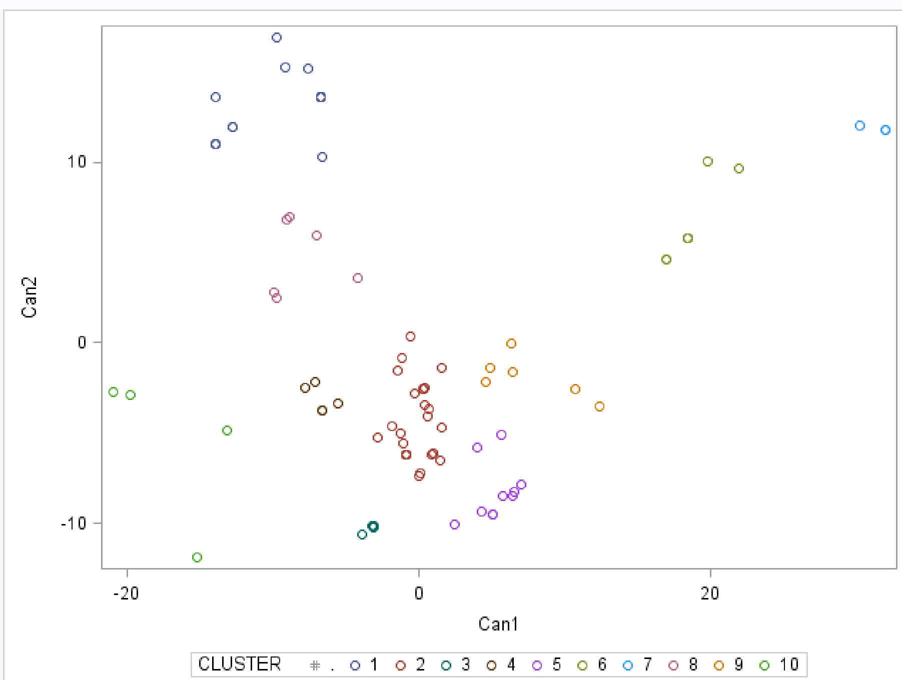
- CCC: Peaks greater than 2, leveling points
- Pseudo F: Large values, leveling points
- Pseudo T-squared: Points to the right of peaks.

Places where 2 or more of these numbers met up were chosen as potential clusters. The second graph shows the plot of the clusters against the canonical values (those values which define the clusters as per the ACECLUS transformation). A test cluster was run for potential clusters. Any sword that created its own cluster was removed as an outlier, and the clustering procedure was performed a second time.

LOCATION CLUSTERS

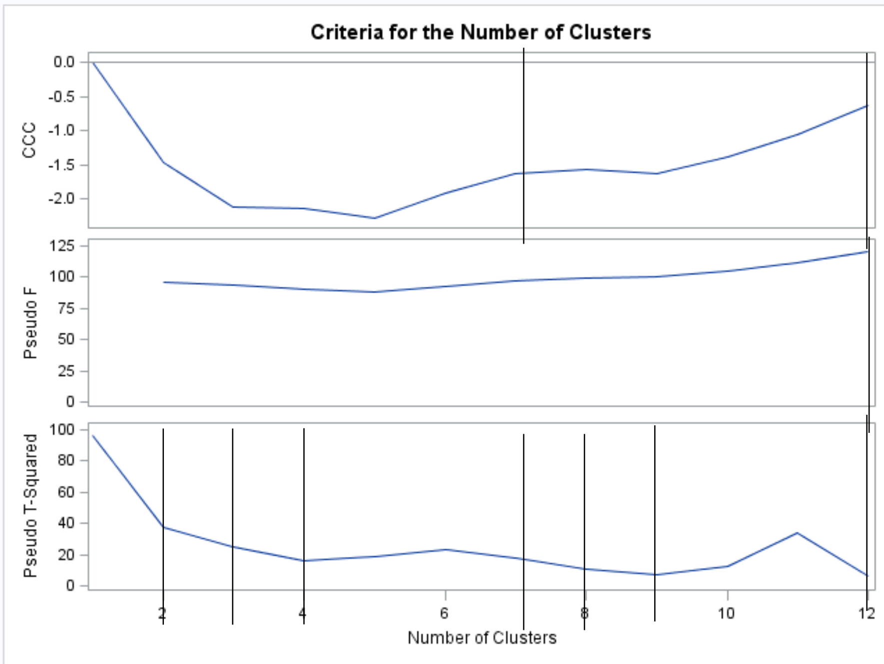
Clusters used: 3, 6, and 10

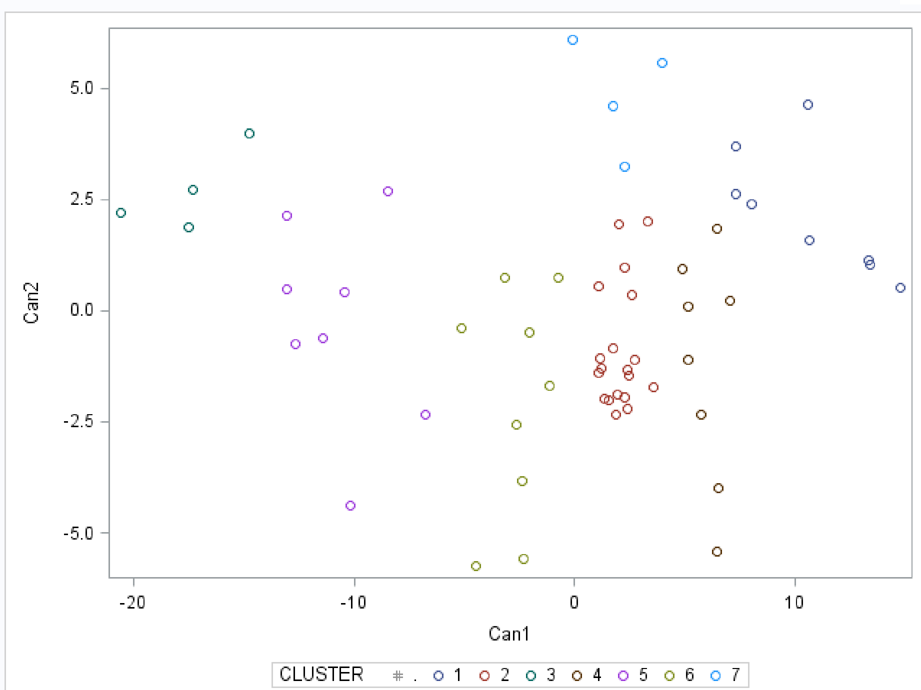




BLADE CLUSTERS

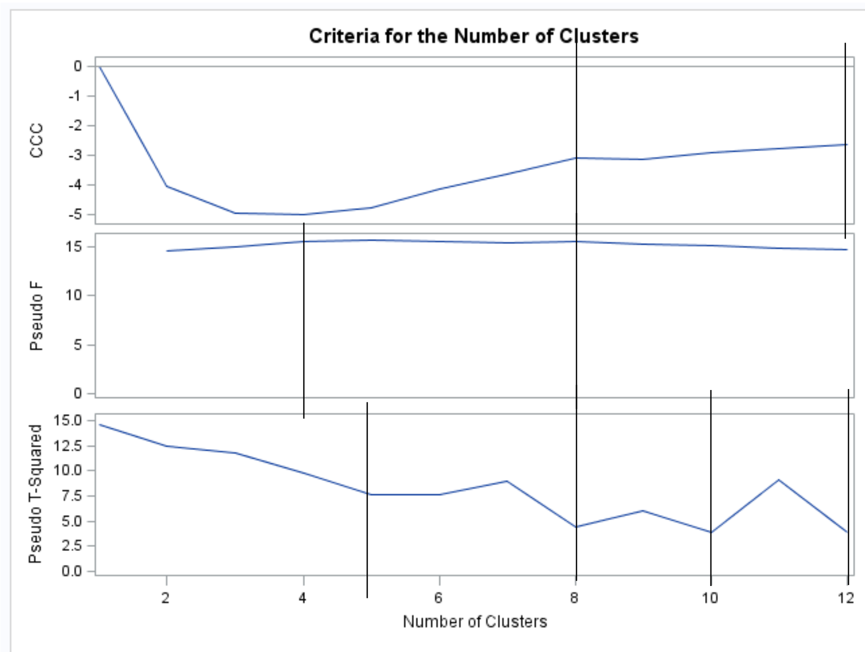
Cluster used: 7
Outliers: 9.005, 9.015, 11.005, 15.490, and 9.175

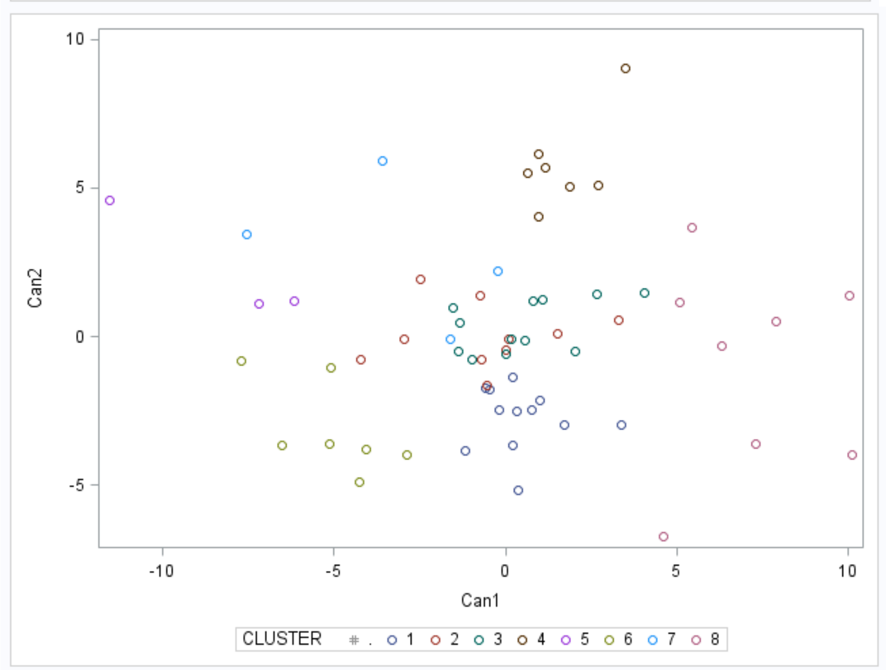




CROSS SECTION CLUSTERS

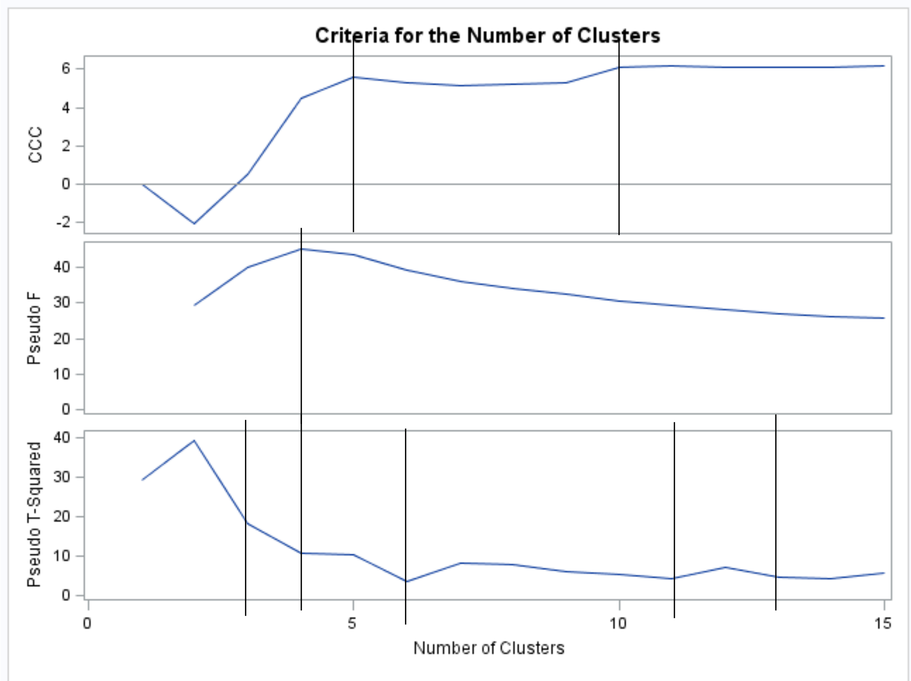
Clusters used: 8 and 12

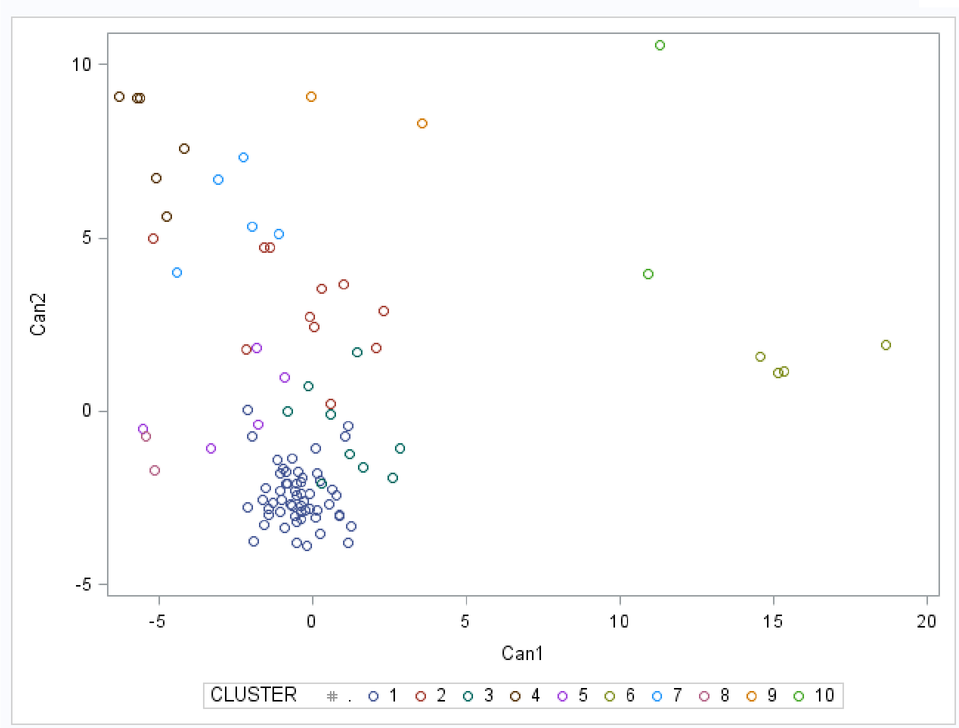




HILT CLUSTERS

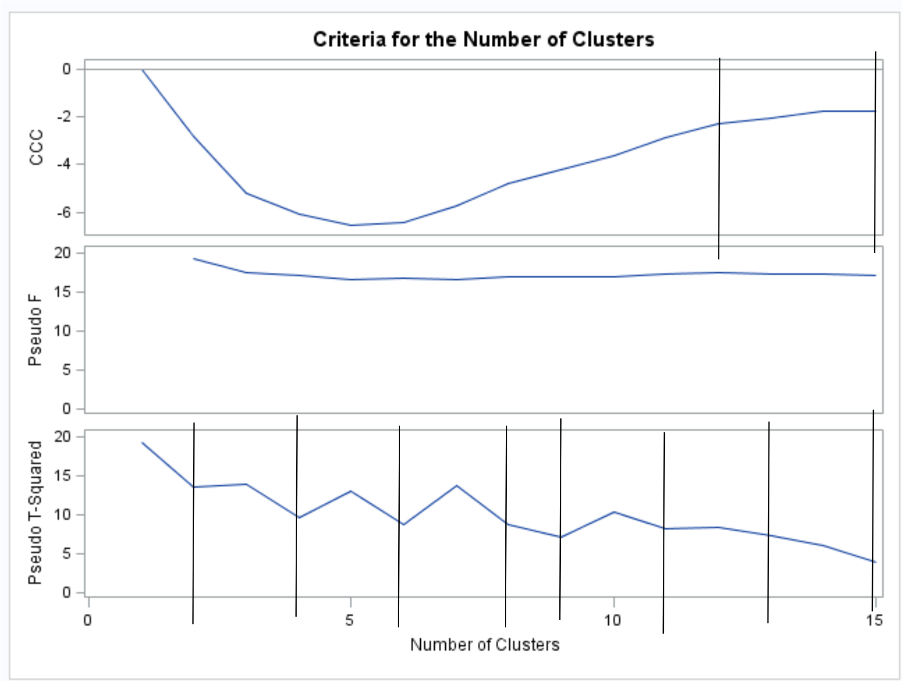
Clusters used: 6 and 10
Outliers: 9.232 and 9.006

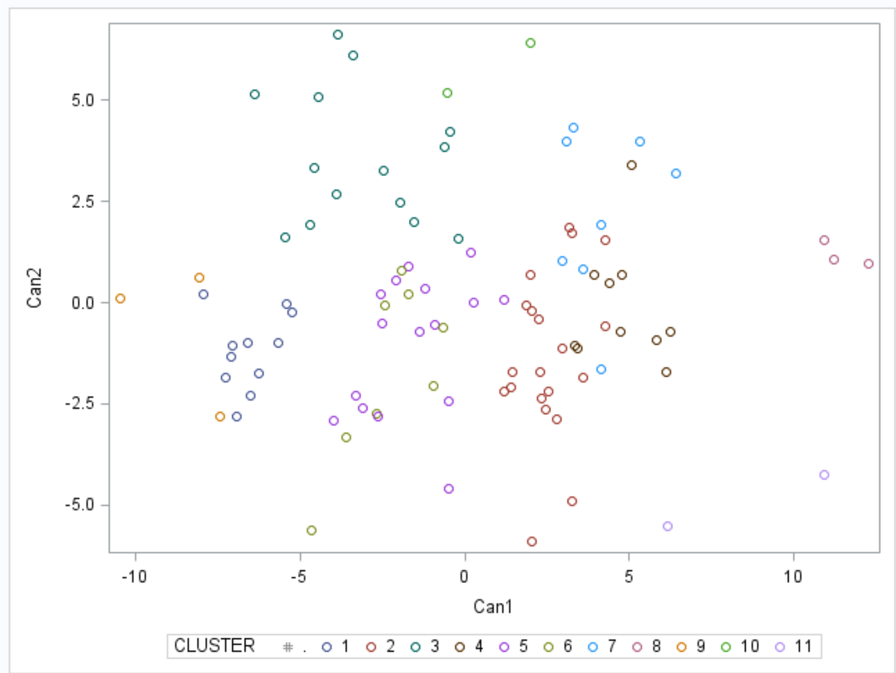




RIVET CLUSTERS

Clusters used: 11
Outliers: 17.186





MATRICES FOR MINIMUM SPANNING TREES

The matrices that follow were used to create minimum spanning trees between groups. See Chapter 9 for more details.

BY CATEGORY

Difference in Means Count					
	Achtkant-schwerter	*Driewulst-schwerter*	*Moerigen-schwerter*	*Riegseeschwerter-schwerter*	*Schalenknauf-schwerter*
Achtkant-schwerter	0				
Driewulst-schwerter	7	0			
Mörigen-schwerter	4	4	0		
Riegseeschwerter-schwerter	5	6	3	0	
Schalenknauf-schwerter	8	10	7	7	0

Weighted Matrix					
	Achtkant-schwerter	*Driewulst-schwerter*	*Moerigen-schwerter*	*Riegseeschwerter-schwerter*	*Schalenknauf-schwerter*
Achtkant-schwerter	0				
Driewulst-schwerter	2.139017	0			
Mörigen-schwerter	1.088844	0.870197	0		
Riegseeschwerter-schwerter	1.434397	1.913983	1.304093	0	
Schalenknauf-schwerter	1.65439	2.84987	1.110226	1.941732	0

6 LOCATION CLUSTERS

Difference in Means Count						
	Loc1	Loc2	Loc3	Loc4	Loc5	Loc6
Loc1	0					
Loc2	2	0				
Loc3	2	2	0			
Loc4	2	4	1	0		
Loc5	2	2	1	1	0	
Loc6	0	0	2	2	1	0

Weighted Matrix						
	Loc1	Loc2	Loc3	Loc4	Loc5	Loc6
Loc1	0					
Loc2	0.29879	0				
Loc3	0.3346	0.14179	0			
Loc4	0.85652	0.6751	0.62479	0		
Loc5	0.91938	0.74165	0.62254	0.99309	0	
Loc6	1.24066	1.12047	0.36613	0.66047	0.73241	0

12 BLADE CLUSTERS

Difference in Means Count												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0											
B2	2	0										
B3	0	0	0									
B4	0	2	0	0								
B5	1	3	1	1	0							
B6	0	2	0	0	1	0						
B7	0	2	0	0	1	0	0					
B8	0	0	0	0	1	0	0	0				
B9	2	0	0	0	1	0	2	0	0			
B10	0	0	0	0	1	0	0	0	0	0		
B11	0	0	0	0	1	0	0	0	0	0	0	
B12	0	0	0	0	0	0	0	0	0	0	0	0

Weighted Matrix												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	0.000											
B2	0.144	0.000										
B3	0.119	0.163	0.000									
B4	0.277	0.316	0.165	0.000								
B5	0.737	0.757	0.619	0.338	0.000							
B6	0.378	0.397	0.278	0.436	0.392	0.000						
B7	0.218	0.243	0.127	0.044	0.539	0.230	0.000					
B8	0.105	0.069	0.114	0.130	0.688	0.348	0.175	0.000				
B9	0.236	0.279	0.163	0.288	0.659	0.294	0.172	0.242	0.000			
B10	0.332	0.296	0.220	0.121	0.470	0.101	0.161	0.255	0.228	0.000		
B11	0.185	0.239	0.089	0.097	0.558	0.192	0.054	0.190	0.120	0.146	0.000	
B12	0.154	0.071	0.184	0.314	0.451	0.668	0.215	0.065	0.300	0.319	0.250	0.000

10 HILT CLUSTERS

Difference in Means Count										
	Hilt1	Hilt2	Hilt3	Hilt4	Hilt5	Hilt6	Hilt7	Hilt8	Hilt9	Hilt10
Hilt1	0									
Hilt2	0	0								
Hilt3	0	0	0							
Hilt4	2	1	0	0						
Hilt5	0	0	0	0	0					
Hilt6	1	1	1	1	1	0				
Hilt7	1	1	0	0	0	1	0			
Hilt8	3	3	3	2	3	1	2	0		
Hilt9	0	0	1	1	0	0	1	1	0	
Hilt10	0	0	0	0	0	0	0	0	0	0

Weighted Matrix										
	Hilt1	Hilt2	Hilt3	Hilt4	Hilt5	Hilt6	Hilt7	Hilt8	Hilt9	Hilt10
Hilt1	0.0000									
Hilt2	0.1470	0.0000								
Hilt3	0.3294	0.2623	0.0000							
Hilt4	0.6392	0.5648	0.3713	0.0000						
Hilt5	0.1304	0.2579	0.3644	0.6572	0.0000					
Hilt6	0.7229	0.7307	0.9573	1.0970	0.8529	0.0000				
Hilt7	0.2169	0.1852	0.2322	0.4553	0.2519	0.8272	0.0000			
Hilt8	1.8573	1.8210	1.9169	1.8360	1.8973	1.2295	1.8771	0.0000		
Hilt9	0.7024	0.6930	0.5820	0.6450	0.7561	0.7806	0.7543	1.5356	0.0000	
Hilt10	0.1864	0.1279	0.0385	0.1603	0.1708	0.2144	0.1452	0.0000	0.1903	0.0000

CHI-SQUARED CHARTS BY STYLE

Not every blade has the necessary morphology to be used each cluster analysis or has a known find type. Therefore, there is a list of missing values at the bottom of each frequency chart. This number indicates the number of blades not used in the calculation, as the SAS procedure does not include items with missing values by default. Most of the chi-squared tables contain cells with structural zeroes. For this reason, the chi-squared tests are taken to be an indication of correlation. An expansion of data to include more swords so that the tables include no structural zeroes is needed to confirm correlation using chi-squared tests.

Table of Style by Find

Frequency Percent Row Pct Col Pct	Find					
Style	single	river	hoard	other	Cremat	Total
Dreiwulstschwerter	3 4.62 14.29 27.27	7 10.77 33.33 33.33	2 3.08 9.52 13.33	5 7.69 23.81 71.43	4 6.15 19.05 36.36	21 32.31
Riegsee	0 0.00 0.00 0.00	4 6.15 57.14 19.05	2 3.08 28.57 13.33	0 0.00 0.00 0.00	1 1.54 14.29 9.09	7 10.77
Schalenknaufschwer	5 7.69 27.78 45.45	4 6.15 22.22 19.05	6 9.23 33.33 40.00	2 3.08 11.11 28.57	1 1.54 5.56 9.09	18 27.69
Achtkantschwerter	3 4.62 23.08 27.27	6 9.23 46.15 28.57	0 0.00 0.00 0.00	0 0.00 0.00 0.00	4 6.15 30.77 36.36	13 20.00
MÃ¶rigenschwerter Mörigenschwert er	0 0.00 0.00 0.00	0 0.00 0.00 0.00	5 7.69 83.33 33.33	0 0.00 0.00 0.00	1 1.54 16.67 9.09	6 9.23
Total	11 16.92	21 32.31	15 23.08	7 10.77	11 16.92	65 100.00
Frequency Missing = 46						

Frequency
Expected
Cell Chi-Square
Percent

Table of BladesCluster12 by Style

BladesCluster12	Style: Dreiwulstschwerter	Riegsee	Schalenknaufschwer	Achtkantschwerter	Mörigenschwerter	Total
6	2 1.3333 0.3333 3.70	1 0.4444 0.6944 1.85	0 0.8148 0.8148 0.00	1 0.963 0.0014 1.85	0 0.4444 0.4444 0.00	4 7.41
2	6 4.3333 0.641 11.11	1 1.4444 0.1368 1.85	0 2.6481 2.6481 0.00	2 3.1296 0.4077 3.70	4 1.4444 4.5214 7.41	13 24.07
4	0 1.3333 1.3333 0.00	2 0.4444 5.4444 3.70	0 0.8148 0.8148 0.00	2 0.963 1.1168 3.70	0 0.4444 0.4444 0.00	4 7.41
11	2 1.6667 0.0667 3.70	0 0.5556 0.5556 0.00	2 1.0185 0.9458 3.70	1 1.2037 0.0345 1.85	0 0.5556 0.5556 0.00	5 9.26
5	1 1.3333 0.0833 1.85	0 0.4444 0.4444 0.00	2 0.8148 1.7239 3.70	0 0.963 0.963 0.00	1 0.4444 0.6944 1.85	4 7.41
8	4 1.3333 5.3333 7.41	0 0.4444 0.4444 0.00	0 0.8148 0.8148 0.00	0 0.963 0.963 0.00	0 0.4444 0.4444 0.00	4 7.41
7	0 2 2 0.00	0 0.6667 0.6667 0.00	6 1.2222 18.677 11.11	0 1.4444 1.4444 0.00	0 0.6667 0.6667 0.00	6 11.11
1	0 1 1 0.00	1 0.3333 1.3333 1.85	0 0.6111 0.6111 0.00	2 0.7222 2.2607 3.70	0 0.3333 0.3333 0.00	3 5.56
10	1 1 0 1.85	0 0.3333 0.3333 0.00	0 0.6111 0.6111 0.00	1 0.7222 0.1068 1.85	1 0.3333 1.3333 1.85	3 5.56
12	1 0.6667 0.1667 1.85	1 0.2222 2.7222 1.85	0 0.4074 0.4074 0.00	0 0.4815 0.4815 0.00	0 0.2222 0.2222 0.00	2 3.70
3	0 1.3333 1.3333 0.00	0 0.4444 0.4444 0.00	1 0.8148 0.0421 1.85	3 0.963 4.3091 5.56	0 0.4444 0.4444 0.00	4 7.41
9	1 0.6667 0.1667 1.85	0 0.2222 0.2222 0.00	0 0.4074 0.4074 0.00	1 0.4815 0.5584 1.85	0 0.2222 0.2222 0.00	2 3.70
Total	18 33.33	6 11.11	11 20.37	13 24.07	6 11.11	54 100.00

Frequency Missing = 57

Frequency Expected Cell Chi-Square Percent						

Table of HiltCluster10 by Style

HiltCluster10	Style: Dreiwulstschwerter	Riegsee	Schalenknaufschwer	Achtkantschwerter	Mörigenschwerter	Total
3	2 2.6582 0.163 2.53	0 0.6076 0.6076 0.00	1 1.2152 0.0381 1.27	2 1.1392 0.6504 2.53	1 0.3797 1.0131 1.27	6 7.59
1	30 22.152 2.7805 37.97	7 5.0633 0.7408 8.86	2 10.127 6.5216 2.53	11 9.4937 0.239 13.92	0 3.1646 3.1646 0.00	50 63.29
5	0 1.7722 1.7722 0.00	0 0.4051 0.4051 0.00	4 0.8101 12.56 5.06	0 0.7595 0.7595 0.00	0 0.2532 0.2532 0.00	4 5.06
4	0 1.7722 1.7722 0.00	0 0.4051 0.4051 0.00	4 0.8101 12.56 5.06	0 0.7595 0.7595 0.00	0 0.2532 0.2532 0.00	4 5.06
9	0 0 . 0.00	0 0 . 0.00	0 0 . 0.00	0 0 . 0.00	0 0 . 0.00	0 0.00
2	2 2.2152 0.0209 2.53	0 0.5063 0.5063 0.00	1 1.0127 0.0002 1.27	2 0.9494 1.1627 2.53	0 0.3165 0.3165 0.00	5 6.33
7	0 2.2152 2.2152 0.00	1 0.5063 0.4813 1.27	4 1.0127 8.8127 5.06	0 0.9494 0.9494 0.00	0 0.3165 0.3165 0.00	5 6.33
6	0 1.3291 1.3291 0.00	0 0.3038 0.3038 0.00	0 0.6076 0.6076 0.00	0 0.5696 0.5696 0.00	3 0.1899 41.59 3.80	3 3.80
8	1 0.443 0.7002 1.27	0 0.1013 0.1013 0.00	0 0.2025 0.2025 0.00	0 0.1899 0.1899 0.00	0 0.0633 0.0633 0.00	1 1.27
10	0 0.443 0.443 0.00	0 0.1013 0.1013 0.00	0 0.2025 0.2025 0.00	0 0.1899 0.1899 0.00	1 0.0633 13.863 1.27	1 1.27
Total	35 44.30	8 10.13	16 20.25	15 18.99	5 6.33	79 100.00

Frequency Missing = 32

Frequency Expected Cell Chi-Square Percent

Table of LocCluster6 by Style

	Style					
LocCluster6	Dreiwulstschwerter	Riegsee	Schalenknaufschwer	Achtkantschwerter	Mörigenschwerter	Total
1	3 5.4795 1.122 4.11	3 1.9726 0.5351 4.11	10 3.9452 9.2924 13.70	0 3.2877 3.2877 0.00	0 1.3151 1.3151 0.00	16 21.92
4	0 1.7123 1.7123 0.00	0 0.6164 0.6164 0.00	0 1.2329 1.2329 0.00	0 1.0274 1.0274 0.00	5 0.411 51.244 6.85	5 6.85
2	15 11.644 0.9674 20.55	4 4.1918 0.0088 5.48	6 8.3836 0.6777 8.22	9 6.9863 0.5804 12.33	0 2.7945 2.7945 0.00	34 46.58
3	4 4.4521 0.0459 5.48	2 1.6027 0.0985 2.74	1 3.2055 1.5174 1.37	6 2.6712 4.1482 8.22	0 1.0685 1.0685 0.00	13 17.81
6	2 1.3699 0.2899 2.74	0 0.4932 0.4932 0.00	1 0.9863 0.0002 1.37	0 0.8219 0.8219 0.00	1 0.3288 1.3704 1.37	4 5.48
5	1 0.3425 1.2625 1.37	0 0.1233 0.1233 0.00	0 0.2466 0.2466 0.00	0 0.2055 0.2055 0.00	0 0.0822 0.0822 0.00	1 1.37
Total	25 34.25	9 12.33	18 24.66	15 20.55	6 8.22	73 100.00

Frequency Missing = 38

Chi-Squared Charts by Find type

Frequency Expected Cell Chi-Square Percent

Table of HiltCluster10 by Find

HiltCluster10	Find: single	river	hoard	other	Cremat	Total
3	0 0.942 0.942 0.00	1 1.6667 0.2667 1.45	1 0.942 0.0036 1.45	0 0.5072 0.5072 0.00	3 0.942 4.4959 4.35	5 7.25
1	5 6.5942 0.3854 7.25	16 11.667 1.6095 23.19	4 6.5942 1.0206 5.80	4 3.5507 0.0568 5.80	6 6.5942 0.0535 8.70	35 50.72
5	0 0.7536 0.7536 0.00	1 1.3333 0.0833 1.45	2 0.7536 2.0613 2.90	1 0.4058 0.8701 1.45	0 0.7536 0.7536 0.00	4 5.80
4	4 0.942 9.9266 5.80	1 1.6667 0.2667 1.45	0 0.942 0.942 0.00	0 0.5072 0.5072 0.00	0 0.942 0.942 0.00	5 7.25
9	1 0.1884 3.4961 1.45	0 0.3333 0.3333 0.00	0 0.1884 0.1884 0.00	0 0.1014 0.1014 0.00	0 0.1884 0.1884 0.00	1 1.45
2	2 1.8841 0.0071 2.90	1 3.3333 1.6333 1.45	1 1.8841 0.4148 1.45	2 1.0145 0.9573 2.90	4 1.8841 2.3764 5.80	10 14.49
7	1 0.5652 0.3344 1.45	2 1 1 2.90	0 0.5652 0.5652 0.00	0 0.3043 0.3043 0.00	0 0.5652 0.5652 0.00	3 4.35
6	0 0.5652 0.5652 0.00	0 1 1 0.00	3 0.5652 10.488 4.35	0 0.3043 0.3043 0.00	0 0.5652 0.5652 0.00	3 4.35
8	0 0.1884 0.1884 0.00	1 0.3333 1.3333 1.45	0 0.1884 0.1884 0.00	0 0.1014 0.1014 0.00	0 0.1884 0.1884 0.00	1 1.45
10	0 0.3768 0.3768 0.00	0 0.6667 0.6667 0.00	2 0.3768 6.9922 2.90	0 0.2029 0.2029 0.00	0 0.3768 0.3768 0.00	2 2.90
Total	13 18.84	23 33.33	13 18.84	7 10.14	13 18.84	69 100.00

Frequency Missing = 42

Frequency Expected Cell Chi-Square Percent

Table of LocCluster6 by Find

LocCluster6	Find: single	river	hoard	other	Cremat	Total
1	9 3.7013 7.5855 11.69	1 5.6753 3.8515 1.30	8 4.1948 3.4518 10.39	1 1.974 0.4806 1.30	0 3.4545 3.4545 0.00	19 24.68
4	0 1.1688 1.1688 0.00	0 1.7922 1.7922 0.00	6 1.3247 16.501 7.79	0 0.6234 0.6234 0.00	0 1.0909 1.0909 0.00	6 7.79
2	5 6.039 0.1787 6.49	13 9.2597 1.5108 16.88	0 6.8442 6.8442 0.00	6 3.2208 2.3982 7.79	7 5.6364 0.3299 9.09	31 40.26
3	1 3.1169 1.4377 1.30	9 4.7792 3.7276 11.69	0 3.5325 3.5325 0.00	1 1.6623 0.2639 1.30	5 2.9091 1.5028 6.49	16 20.78
6	0 0.7792 0.7792 0.00	0 1.1948 1.1948 0.00	3 0.8831 5.0743 3.90	0 0.4156 0.4156 0.00	1 0.7273 0.1023 1.30	4 5.19
5	0 0.1948 0.1948 0.00	0 0.2987 0.2987 0.00	0 0.2208 0.2208 0.00	0 0.1039 0.1039 0.00	1 0.1818 3.6818 1.30	1 1.30
Total	15 19.48	23 29.87	17 22.08	8 10.39	14 18.18	77 100.00

Frequency Missing = 34

Appendix C: Software

CartoDB

Mapping

CartoDB is an online mapping software that uses databases. Most of the maps in this dissertation were made by importing a database containing sword identification, latitude and longitude, and the cluster groups. The database used for mapping can be found in the DRUM files.

David 3d Scanner Pro v4.3.5

Scanning and Scan Post Processing

David scanner was used to capture the 3D scans. It was also used for initial alignment and the final merge of scans.

Geomagic Design X build version 2015.2.0

Scan Post Processing

Geomagic was used to process the 3D models. Extraneous data and bad data were removed using the "find noisy clusters" and "remove edge" options in the Mesh buildup tool. Scans were aligned using the picked point alignment and global fine alignment options.

Gephi v0.8.2

Network Analysis

Gephi is an open source network analysis program. For this dissertation, it was used to create the network graphs shown in Chapter 11. Graphs that are shown superimposed over a map were compiled in Photoshop and include both the Gephi network using a geographical layout over a CartoDB map.

Photoshop CS5

Profile Preparation

Photoshop was used to prepare the 2D and 3D scans for Fourier transformation. Figures that were scanned or captured via screenshot were imported into Photoshop where non profile data were removed and the profiles were turned into a single closed shape. The shape was also filled in with black and the image turned into a black and white image and saved as a .bmp file, with only the profile remaining.

SAS™ v9.4

Statistical Analysis

The data analysis for this paper was generated using SAS software, Version 9.4 of the SAS System for Windows. Copyright © 2012 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. SAS software was used to perform the analyses described in Chapter 9. This includes the PCA of hilt Fourier transform variables, ACECLUS procedure to compute canonical variables for a CLUSTER analysis using Ward's minimum-variance method, ANOVA and MANOVAS, Chi-squared testing, and regression. Annotated SAS code for this dissertation, as well as the data analyzed, can be found on the DRUM site.

SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® indicates USA registration.

SHAPE version 1.3: ChainCoder, CHC2NEF, PrinComp

Fourier transforms

SHAPE was used to transform the images processed in Photoshop. Each profile was imported into ChainCoder and given a chain code, a numerical system for recording the shape. The chain codes were opened with CHC2NEF, where the Fourier transforms were calculated with 20 harmonics per profile. Principle components for the blade and cross section transforms were calculated using PrinComp. PrinComp also provides an average value based on the transforms. I used this functionality to input the clustered profile groups for an average of each profile cluster.

APPENDIX D: SWORD DATA SHEETS

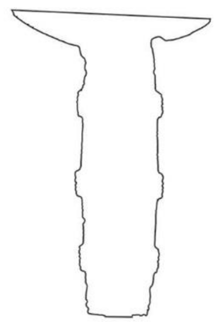
BLADE:0.001

Style: Vollgriffschwerter
Find Type: Unknown

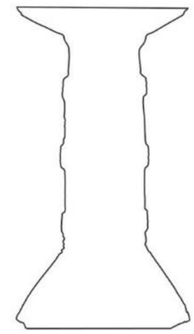
Museum: HNM
Accession #: 855/35.1

Lattitude: -
Longitude: -

Side Profile



Top Profile



Blade Profile

Cross Section

© Hungarian National Museum - Magyar Nemzeti Múzeum

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

4

BLADE: 0.002

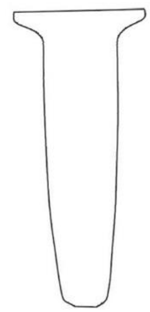
Style: Vollgriffschwerter
Find Type: Unknown

Museum: TL
Accession #: 1

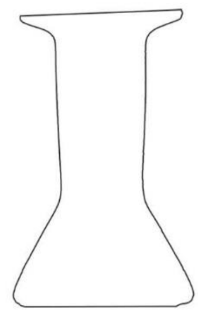
Lattitude: -
Longitude: -

© Tiroler Landesmuseen

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

3

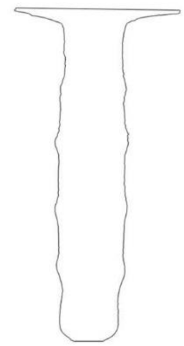
BLADE: 0.004

Style: Vollgriffschwerter
Find Type: Unknown

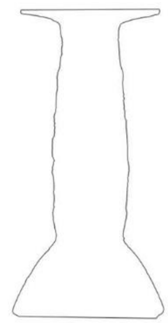
Museum: TL
Accession #: 18.262

Lattitude: -
Longitude: -

Side Profile



Top Profile



Blade Profile

Cross Section

© Tiroler Landesmuseen

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

BLADE: 0.006

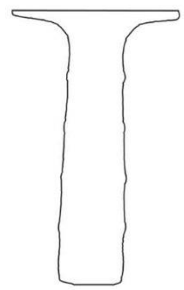
Style: Vollgriffschwerter
Find Type: Unknown

Museum: TL
Accession #: 19.302

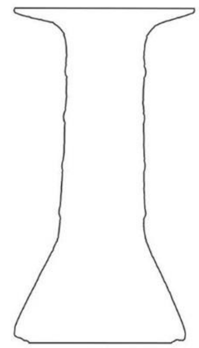
Lattitude: -
Longitude: -

© Tiroler Landesmuseen

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

4

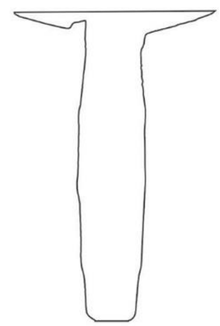
BLADE: 0.007

Style: Vollgriffschwerter
Find Type: Unknown

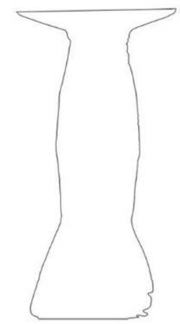
Museum: AMSE
Accession #: 6135

Lattitude: -
Longitude: -

Side Profile



Top Profile



Blade Profile

Cross Section

© Archaeology Musem Schloss Eggenberg

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

6

BLADE: 0.008

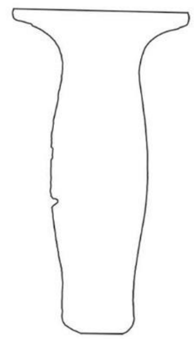
Style: Vollgriffschwerter
Find Type: Unknown

Museum: ASM
Accession #: 1897.191

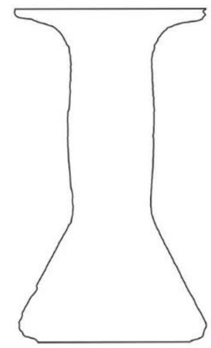
Lattitude: -
Longitude: -

© Archäologische Staatssammlung München, Museum für Vor-und Frühgeschichte

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

BLADE: 0.009

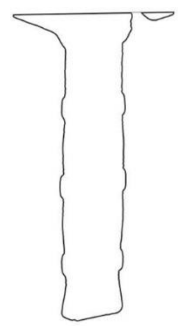
Style: Vollgriffschwerter
Find Type: Unknown

Museum: ASM
Accession #: 19,853,000

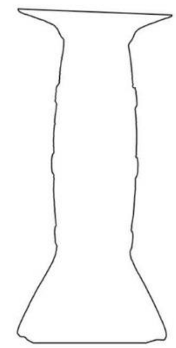
Lattitude: -
Longitude: -

© Archäologische Staatssammlung München, Museum für Vor-und Frühgeschichte

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

BLADE:0.001

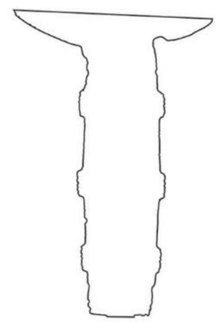
Style: Vollgriffschwerter
Find Type: Unknown

Museum: HNM
Accession #: 855/35.1

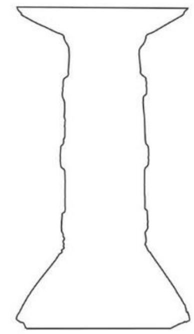
Lattitude: -
Longitude: -

© Hungarian National Museum - Magyar Nemzeti Múzeum

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

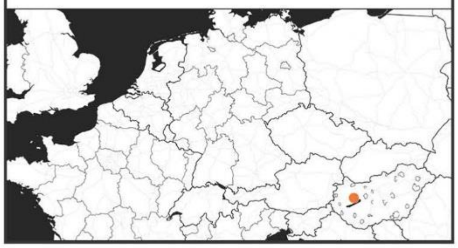
4

BLADE:9.005

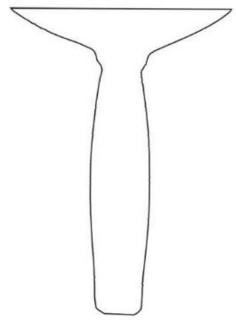
Style: Vollgriffschwerter
Find Type: Single

Museum: HNM
Accession #: 52.32.01

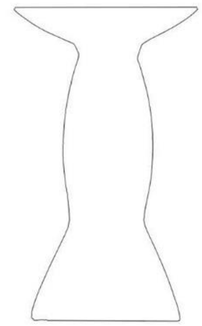
Lattitude: 47.114751
Longitude: 17.733144



Side Profile

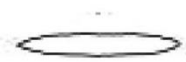


Top Profile



Blade Profile

Cross Section



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Loc. Cluster

8

Blade Cluster

-

Hilt Cluster

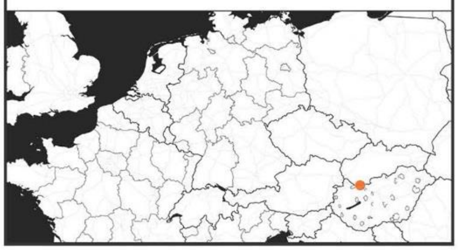
5

BLADE:9.006

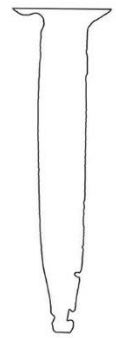
Style: Vollgriffschwerter
Find Type: Single

Museum: HNM
Accession #: 65/1892.3

Lattitude: 47.739085
Longitude: 18.126701



Side Profile



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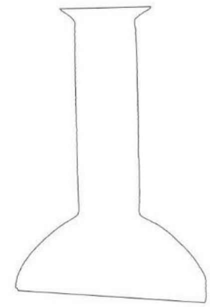

Blade Profile

Cross Section

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Loc. Cluster

8

Blade Cluster

-

Hilt Cluster

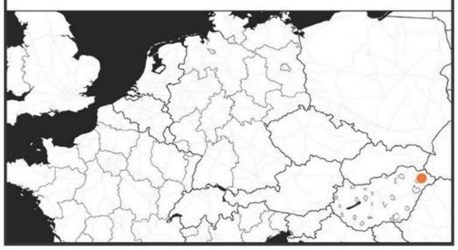
14

BLADE:9.015

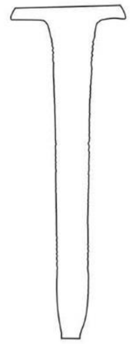
Style: Vollgriffschwerter
Find Type: Unknown

Museum: HNM
Accession #: 77/1857

Lattitude: 48.039495
Longitude: 22.00333



Side Profile



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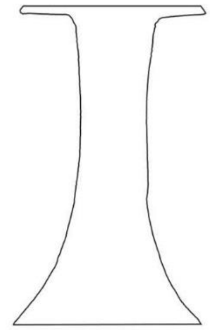
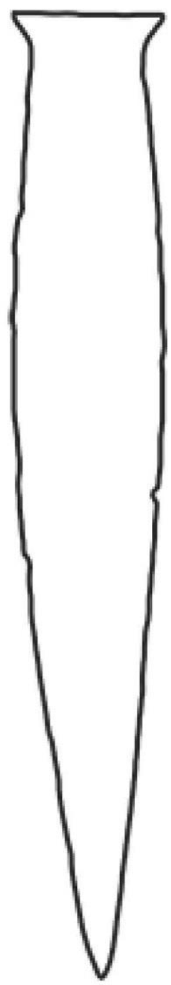


Blade Profile



Cross Section

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Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

12

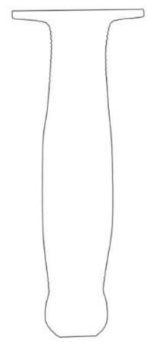
BLADE:9.019

Style: Vollgriffschwerter
Find Type: Unknown

Museum: HNM
Accession #: 52.29.748

Lattitude: -
Longitude: -

Side Profile



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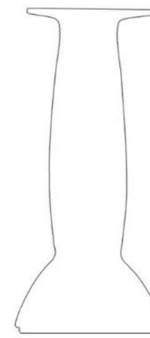

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Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

BLADE:9.026

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 76/1886

Lattitude: -
Longitude: -

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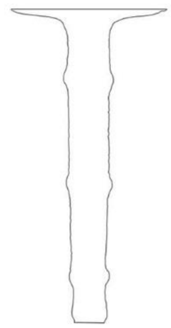
Side Profile



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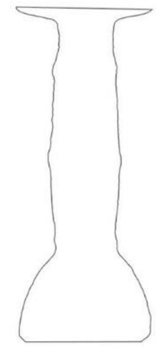


Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

4

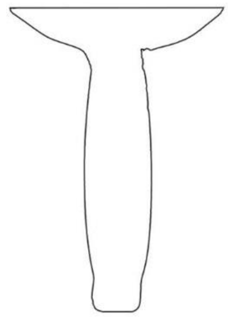
BLADE:9.027

Style: Scheibenknaufschwert
Find Type: Unknown

Museum: HNM
Accession #: 52.29.758

Lattitude: -
Longitude: -

Side Profile



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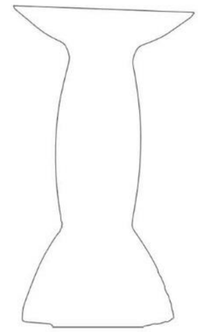
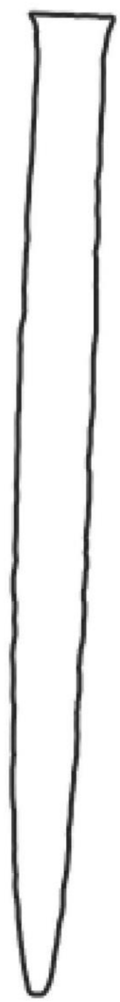


Blade Profile



Cross Section

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Loc. Cluster

-

Blade Cluster

4

Hilt Cluster

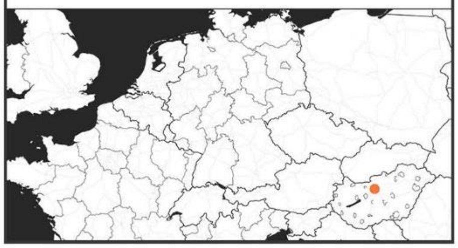
5

BLADE:9.061

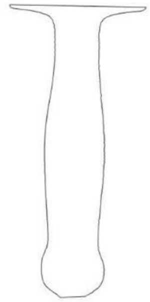
Style: Riegsee
Find Type: River

Museum: HNM
Accession #: 18.1893.2

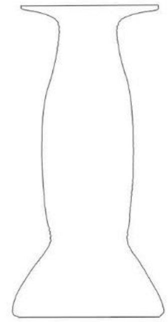
Lattitude: 47.497912
Longitude: 19.040235



Side Profile



Top Profile



Blade Profile

Cross Section

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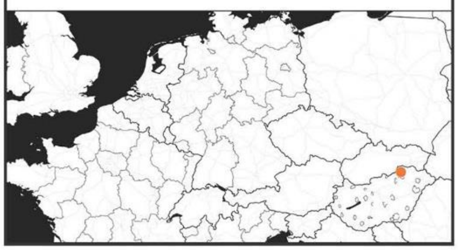
Loc. Cluster
8
Blade Cluster
1
Hilt Cluster
2

BLADE:9.062

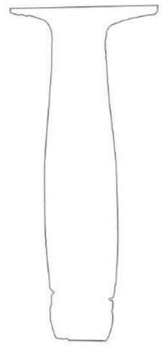
Style: Riegsee
Find Type: Hoard

Museum: HNM
Accession #: 43/1895.5

Lattitude: 48.29394
Longitude: 20.693411



Side Profile



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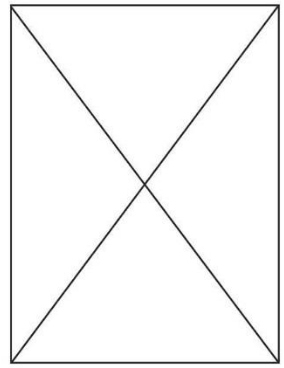

Blade Profile

Cross Section

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Loc. Cluster

1

Blade Cluster

4

Hilt Cluster

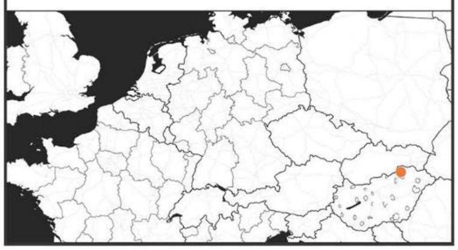
-

BLADE:9.067

Style: Riegsee
Find Type: Hoard

Museum: HNM
Accession #: 60/1903

Lattitude: 48.29394
Longitude: 20.693411



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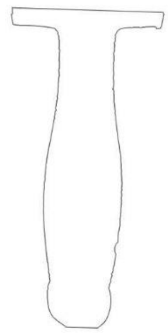
Side Profile



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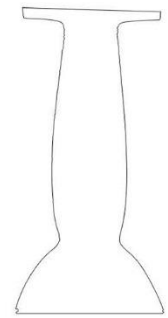


Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

4

Hilt Cluster

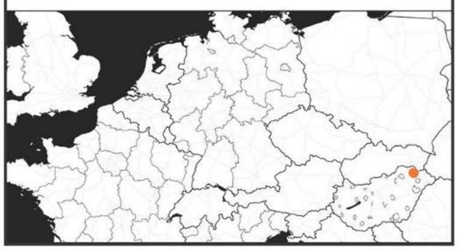
2

BLADE:9.076

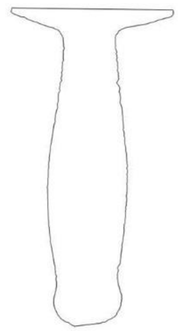
Style: Regály
Find Type: Hoard

Museum: HNM
Accession #: 74.6.2

Lattitude: 48.261371
Longitude: 21.497196



Side Profile



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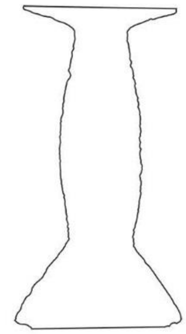

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Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

4

Hilt Cluster

2

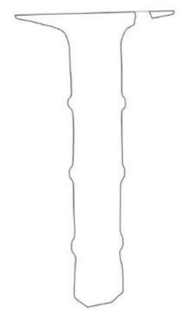
BLADE:9.079

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #:39.1917.1

Lattitude: -
Longitude: -

Side Profile



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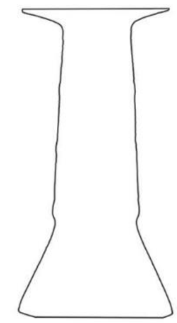

Blade Profile

Cross Section

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Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

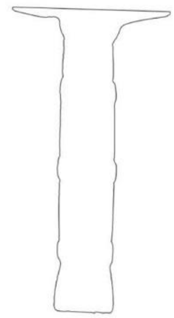
BLADE:9.113

Style: Dreiwulstschwerter
Find Type: Unknown

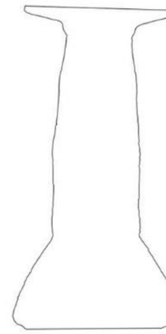
Museum: HNM
Accession #:61.16.78

Lattitude: -
Longitude: -

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

-

Blade Cluster

3

Hilt Cluster

4

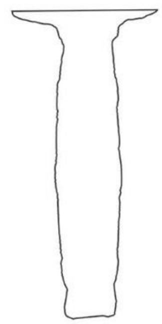
BLADE: 9.136

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 56/1879.1

Lattitude: -
Longitude: -

Side Profile



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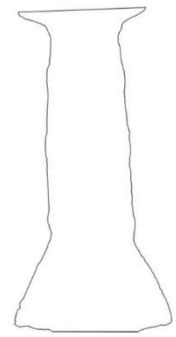

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Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

4

BLADE:9.145

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 62.43.65

Lattitude: -
Longitude: -

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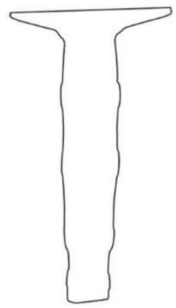
Side Profile



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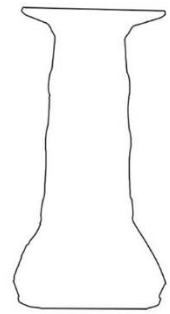

Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

3

Hilt Cluster

4

BLADE:9.15

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 50.1875.15

Lattitude: -
Longitude: -

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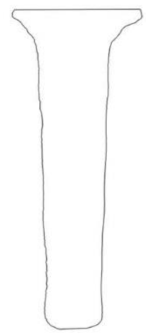
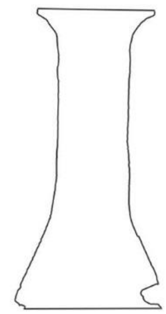
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

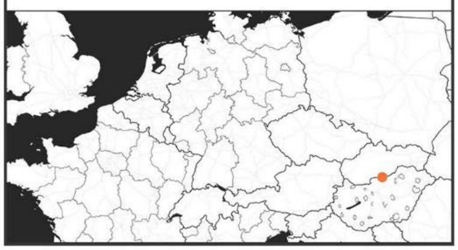
3

BLADE:9.16

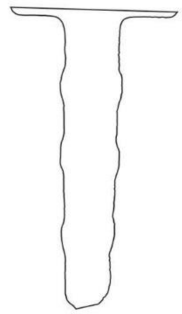
Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 81.187

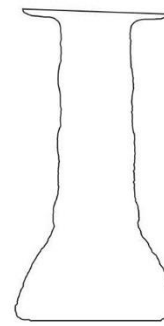
Lattitude: 48.080181
Longitude: 19.519965



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

4

BLADE:9.17

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 83.32.2

Lattitude: -
Longitude: -

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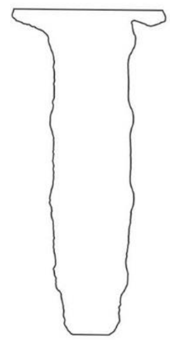
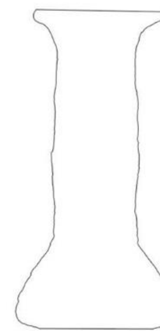
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

3

Hilt Cluster

4

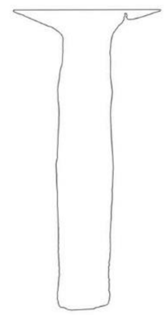
BLADE:9.174

Style: Dreiwulstschwerter
Find Type: Unknown

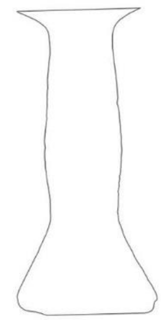
Museum: HNM
Accession #: 23/1883.2

Lattitude: -
Longitude: -

Side Profile



Top Profile



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Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

2

BLADE:9.175

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: HNM
Accession #: 62.3.225

Lattitude: -
Longitude: -

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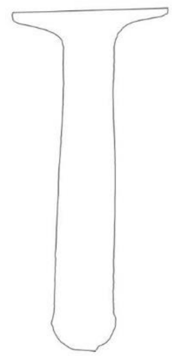
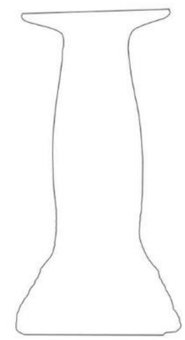
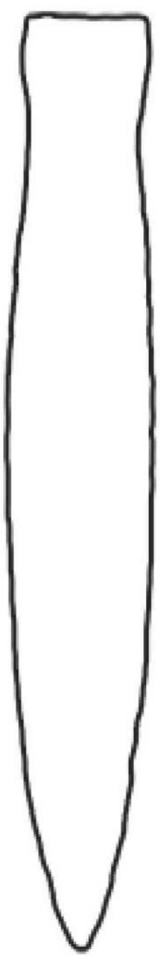
Side Profile



Top Profile



Blade Profile



Cross Section

Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

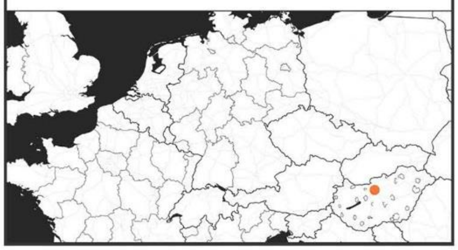
3

BLADE:9.199

Style: Schalenknaufschwerter
Find Type: Single

Museum: HNM
Accession #: 171/1874/4

Lattitude: 47.539438
Longitude: 19.038566



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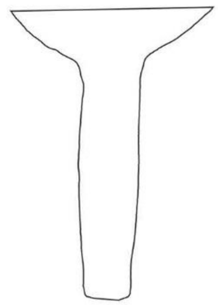
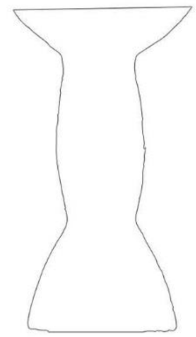
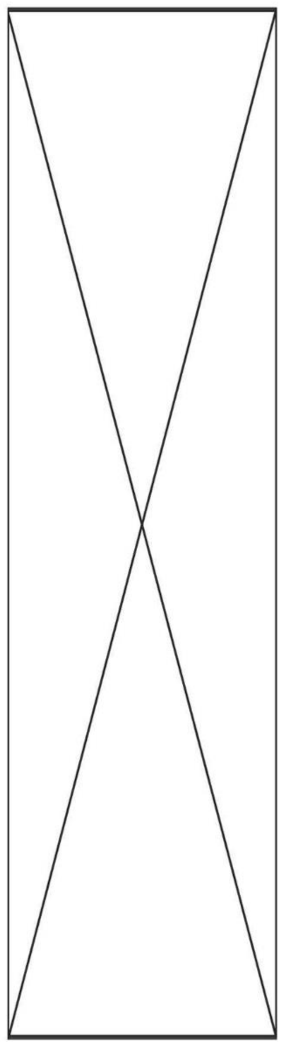
Side Profile



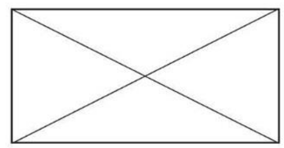
Top Profile



Blade Profile



Cross Section



Loc. Cluster

8

Blade Cluster

-

Hilt Cluster

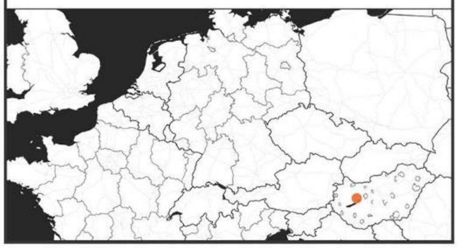
5

BLADE:9.201

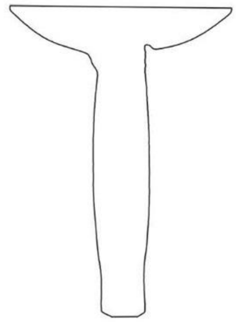
Style: Schalenknaufschwerter
Find Type: Single

Museum: HNM
Accession #: 60.1951.10

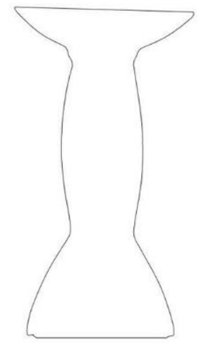
Lattitude: 47.102809
Longitude: 17.909302



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

8

Blade Cluster

6

Hilt Cluster

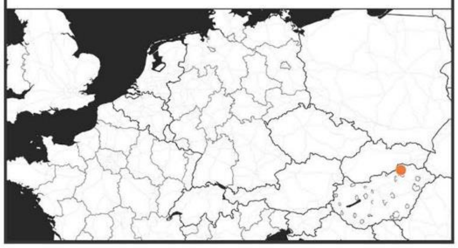
5

BLADE:9.202

Style: Schalenknaufschwerter
Find Type: Single

Museum: HNM
Accession #: 25_1944

Lattitude: 48.29394
Longitude: 20.693411



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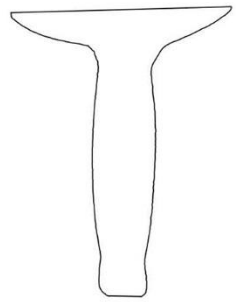
Side Profile



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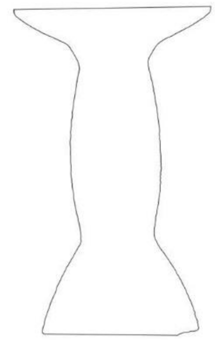


Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

8

Hilt Cluster

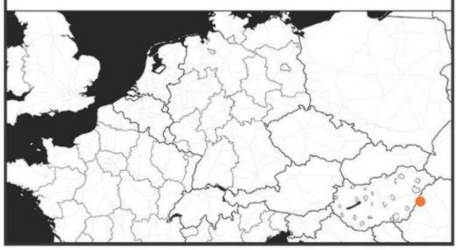
5

BLADE:9.206

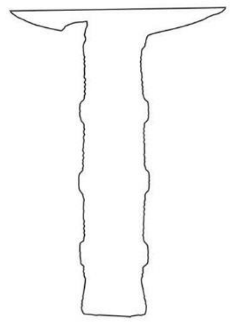
Style: Schalenknaufschwerter
Find Type: Hoard

Museum: HNM
Accession #: 91/1870.1

Lattitude: 47.046501
Longitude: 21.918944



Side Profile



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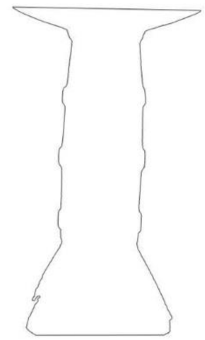
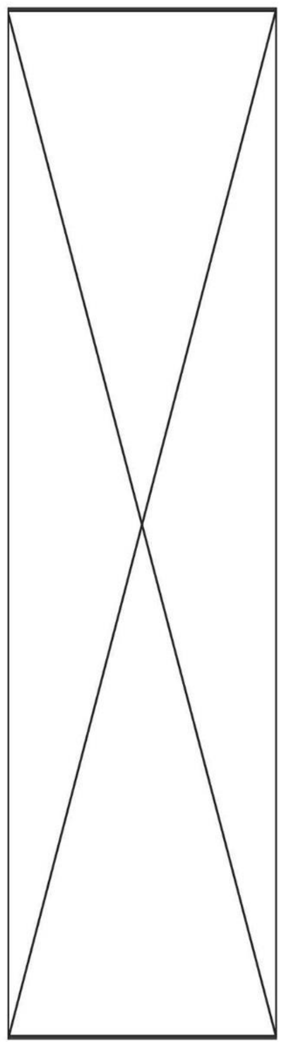


Blade Profile



Cross Section

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Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

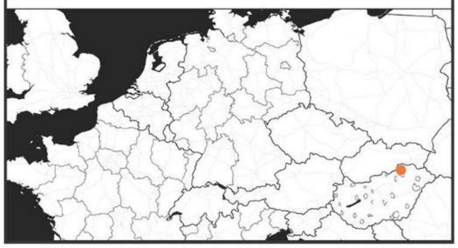
6

BLADE:9.207

Style: Schalenknaufschwerter
Find Type: Single

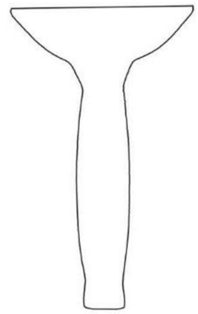
Museum: HNM
Accession #: 52.32.69

Lattitude: 48.29394
Longitude: 20.693411



© Hungarian National Museum - Magyar Nemzeti Múzeum

Side Profile



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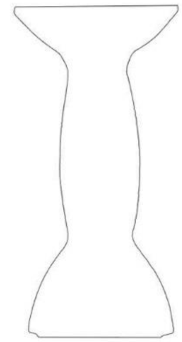
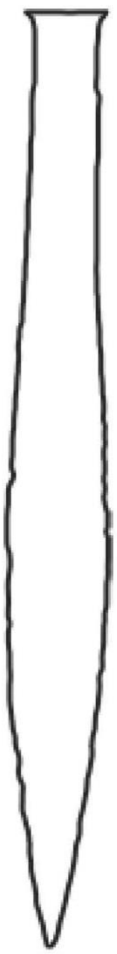


Blade Profile



Cross Section

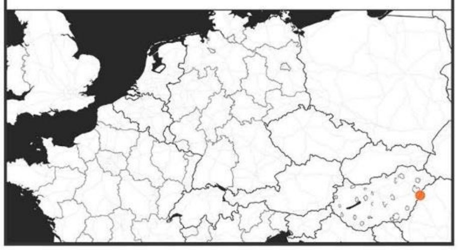
Loc. Cluster
1
Blade Cluster
8
Hilt Cluster
9

BLADE:9.211

Style: Schalenknaufschwerter
Find Type: Hoard

Museum: HNM
Accession #: 45/1983.2

Lattitude: 47.297489
Longitude: 21.9042505



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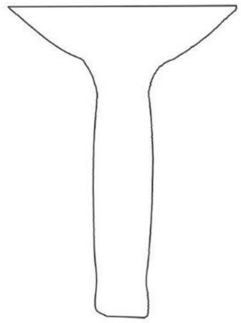
Side Profile



Top Profile

Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

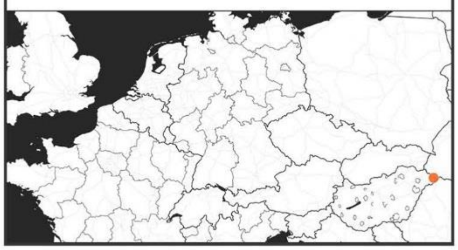
-

BLADE:9.223

Style: Schalenknaufschwerter
Find Type: Single

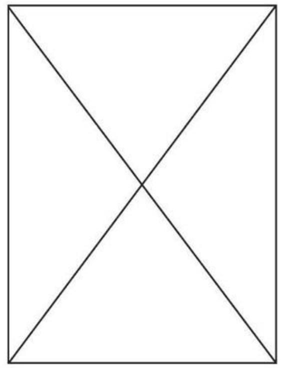
Museum: HNM
Accession #: 7.1891

Lattitude: 48.054104
Longitude: 22.748529



© Hungarian National Museum - Magyar Nemzeti Múzeum

Side Profile



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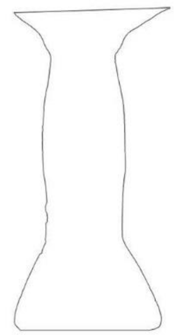


Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

7

Hilt Cluster

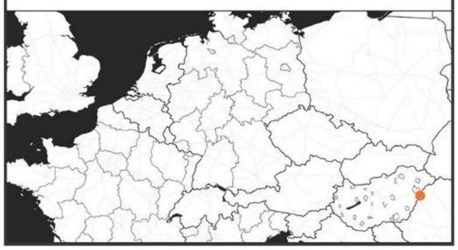
-

BLADE:9.232

Style: Schalenknaufschwerter
Find Type: Hoard

Museum: HNM
Accession #:45/1893.1

Lattitude: 47.297489
Longitude: 21.9042505



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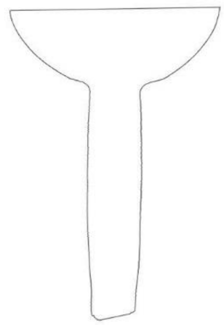
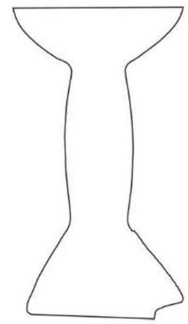
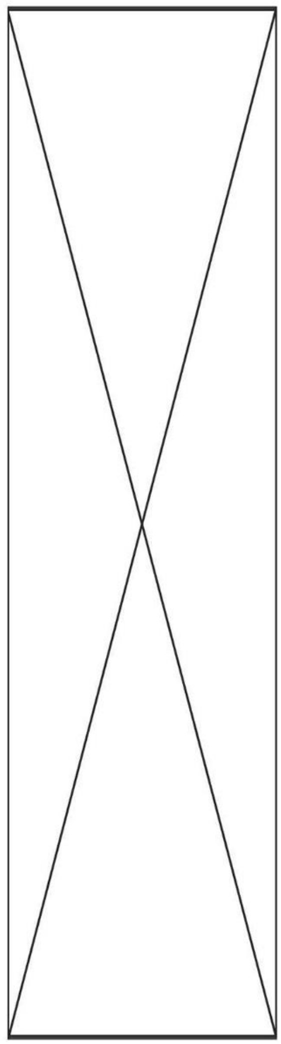
Side Profile



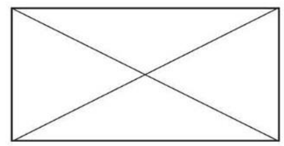
Top Profile



Blade Profile



Cross Section



Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

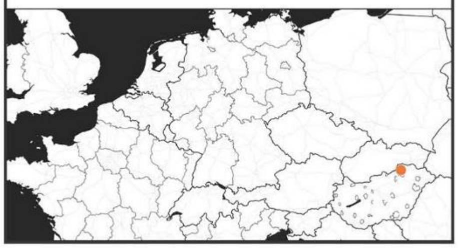
13

BLADE:9.234

Style: Schalenknaufschwerter
Find Type: Hoard

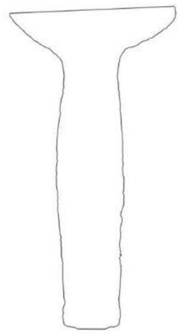
Museum: HNM
Accession #: 245/1875.1

Lattitude: 48.29394
Longitude: 20.693411

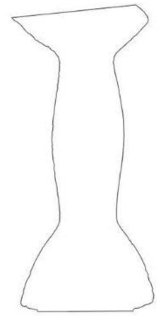


© Hungarian National Museum - Magyar Nemzeti Múzeum

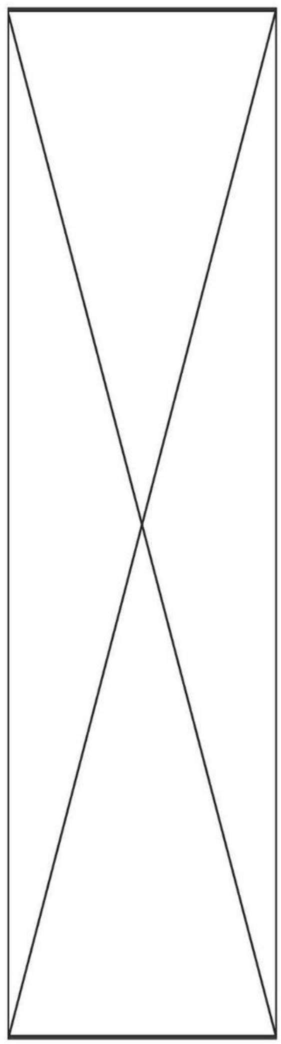
Side Profile



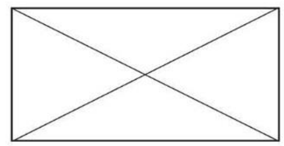
Top Profile



Blade Profile



Cross Section



Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

4

BLADE:9.235

Style: Schalenknaufschwerter
Find Type: Unknown

Museum: HNM
Accession #: 60.951.11

Lattitude: -
Longitude: -

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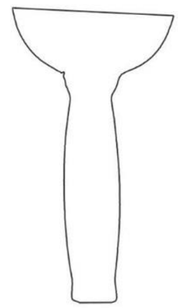
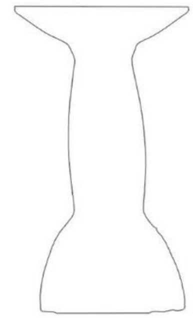
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

8

Hilt Cluster

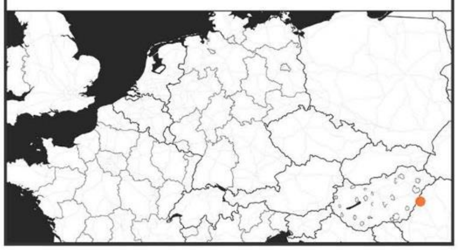
9

BLADE:9.244

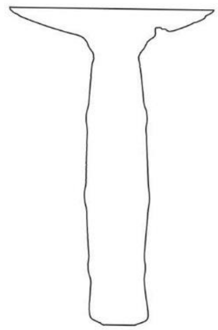
Style: Schalenknaufschwerter
Find Type: Hoard

Museum: HNM
Accession #: 91/1870.2

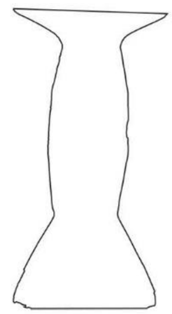
Lattitude: 47.046501
Longitude: 21.918944



Side Profile



Top Profile



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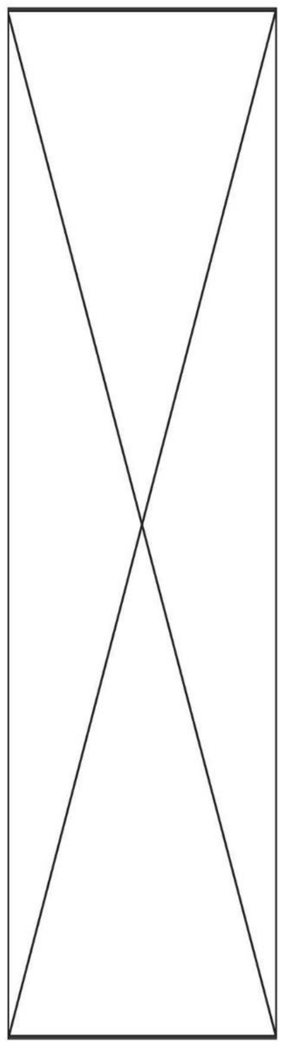
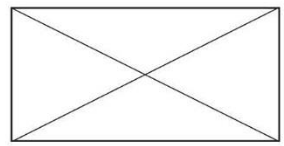
Blade Profile



Cross Section



Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

6

BLADE:9.249

Style: Schalenknaufschwerter
Find Type: Unknown

Museum: HNM
Accession #: 70.2.1

Lattitude: -
Longitude: -

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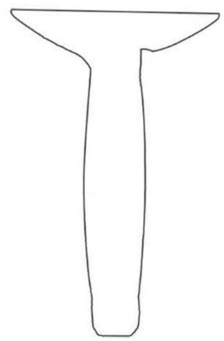
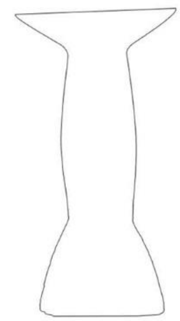
Side Profile



Top Profile



Blade Profile

Cross Section

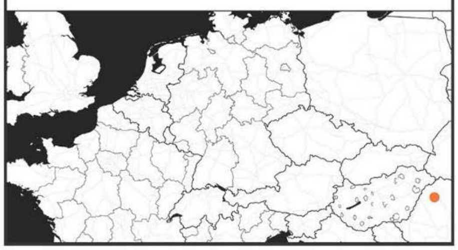
Loc. Cluster
-
Blade Cluster
3
Hilt Cluster
9

BLADE:9.49

Style: Vollgriffdolch
Find Type: Single

Museum: HNM
Accession #: 104/1889.2

Lattitude: 47.226073
Longitude: 22.803786



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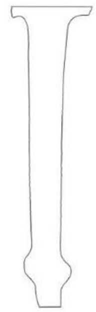
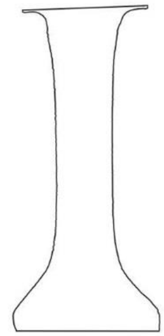
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

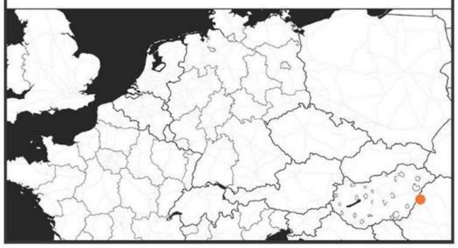
12

BLADE:9.523

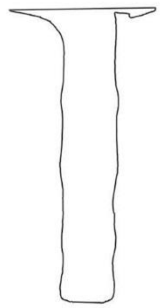
Style: Dreiwulstschwerter
Find Type: Single

Museum: HNM
Accession #: 62/1907

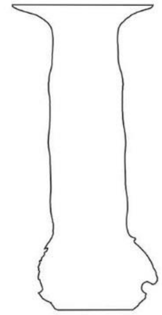
Lattitude: 47.046501
Longitude: 21.918944



Side Profile



Top Profile



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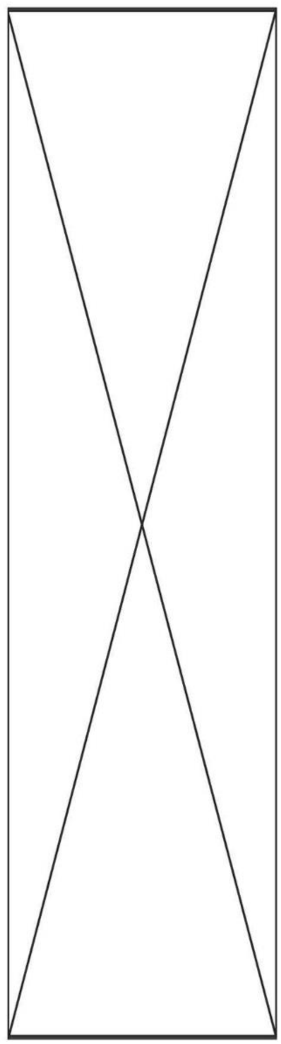
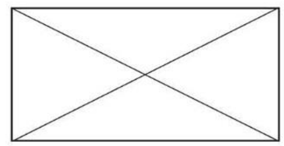
Blade Profile



Cross Section



Loc. Cluster

1

Blade Cluster

-

Hilt Cluster

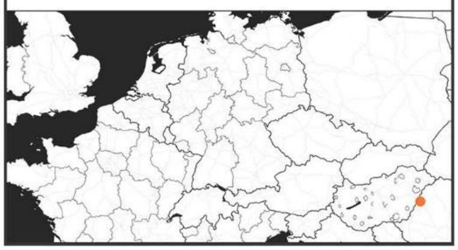
2

BLADE:9.524

Style: Scheibenknaufschwert
Find Type: Unknown

Museum: HNM
Accession #: 1.1907.34

Lattitude: 52.248287
Longitude: 10.912878



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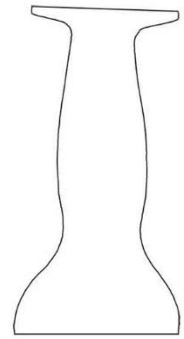
Side Profile

Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

-

Hilt Cluster

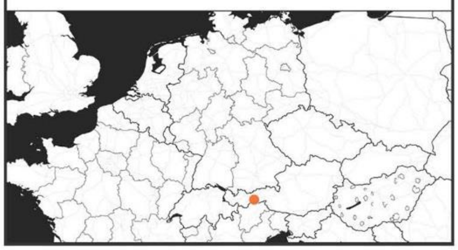
3

BLADE: 10.003

Style: Vollgriffschwerter
Find Type: Other

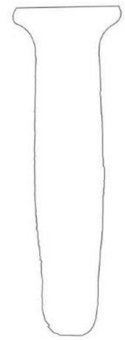
Museum: TL
Accession #: 8.934

Lattitude: 47.125662
Longitude: 11.452127

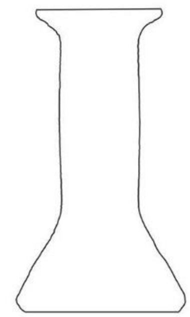


© Tiroler Landesmuseen

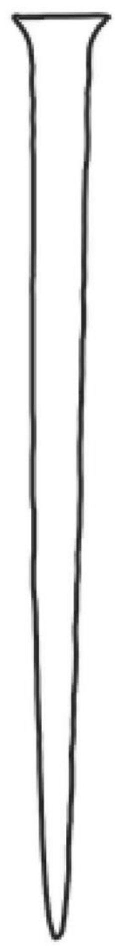
Side Profile



Top Profile



Blade Profile



Cross Section

Loc. Cluster

3

Blade Cluster

5

Hilt Cluster

1

BLADE: 10.021

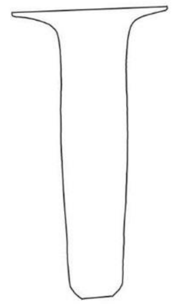
Style: Achtkantschwerter
Find Type: River

Museum: OL
Accession #: A4332

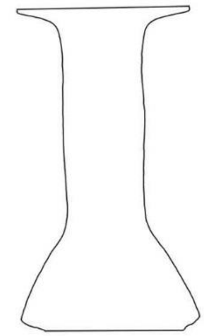
Lattitude: 48.063207
Longitude: 13.901777

© Oberösterreichisches Landesmusem

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

5

Hilt Cluster

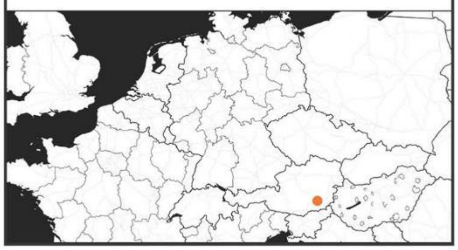
2

BLADE: 10.023

Style: Achtkantschwerter
Find Type: Single

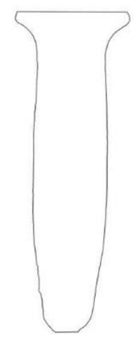
Museum: AMSE
Accession #: 8977

Lattitude: 47.070714
Longitude: 15.439504

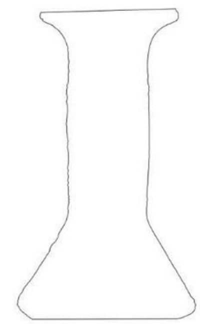


© Archaeology Musem Schloss Eggenberg

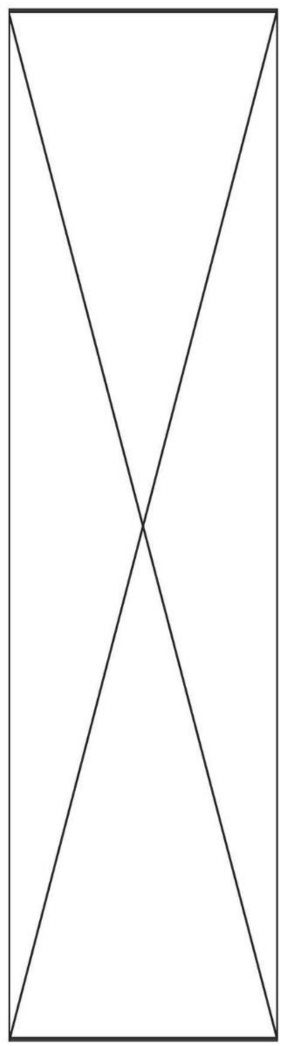
Side Profile



Top Profile



Blade Profile



Cross Section

Loc. Cluster

4

Blade Cluster

-

Hilt Cluster

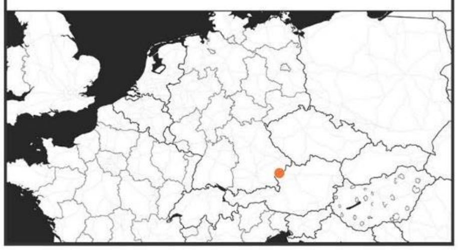
1

BLADE: 10.032

Style: Riegsee
Find Type: Unknown

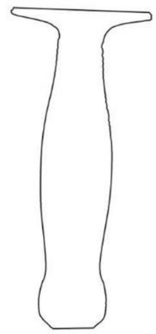
Museum: OL
Accession #: A599

Lattitude: 48.25573
Longitude: 13.04432

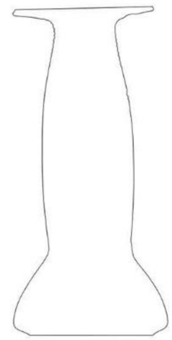


© Oberösterreichisches Landesmusem

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

2

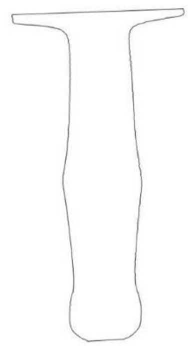
BLADE: 10.033

Style: Riegsee
Find Type: Cremation/grave

Museum: OL
Accession #: A607

Lattitude: 48.25573
Longitude: 13.04432

Side Profile



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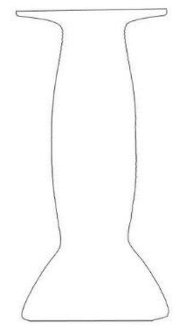

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Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

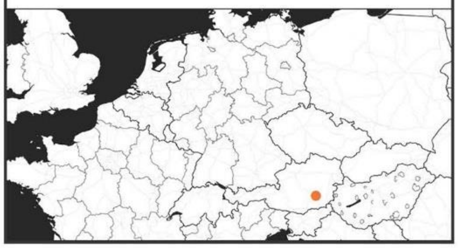
2

BLADE: 10.034

Style: Riegsee
Find Type: Unknown

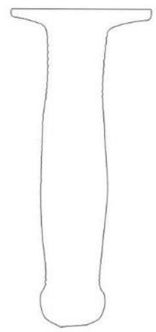
Museum: AMSE
Accession #: 16910

Lattitude: 47.205611
Longitude: 15.343447

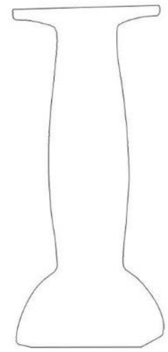


© Archaeology Musem Schloss Eggenberg

Side Profile

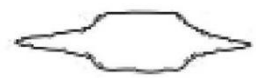


Top Profile



Blade Profile

Cross Section



Loc. Cluster

4

Blade Cluster

5

Hilt Cluster

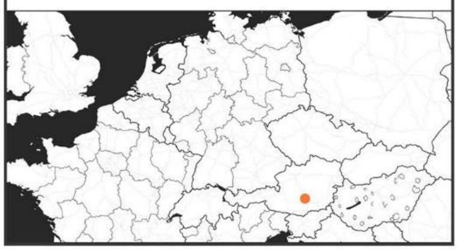
2

BLADE: 10.037

Style: Riegsee
Find Type: River

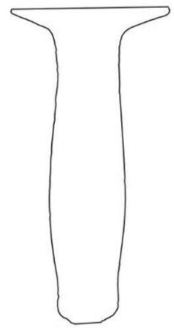
Museum: AMSE
Accession #: 6138

Lattitude: 47.16826
Longitude: 14.65811



© Archaeology Musem Schloss Eggenberg

Side Profile



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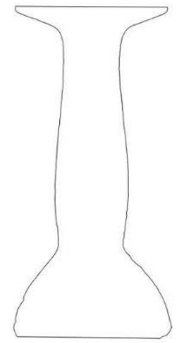


Blade Profile

Cross Section

Loc. Cluster

4

Blade Cluster

5

Hilt Cluster

4

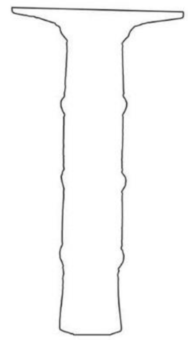
BLADE: 10.048

Style: Dreiwulstschwerter
Find Type: Other

Museum: AMSE
Accession #: 4297

Lattitude: 47.997465
Longitude: 16.474808

Side Profile



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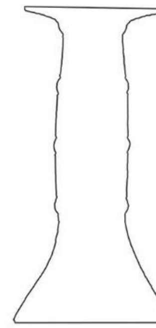

Blade Profile

Cross Section

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Loc. Cluster

8

Blade Cluster

2

Hilt Cluster

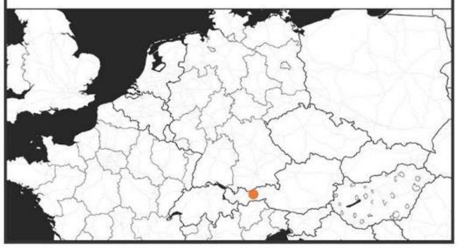
4

BLADE: 10.065

Style: Dreiwulstschwerter
Find Type: Cremation/grave

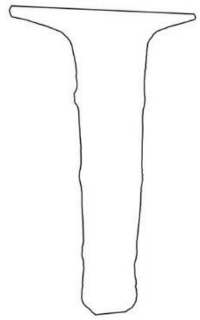
Museum: TL
Accession #: 18.757a-d

Lattitude: 47.269212
Longitude: 11.404102

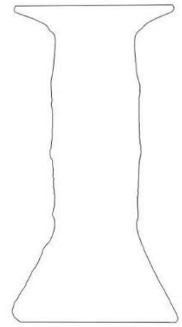


© Tiroler Landesmuseen

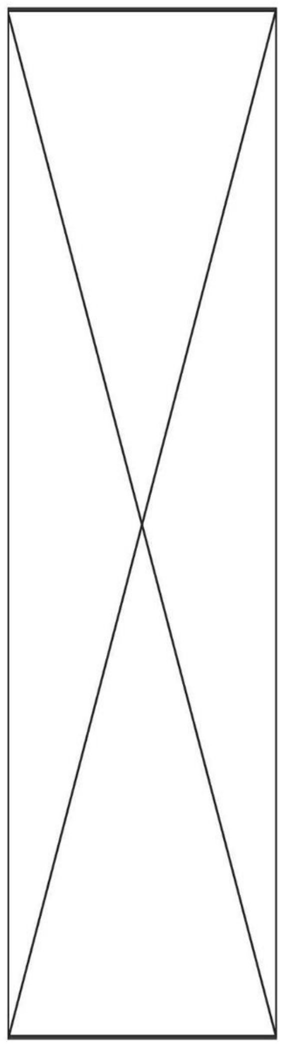
Side Profile



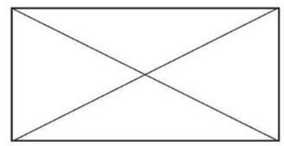
Top Profile



Blade Profile



Cross Section



Loc. Cluster

3

Blade Cluster

-

Hilt Cluster

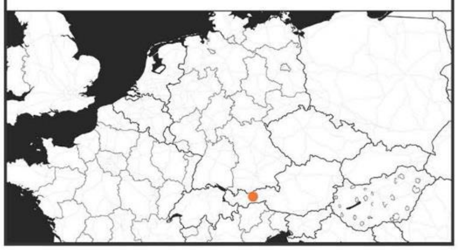
4

BLADE: 10.067

Style: Dreiwulstschwerter
Find Type: Other

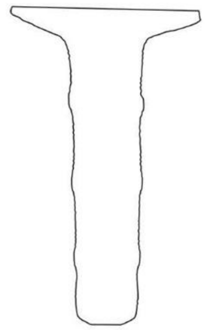
Museum: TL
Accession #: 18596

Lattitude: 47.256112
Longitude: 11.384199

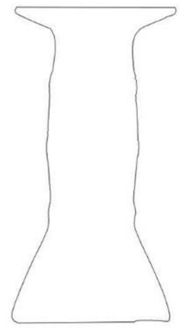


© Tiroler Landesmuseen

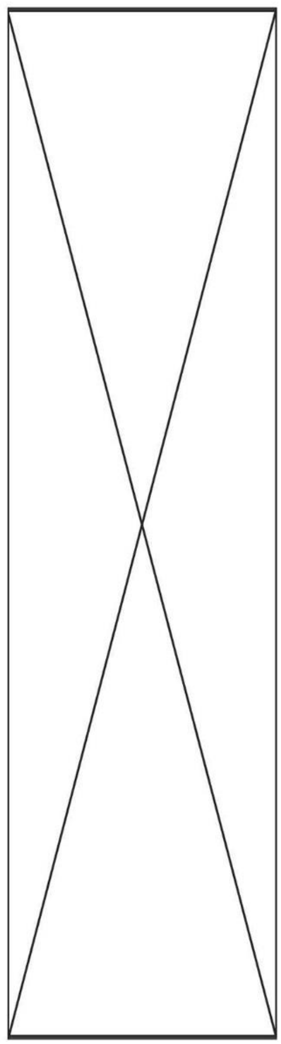
Side Profile



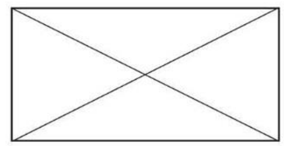
Top Profile



Blade Profile



Cross Section



Loc. Cluster

3

Blade Cluster

-

Hilt Cluster

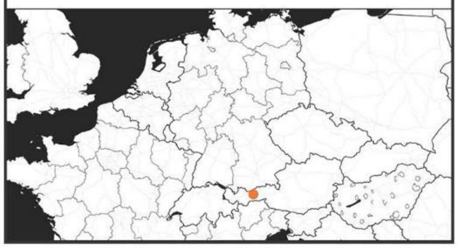
4

BLADE: 10.068

Style: Dreiwulstschwerter
Find Type: Cremation/grave

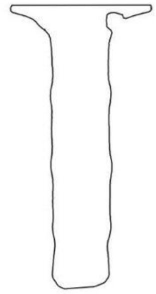
Museum: TL
Accession #: 110

Lattitude: 47.269212
Longitude: 11.404102

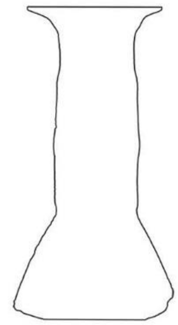


© Tiroler Landesmuseen

Side Profile

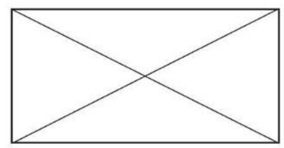


Top Profile



Blade Profile

Cross Section



Loc. Cluster

3

Blade Cluster

3

Hilt Cluster

2

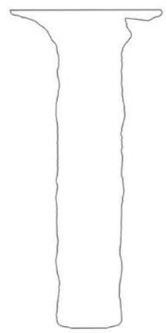
BLADE: 10.071

Style: Dreiwulstschwerter
Find Type: Unknown

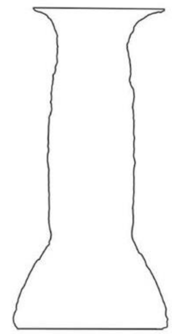
Museum: TL
Accession #: 18.093

Lattitude: -
Longitude: -

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

-

Blade Cluster

-

Hilt Cluster

4

BLADE: 10.081

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: TL
Accession #: 18.506

Lattitude: -
Longitude: -

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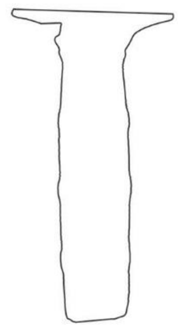
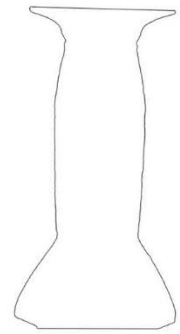
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

-

Blade Cluster

7

Hilt Cluster

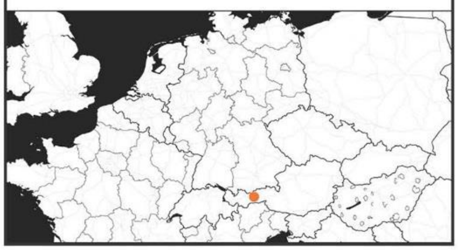
4

BLADE: 10.085

Style: Dreiwulstschwerter
Find Type: Cremation/grave

Museum: TL
Accession #: 109

Lattitude: 47.251309
Longitude: 11.445987



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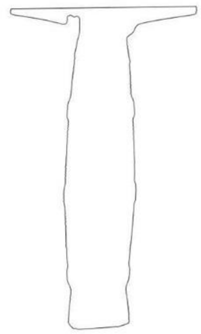
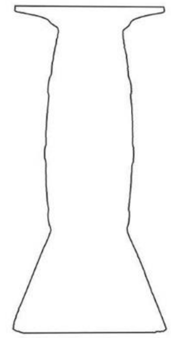
Side Profile

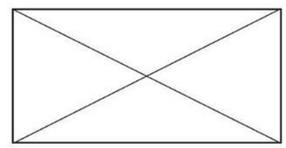


Top Profile



Blade Profile

Cross Section



Loc. Cluster

3

Blade Cluster

6

Hilt Cluster

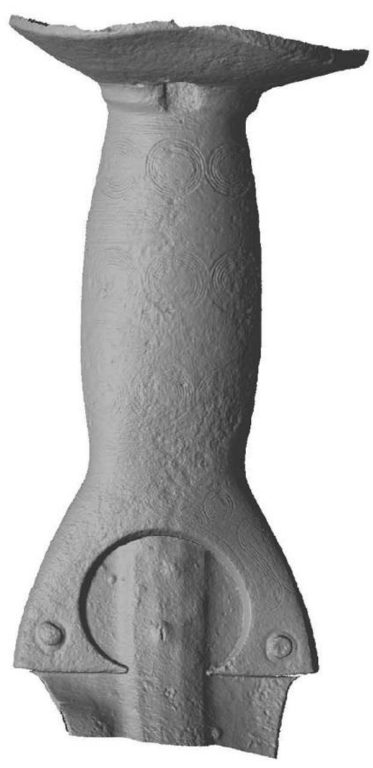
4

BLADE: 10.096

Style: Schalenknaufschwerter
Find Type: Cremation/grave

Museum: AMSE
Accession #: 16167

Lattitude: 47.359344
Longitude: 14.469983



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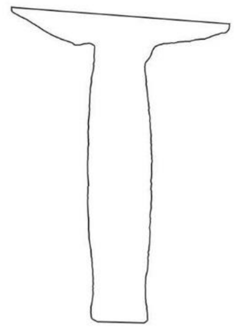
Side Profile



Top Profile

Blade Profile

Cross Section

Loc. Cluster

4

Blade Cluster

-

Hilt Cluster

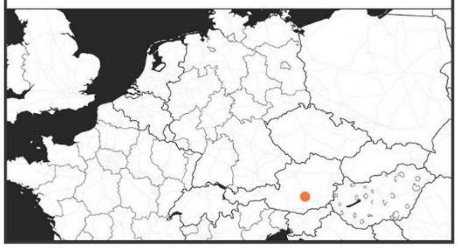
-

BLADE: 10.098

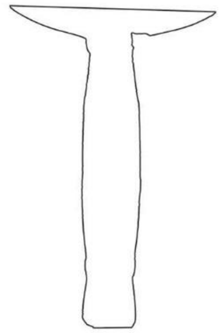
Style: Schalenknaufschwerter
Find Type: Other

Museum: AMSE
Accession #: 6137

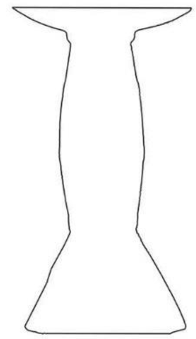
Lattitude: 47.16826
Longitude: 14.65811



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

4

Blade Cluster

4

Hilt Cluster

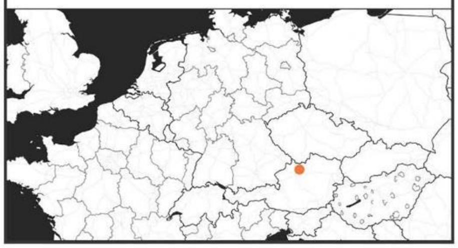
6

BLADE: 10.103

Style: Schalenknaufschwerter
Find Type: River

Museum: OL
Accession #: A606

Lattitude: 48.318915
Longitude: 14.306757



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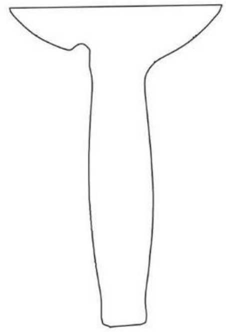
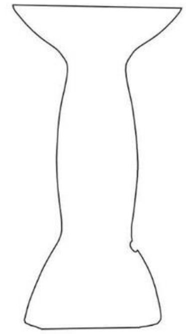
Side Profile

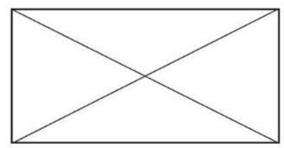


Top Profile



Blade Profile

Cross Section



Loc. Cluster

2

Blade Cluster

7

Hilt Cluster

9

BLADE: 10.104

Style: Schalenknaufschwerter
Find Type: Other

Museum: OL
Accession #: A-4483

Lattitude: 48.25573
Longitude: 13.04432

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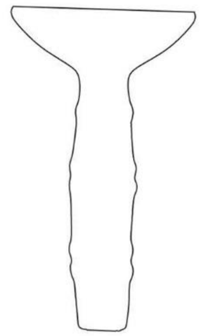
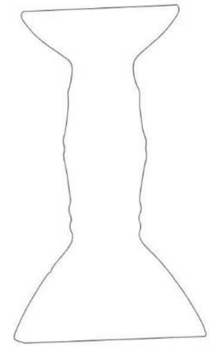
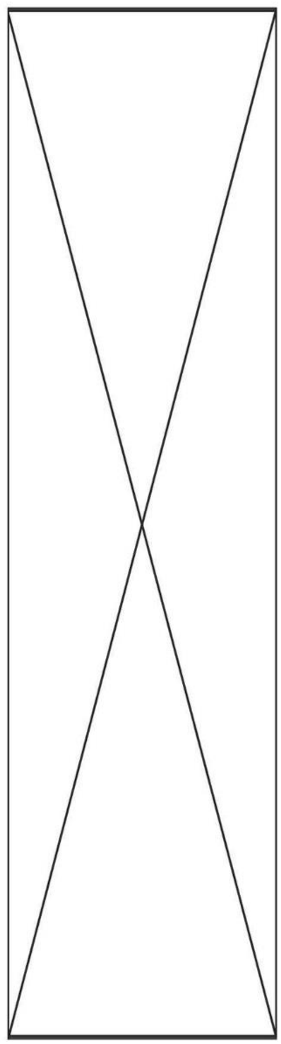
Side Profile



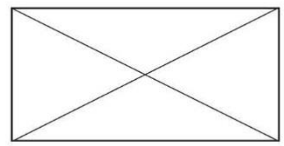
Top Profile



Blade Profile



Cross Section



Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

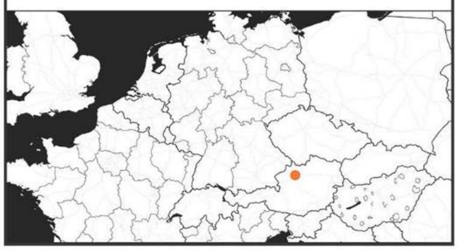
3

BLADE: 10.105

Style: Schalenknaufschwerter
Find Type: River

Museum: OL
Accession #: A609

Lattitude: 48.16542
Longitude: 14.03664



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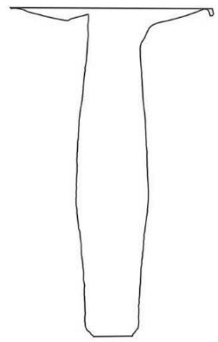
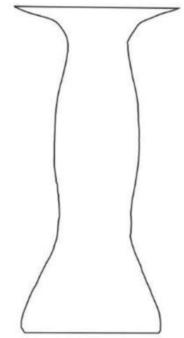
Side Profile

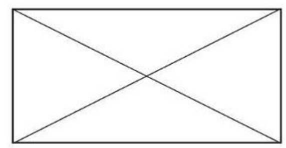


Top Profile



Blade Profile

Cross Section



Loc. Cluster

2

Blade Cluster

7

Hilt Cluster

6

BLADE: 10.147

Style:	Vollgriffschwerter
Find Type:	Unknown
Museum:	OL
Accession #:	A611
Lattitude:	48.153934
Longitude:	13.118219

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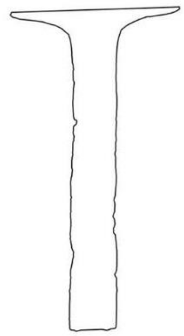
Side Profile



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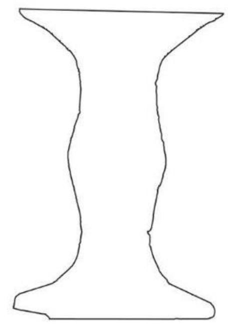
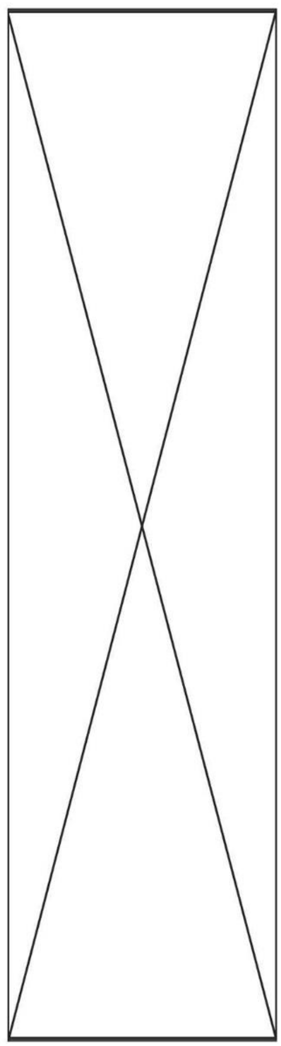
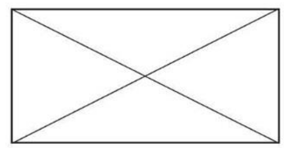


Blade Profile



Cross Section



Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

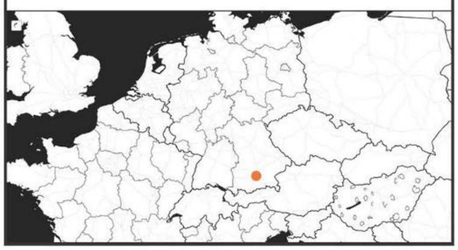
7

BLADE: 11.005

Style: Vollgriffschwerter
Find Type: Cremation/grave

Museum: ASM
Accession #: 1911.874

Lattitude: 48.135125
Longitude: 11.581981



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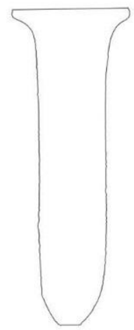
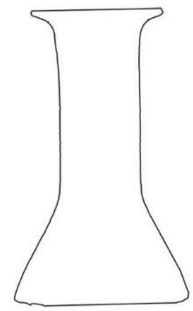
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

9

Hilt Cluster

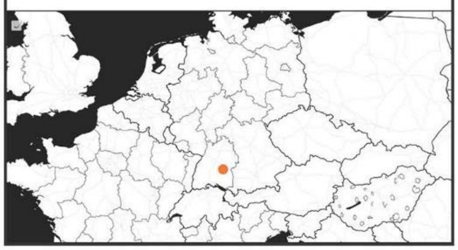
1

BLADE: 11.011

Style: Vollgriffschwerter
Find Type: Cremation/grave

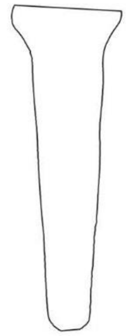
Museum: LW
Accession #: 10504

Lattitude: 48.411446
Longitude: 9.498036

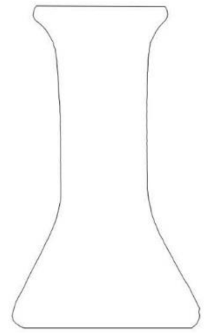


© Lanedmuseum Württemberg

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

5

Blade Cluster

2

Hilt Cluster

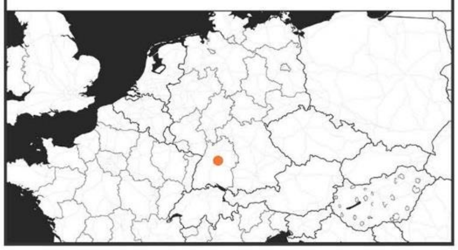
1

BLADE: 11.017

Style: Vollgriffschwerter
Find Type: River

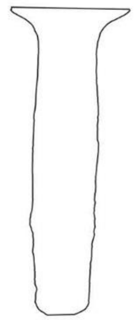
Museum: LW
Accession #: 11333

Lattitude: 48.775846
Longitude: 9.182932



© Lanedmuseum Württemberg

Side Profile



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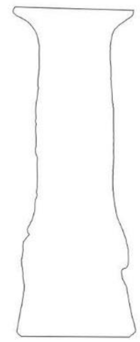
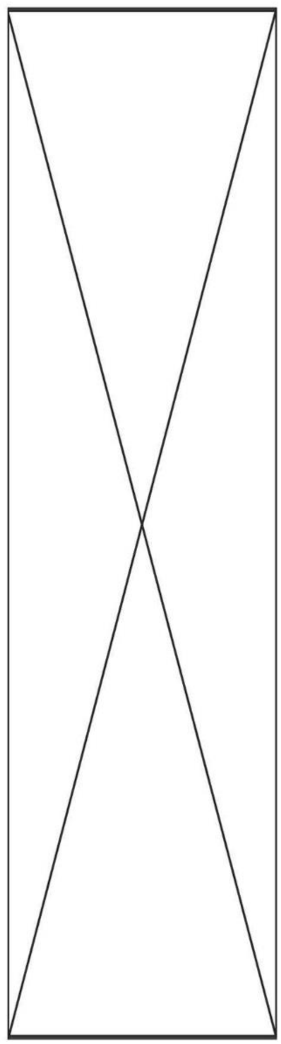
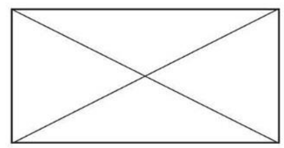


Blade Profile



Cross Section



Loc. Cluster

5

Blade Cluster

-

Hilt Cluster

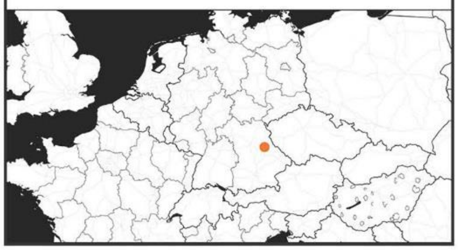
11

BLADE: 11.024

Style: Achtkantschwerter
Find Type: Cremation/grave

Museum: ASM
Accession #: NM 3548

Lattitude: 49.319888
Longitude: 12.109135



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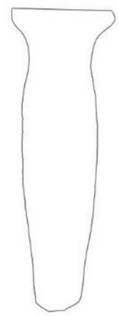
Side Profile



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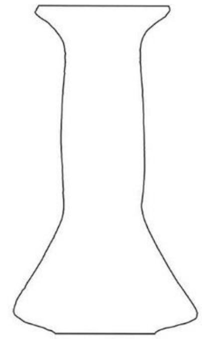


Blade Profile

Cross Section

Loc. Cluster

9

Blade Cluster

1

Hilt Cluster

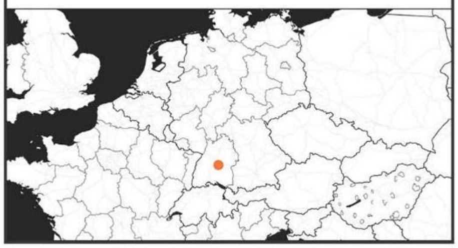
1

BLADE: 11.026

Style: Achtkantschwerter
Find Type: Cremation/grave

Museum: LW
Accession #: 11433

Lattitude: 48.506939
Longitude: 9.203804



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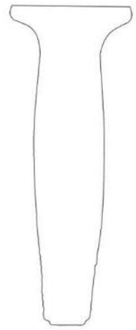

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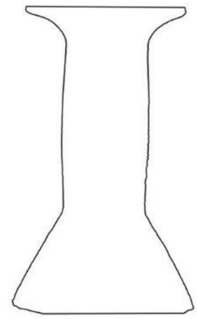

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Blade Profile

Cross Section

Loc. Cluster

5

Blade Cluster

5

Hilt Cluster

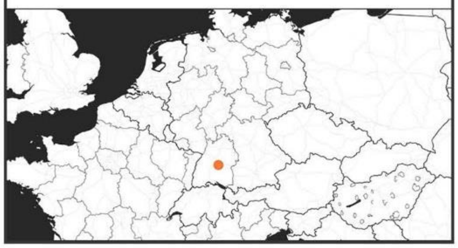
3

BLADE: 11.03

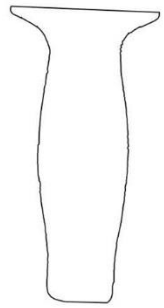
Style: Achtkantschwerter
Find Type: Single

Museum: LW
Accession #: V54,23

Lattitude: 48.506939
Longitude: 9.203804



<u>Side Profile</u>



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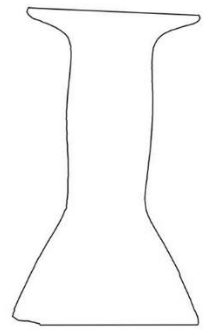
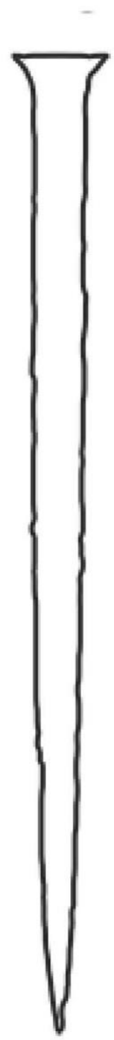


<u>Blade Profile</u>



<u>Cross Section</u>

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<u>Loc. Cluster</u>

5

<u>Blade Cluster</u>

2

<u>Hilt Cluster</u>

2

BLADE: 11.031

Style: Achtkantschwerter
Find Type: River

Museum: ASM
Accession #: 1920.17

Lattitude: 48.135125
Longitude: 11.581981

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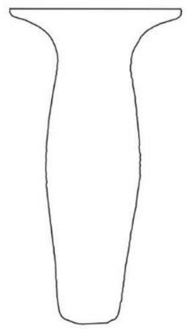
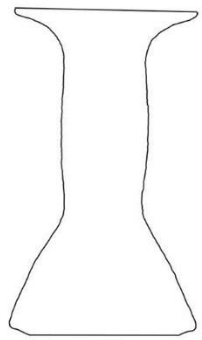
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

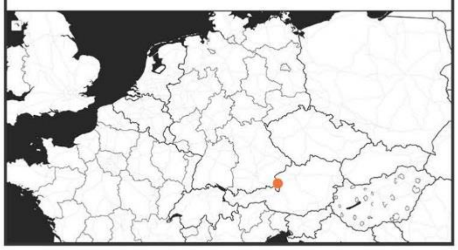
2

BLADE: 11.033

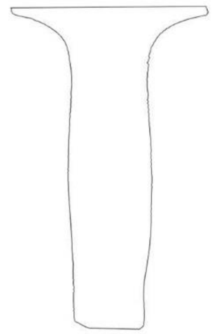
Style: Achtkantschwerter
Find Type: Unknown

Museum: ASM
Accession #: 1937, 50

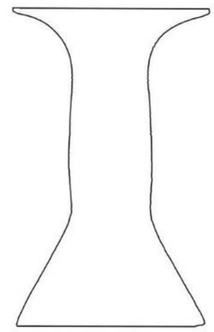
Lattitude: 47.814582
Longitude: 12.941546



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

5

Hilt Cluster

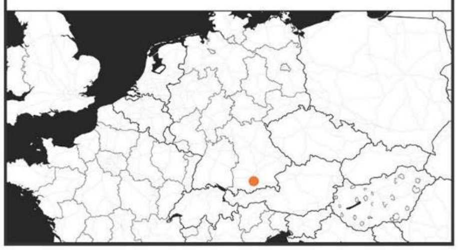
2

BLADE: 11.036

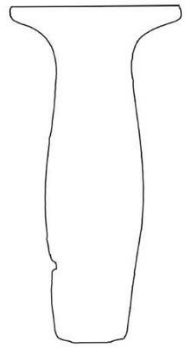
Style: Achtkantschwerter
Find Type: River

Museum: ASM
Accession #: HV80

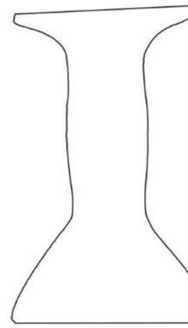
Lattitude: 47.91023
Longitude: 11.427416



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

2

Hilt Cluster

3

BLADE: 11.037

Style: Achtkantschwerter
Find Type: Single

Museum: ASM
Accession #: 1963, 330

Lattitude: 48.528824
Longitude: 13.054808

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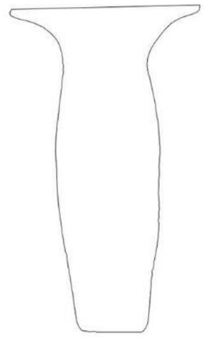
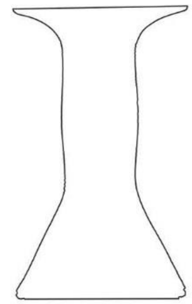
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

2

BLADE: 11.04

Style: Achtkantschwerter
Find Type: Unknown

Museum: ASM
Accession #: IV570

Lattitude: 47.857127
Longitude: 12.118105

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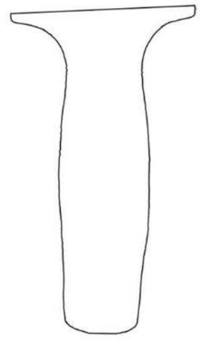
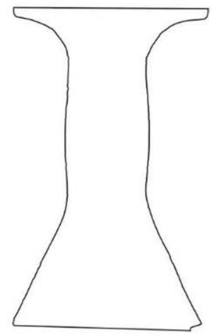
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

2

BLADE: 11.042

Style: Achtkantschwerter
Find Type: River

Museum: LW
Accession #: A733

Lattitude: 49.791304
Longitude: 9.953355

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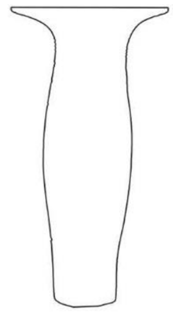
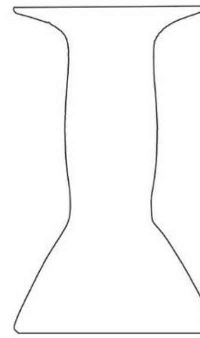
Side Profile

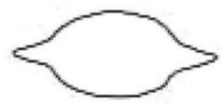


Top Profile



Blade Profile

Cross Section



Loc. Cluster

9

Blade Cluster

2

Hilt Cluster

2

BLADE: 11.051

Style: Achtkantschwerter
Find Type: Cremation/grave

Museum: ASM
Accession #: IV147

Lattitude: 49.227419
Longitude: 11.540252

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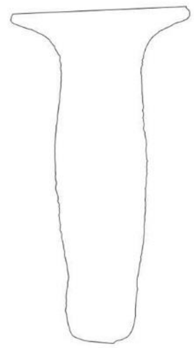
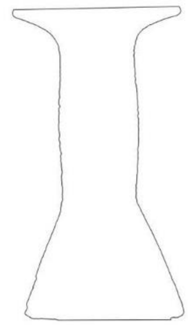
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

9

Blade Cluster

1

Hilt Cluster

2

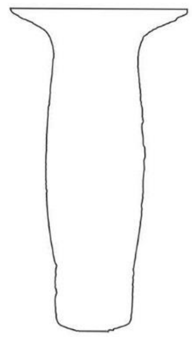
BLADE: 11.052

Style: Achtkantschwerter
Find Type: Cremation/grave

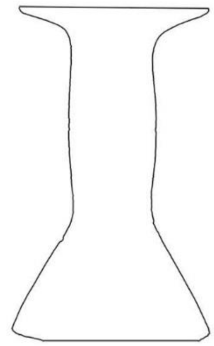
Museum: ASM
Accession #: HV79

Lattitude: 48.224643
Longitude: 12.676784

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

2

BLADE: 11.066

Style: Achtkantschwerter
Find Type: River

Museum: ASM
Accession #: 1927.54

Lattitude: 47.929332
Longitude: 11.477383

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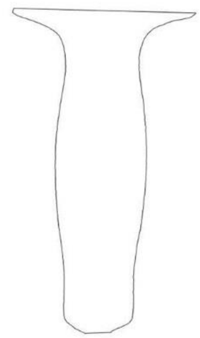
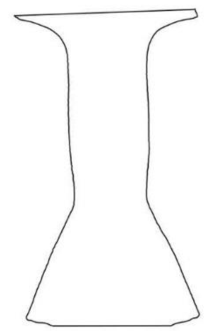
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

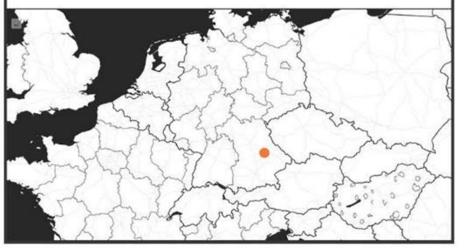
2

BLADE: 11.072

Style: Achtkantschwerter
Find Type: River

Museum: ASM
Accession #: 1922.1

Lattitude: 49.01343
Longitude: 12.101624



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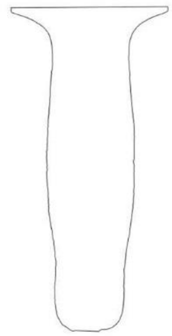
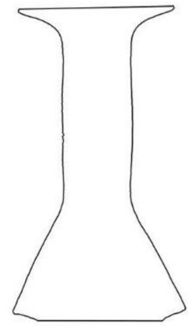
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

9

Blade Cluster

1

Hilt Cluster

4

BLADE: 11.082

Style: Vollgriffschwerter
Find Type: Single

Museum: ASM
Accession #: IV128

Lattitude: 47.857127
Longitude: 12.118105

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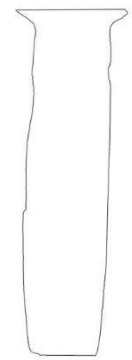
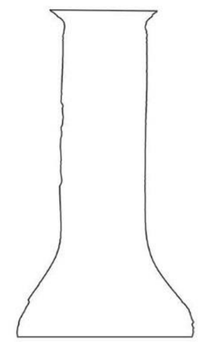
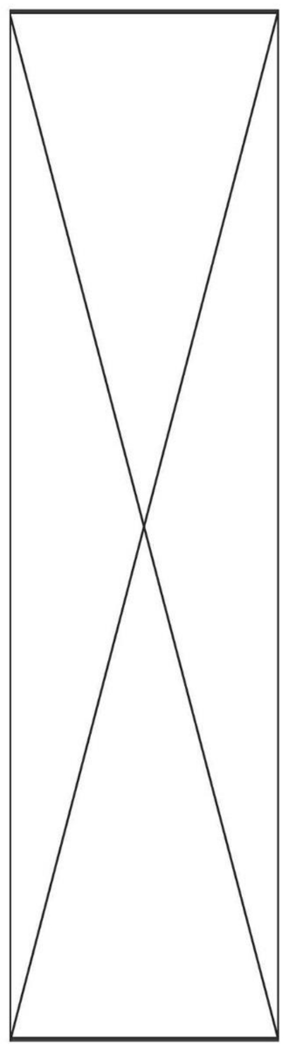
Side Profile



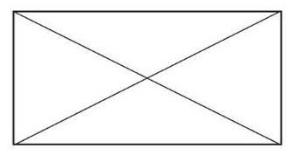
Top Profile



Blade Profile



Cross Section



Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

1

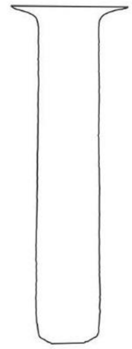
BLADE: 11.083

Style: Vollgriffschwerter
Find Type: River

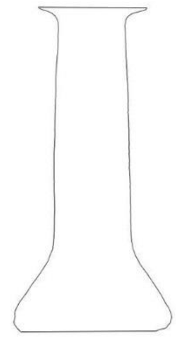
Museum: LW
Accession #: 8903

Lattitude: 48.808458
Longitude: 9.225035

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

5

Blade Cluster

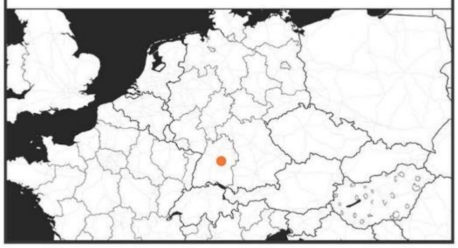
1

Hilt Cluster

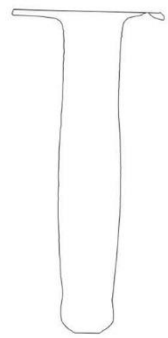
1

BLADE: 11.112

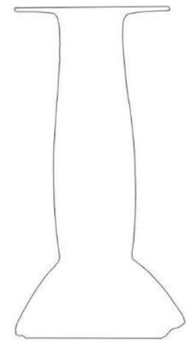
Style:	Riegsee
Find Type:	River
Museum:	LW
Accession #:	11514
Lattitude:	48.671757
Longitude:	9.382768



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

5

Blade Cluster

-

Hilt Cluster

2

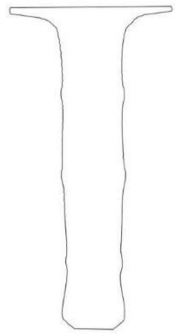
BLADE: 11.133

Style: Dreiwulstschwerter
Find Type: Other

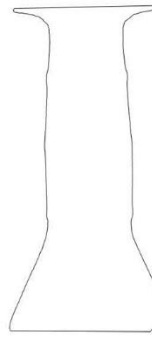
Museum: ASM
Accession #: 1964, 1021

Lattitude: 48.17498
Longitude: 11.321208

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

4

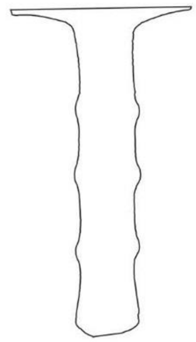
BLADE: 11.136

Style: Dreiwulstschwerter
Find Type: River

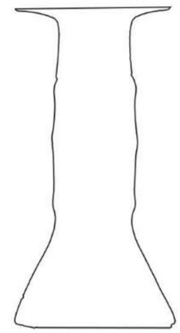
Museum: ASM
Accession #: 1/1/1903

Lattitude: 48.275713
Longitude: 13.043417

Side Profile



Top Profile



Blade Profile

Cross Section

© Archäologische Staatssammlung München, Museum für Vor-und Frühgeschichte

Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

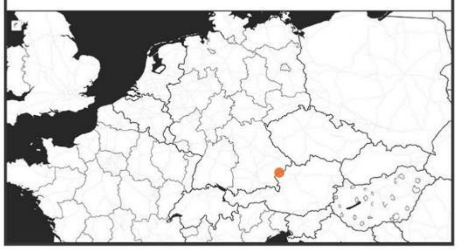
4

BLADE: 11.139

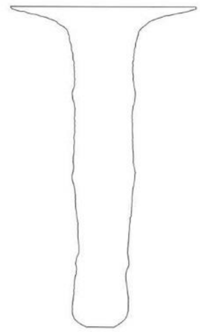
Style: Dreiwulstschwerter
Find Type: River

Museum: ASM
Accession #: 1937.53

Lattitude: 47.857127
Longitude: 12.118105



Side Profile



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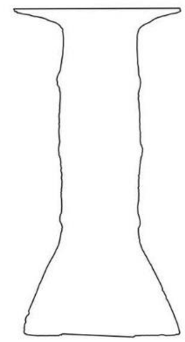

Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

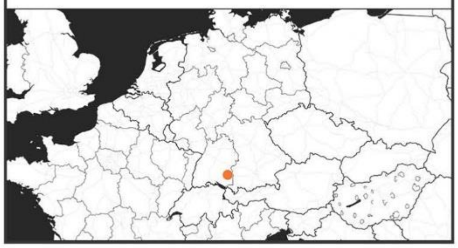
4

BLADE: 11.14

Style: Dreiwulstschwerter
Find Type: River

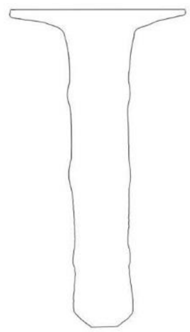
Museum: LW
Accession #: A541

Lattitude: 48.095147
Longitude: 9.790152

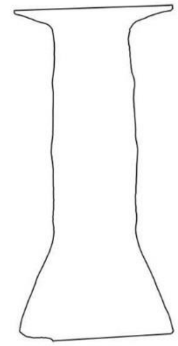


© Lanedmuseum Württemberg

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

5

Blade Cluster

1

Hilt Cluster

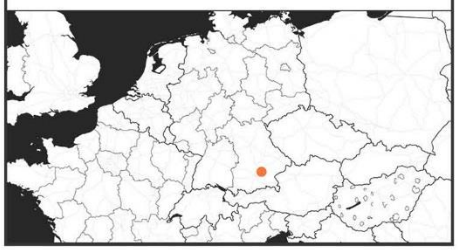
4

BLADE: 11.142

Style: Dreiwulstschwerter
Find Type: Single

Museum: ASM
Accession #: 1969, 246

Lattitude: 48.311465
Longitude: 11.918876



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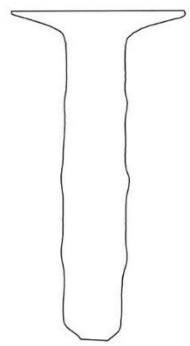
Side Profile



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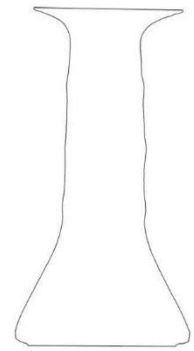


Blade Profile

Cross Section

Loc. Cluster
2
Blade Cluster
4
Hilt Cluster
4

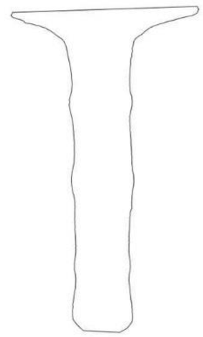
BLADE: 11.145

Style: Dreiwulstschwerter
Find Type: Single

Museum: ASM
Accession #: 1982, 129

Lattitude: 47.857127
Longitude: 12.118105

Side Profile



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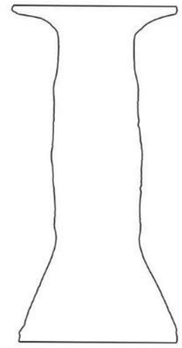

Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

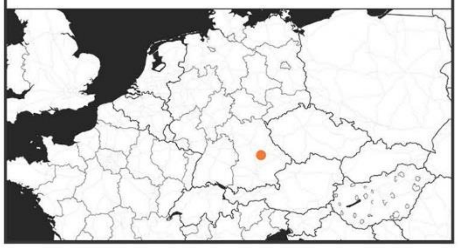
4

BLADE: 11.151

Style: Dreiwulstschwerter
Find Type: Other

Museum: ASM
Accession #: 1921.11

Lattitude: 48.918412
Longitude: 11.886563



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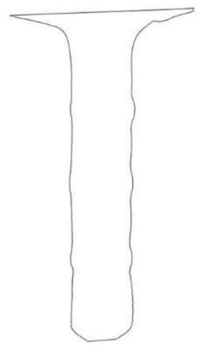
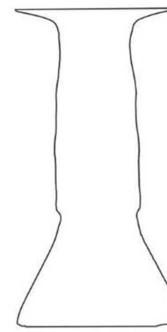
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

9

Blade Cluster

4

Hilt Cluster

2

BLADE: 11.154

Style: Dreiwulstschwerter
Find Type: River

Museum: ASM
Accession #: 1958.549

Lattitude: 47.857127
Longitude: 12.118105

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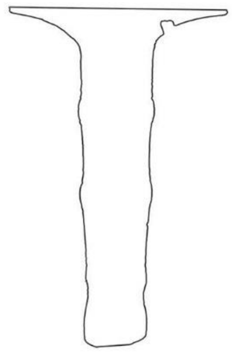
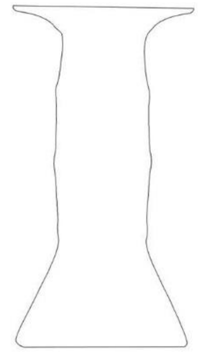
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

2

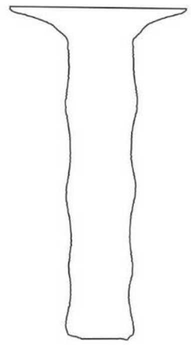
BLADE: 11.158

Style: Dreiwulstschwerter
Find Type: Cremation/grave

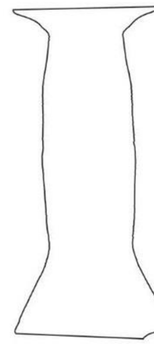
Museum: LW
Accession #: A249

Lattitude: 48.597969
Longitude: 10.801957

Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

5

Blade Cluster

3

Hilt Cluster

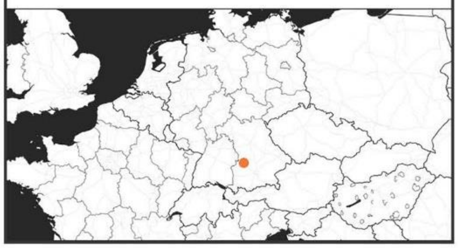
4

BLADE: 11.161

Style: Dreiwulstschwerter
Find Type: River

Museum: ASM
Accession #: 1934.3

Lattitude: 48.883334
Longitude: 10.566668



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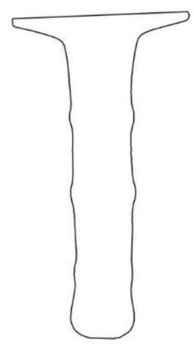
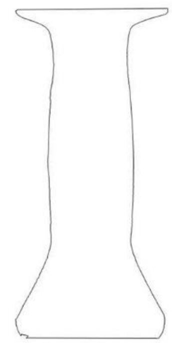
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

5

Blade Cluster

6

Hilt Cluster

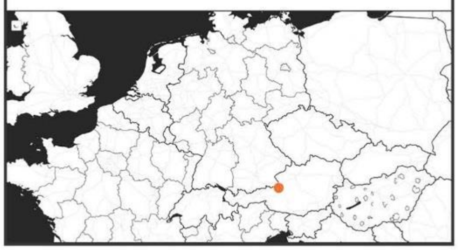
4

BLADE: 11.162

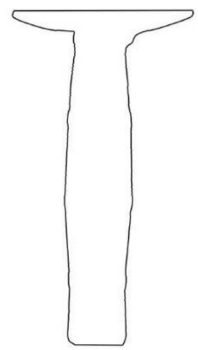
Style: Dreiwulstschwerter
Find Type: Unknown

Museum: ASM
Accession #: 1960.795

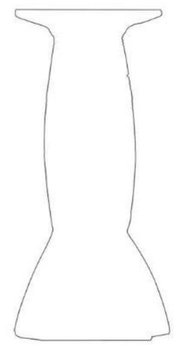
Lattitude: 47.63018
Longitude: 13.000074



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

4

BLADE: 11.175

Style:	Dreiwulstschwerter
Find Type:	Unknown
Museum:	ASM
Accession #:	1954.1
Lattitude:	47.859367
Longitude:	12.39881

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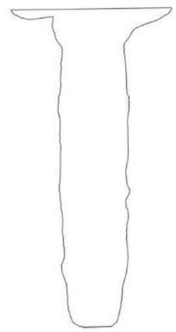
Side Profile



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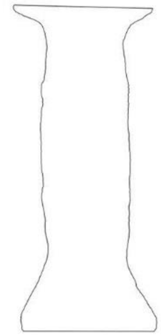
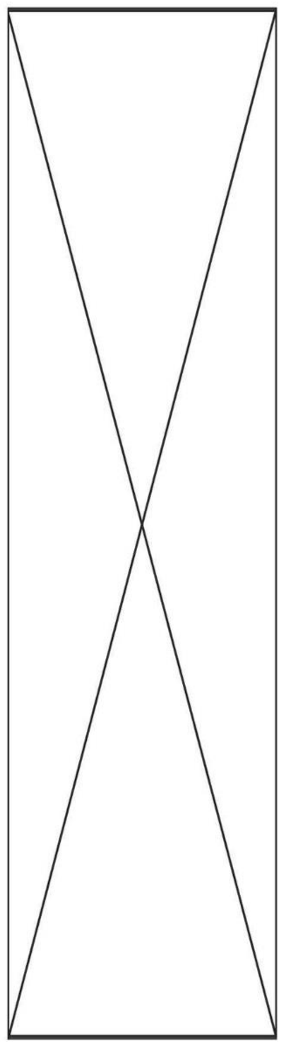
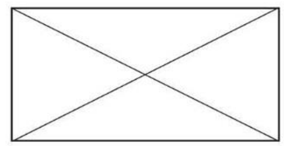


Blade Profile



Cross Section



Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

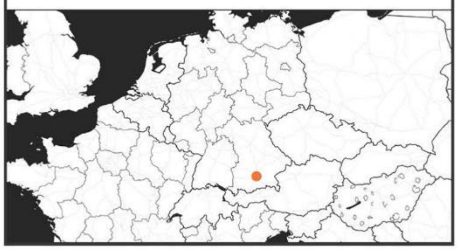
4

BLADE: 11.175A

Style: Dreiwulstschwerter
Find Type: Other

Museum: ASM
Accession #: 1,982,130

Lattitude: 48.107514
Longitude: 11.59892



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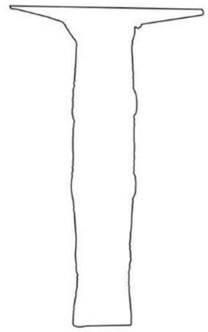
Side Profile



Top Profile

Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

-

Hilt Cluster

-

BLADE: 11.185

Style: Dreiwulstschwerter
Find Type: River

Museum: ASM
Accession #: 1936.3

Lattitude: 48.208652
Longitude: 12.401636

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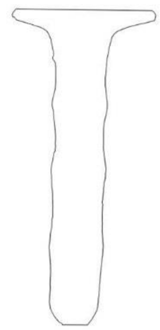
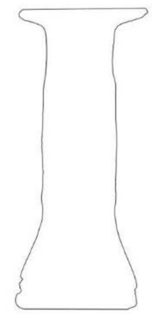
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

1

Hilt Cluster

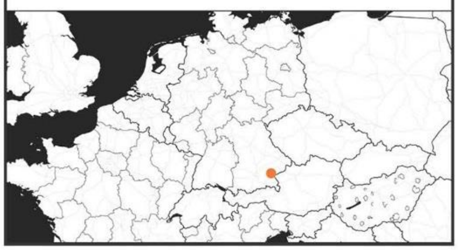
4

BLADE: 11.186

Style: Dreiwulstschwerter
Find Type: River

Museum: ASM
Accession #: 1950.9

Lattitude: 48.245772
Longitude: 12.52199



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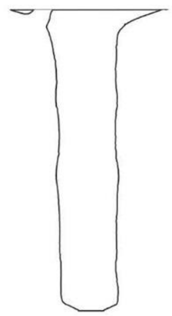
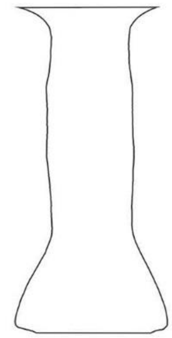
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

3

Hilt Cluster

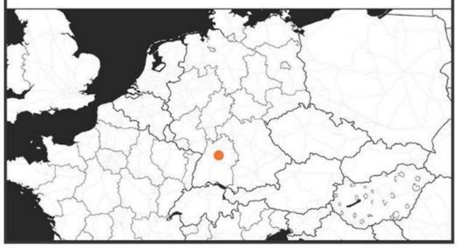
4

BLADE: 11.188

Style: Schalenknaufschwerter
Find Type: River

Museum: LW
Accession #: 11148

Lattitude: 48.910306
Longitude: 9.222576



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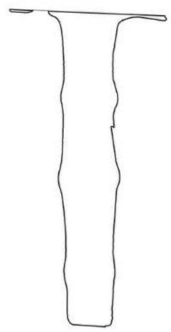
Side Profile



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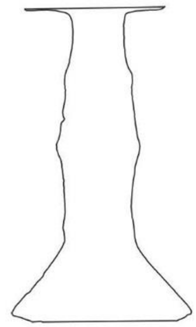


Blade Profile

Cross Section

Loc. Cluster

5

Blade Cluster

3

Hilt Cluster

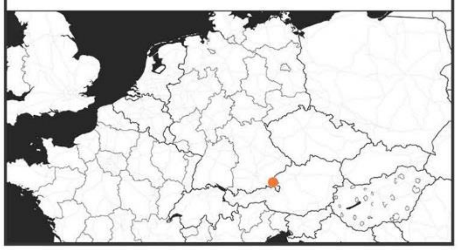
2

BLADE: 11.198

Style: Schalenknaufschwerter
Find Type: River

Museum: ASM
Accession #: 3763

Lattitude: 47.867757
Longitude: 12.638404



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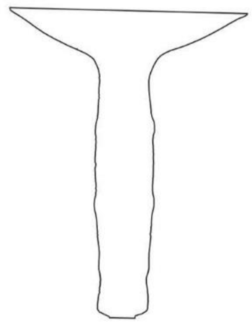
Side Profile



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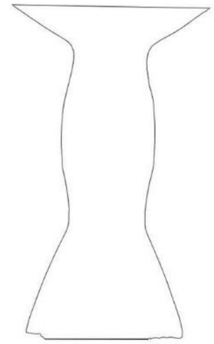

Blade Profile

Cross Section

Loc. Cluster

2

Blade Cluster

6

Hilt Cluster

5

BLADE: 11.206

Style: Riegsee
Find Type: River

Museum: ASM
Accession #: NM 1923.12

Lattitude: 49.980663
Longitude: 9.135555

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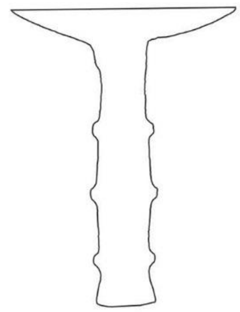
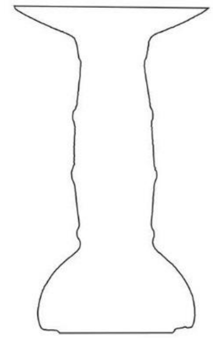
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

9

Blade Cluster

3

Hilt Cluster

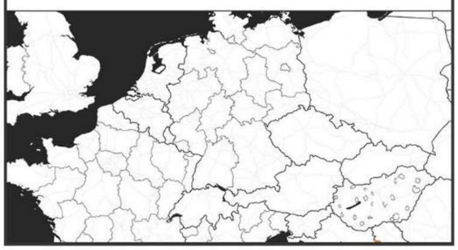
9

BLADE: 14.231

Style: Dreiwulstschwerter
Find Type: Hoard

Museum: AM
Accession #: 3923

Lattitude: 45.125799
Longitude: 19.228288



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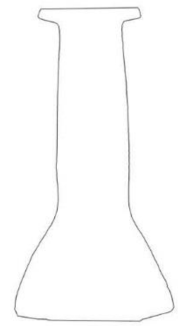
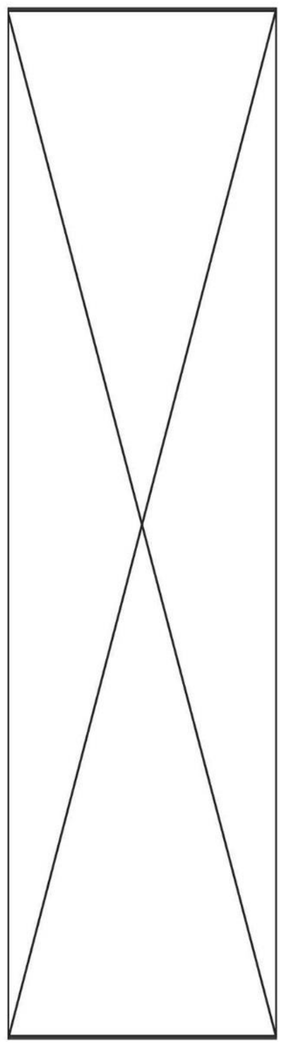
Side Profile

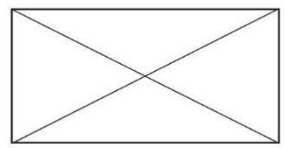
Top Profile



Blade Profile



Cross Section



Loc. Cluster

10

Blade Cluster

-

Hilt Cluster

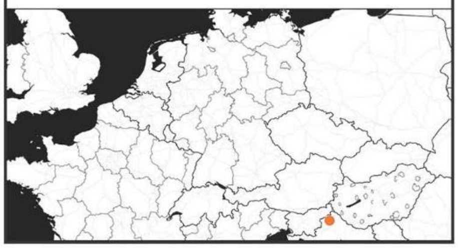
1

BLADE: 14.234

Style: Dreiwulstschwerter
Find Type: Hoard

Museum: AM
Accession #: 10769

Lattitude: 46.128734
Longitude: 16.205633



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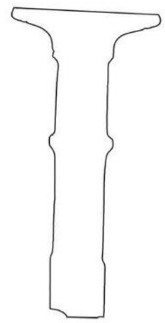
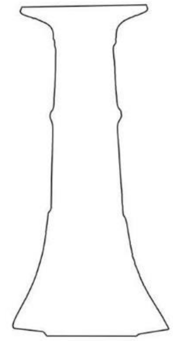
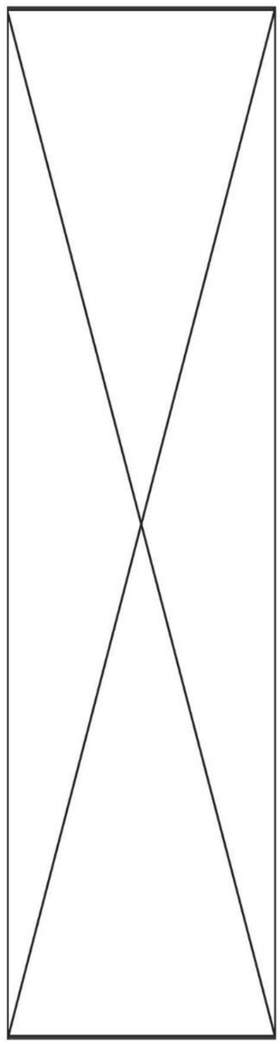
Side Profile



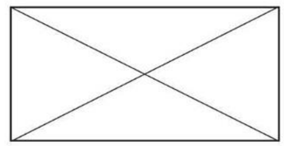
Top Profile



Blade Profile



Cross Section



Loc. Cluster

10

Blade Cluster

-

Hilt Cluster

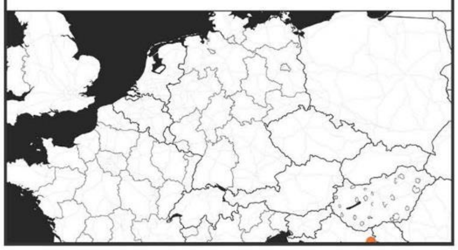
4

BLADE: 14.236

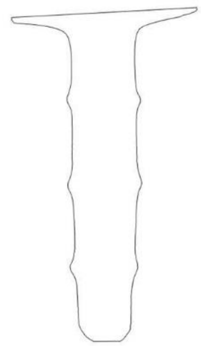
Style: Schalenknaufschwerter
Find Type: Hoard

Museum: AM
Accession #: 2195

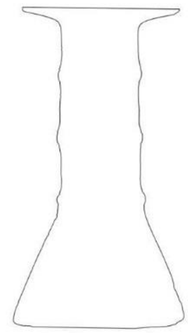
Lattitude: 45.287906
Longitude: 18.805678



Side Profile



Top Profile



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Blade Profile

Cross Section

Loc. Cluster

10

Blade Cluster

-

Hilt Cluster

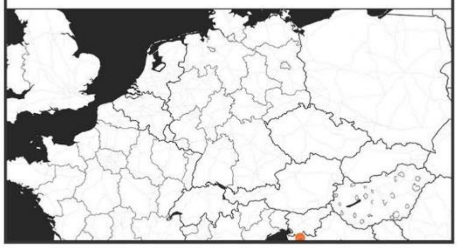
4

BLADE: 14.244

Style: Mörigenschwerter
Find Type: Cremation/grave

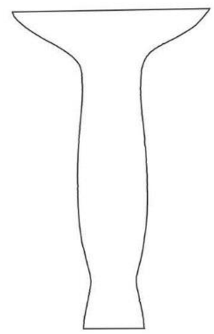
Museum: AM
Accession #: 10468

Lattitude: 45.37158
Longitude: 14.350424

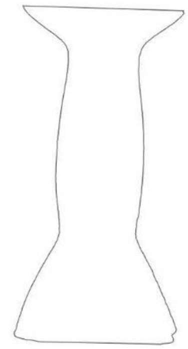


© Arheološki muzej u Zagrebu

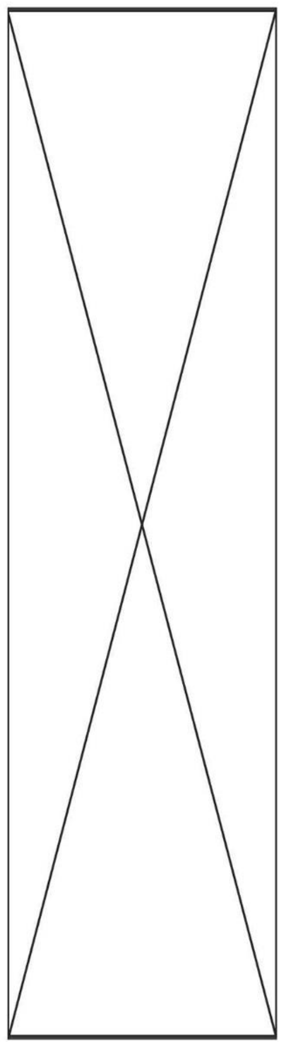
Side Profile



Top Profile



Blade Profile



Cross Section

Loc. Cluster

10

Blade Cluster

-

Hilt Cluster

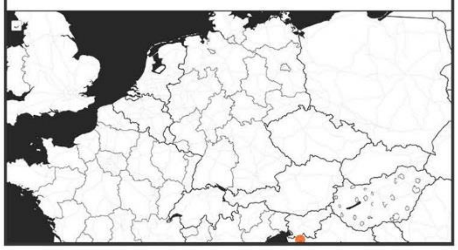
4

BLADE: 15.478

Style: Mörigenschwerter
Find Type: Hoard

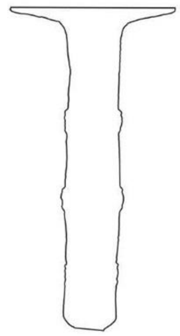
Museum: LHS
Accession #: 9392

Lattitude: 51.472736
Longitude: 10.610292

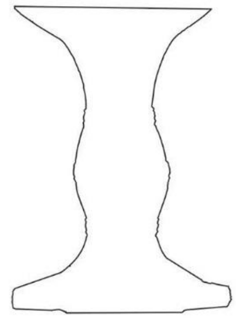


© Landesmuseum für Vorgeschichte in Halle/Saale

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

1

Hilt Cluster

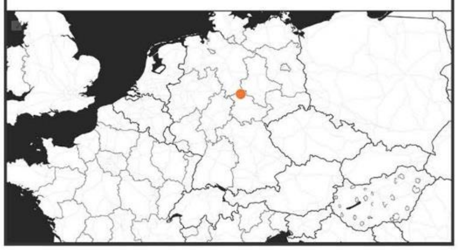
8

BLADE: 15.479

Style: Mörigenschwerter
Find Type: Hoard

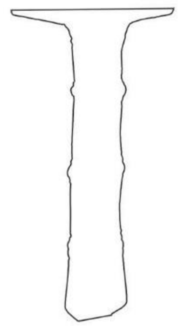
Museum: LHS
Accession #: 9393

Lattitude: 51.472736
Longitude: 10.610292

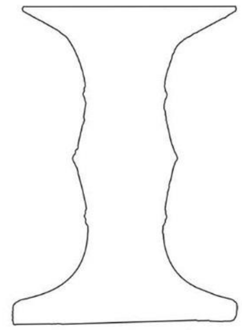


© Landesmuseum für Vorgeschichte in Halle/Saale

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

4

Hilt Cluster

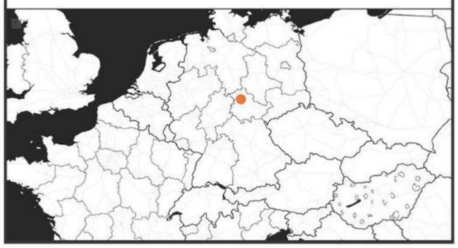
7

BLADE: 15.481

Style: Mörigenschwerter
Find Type: Hoard

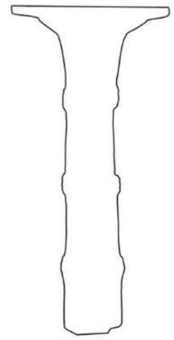
Museum: LHS
Accession #: 31-1428a

Lattitude: 51.186489
Longitude: 10.623479

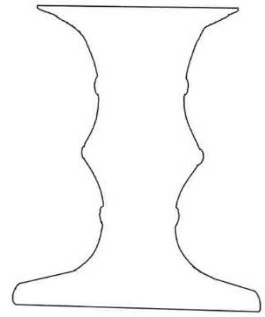


© Landesmuseum für Vorgeschichte in Halle/Saale

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

1

Hilt Cluster

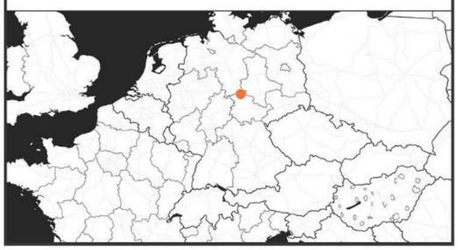
8

BLADE: 15.487

Style: Mörigenschwerter
Find Type: Hoard

Museum: LHS
Accession #: 9391

Lattitude: 51.472736
Longitude: 10.610292



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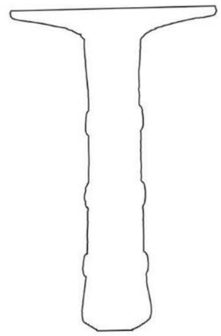
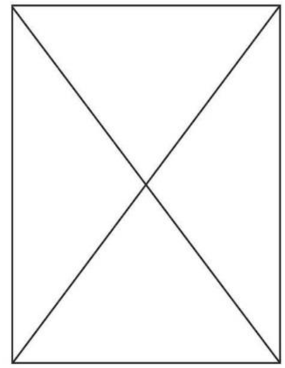
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

1

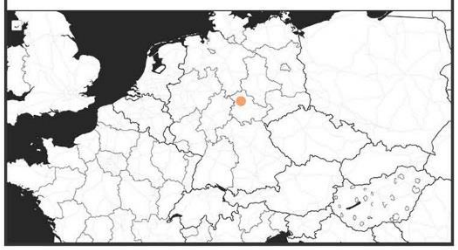
Hilt Cluster

BLADE: 15.489

Style: Mörigenschwerter
Find Type: Hoard

Museum: LHS
Accession #: 31-1428d

Lattitude: 51.186489
Longitude: 10.623479



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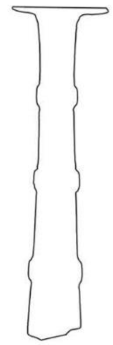
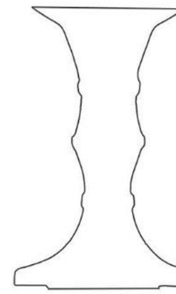
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

6

Blade Cluster

1

Hilt Cluster

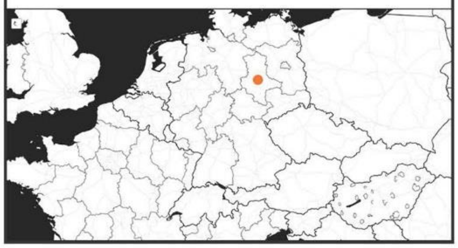
10

BLADE: 15.49

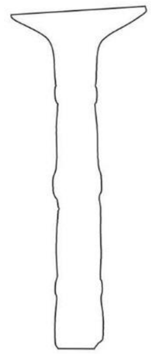
Style: Vollgriffschwerter
Find Type: Hoard

Museum: LHS
Accession #: 7965

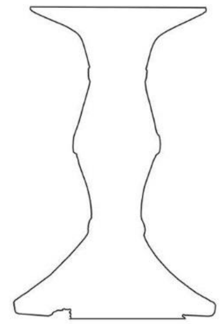
Lattitude: 51.950265
Longitude: 11.692274



Side Profile



Top Profile



Blade Profile

Cross Section

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Loc. Cluster

6

Blade Cluster

9

Hilt Cluster

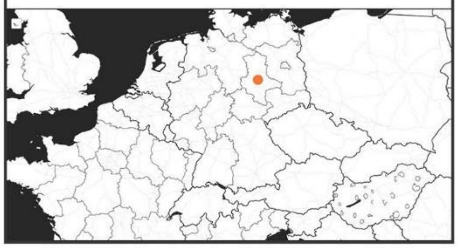
10

BLADE: 17.168

Style: Vollgriffschwerter
Find Type: Cremation/grave

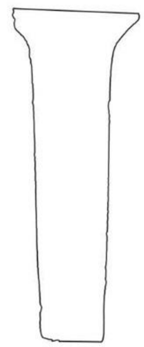
Museum: LH
Accession #: 15555

Lattitude: 53.859336
Longitude: 8.687906

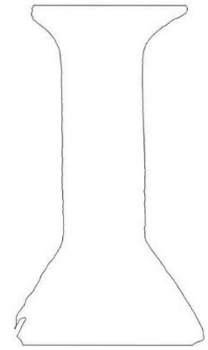


© Landesmuseum Hannover

Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

7

Blade Cluster

1

Hilt Cluster

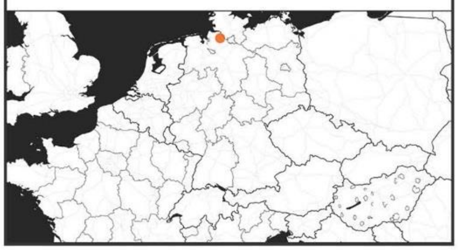
3

BLADE: 17.176

Style: Vollgriffschwerter
Find Type: Unknown

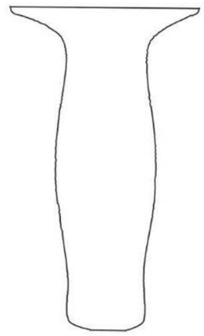
Museum: LH
Accession #: 5430

Lattitude: 53.616427
Longitude: 9.310492

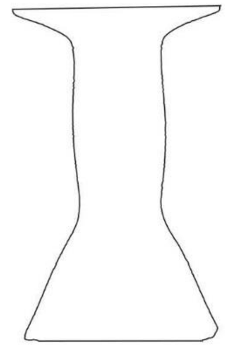


© Landesmuseum Hannover

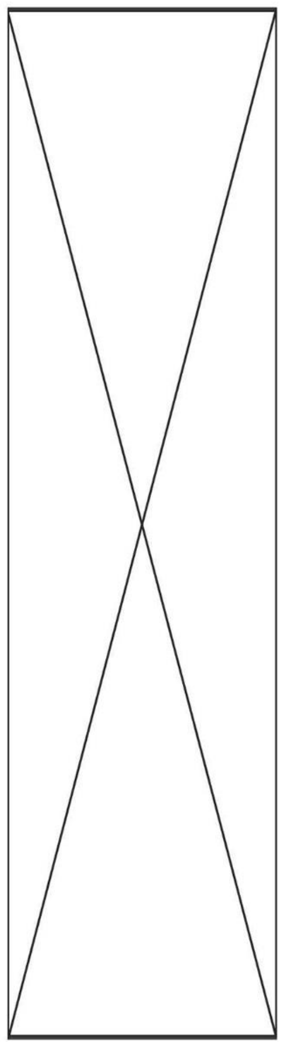
Side Profile



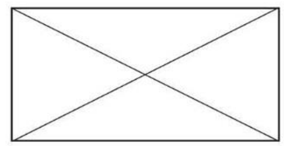
Top Profile



Blade Profile



Cross Section



Loc. Cluster

7

Blade Cluster

-

Hilt Cluster

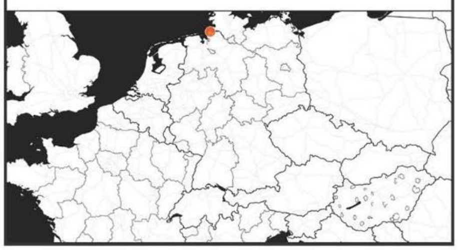
2

BLADE: 17.186

Style: Dreiwulstschwerter
Find Type: Unknown

Museum: LH
Accession #: 5431

Lattitude: 53.859336
Longitude: 8.687906



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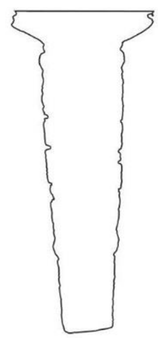
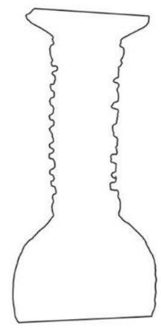
Side Profile



Top Profile



Blade Profile

Cross Section

Loc. Cluster

7

Blade Cluster

-

Hilt Cluster

11

APPENDIX E: DATA COLLECTED

Data can be downloaded in .csv format from the DRUM service at http://hdl.handle.net/11299/180367 in the Statistics folder. The file name is SwordDataStats.csv

St. Dev = standard deviation.
All measurements are in millimeters unless otherwise noted.
Variables included in the table below are:

ID: The first part of the number indicates the PBF volume where the sword is recorded, and the second part indicates the number identifying that sword in the volume.
Category: PBF typological designation.
Find Location: The city or town where the sword was found.
Lat: The latitude of the city where the sword was found.
Lon: The longitude of the city where the sword was found.
Est?: An “x” indicates if the latitude and longitude were estimated using the method described in Chapter 9.
Find type: The type of site the sword was found at.
Length: PBF recorded length in cm.
Frag?: If the sword is fragmented or not.
Museum: The museum where the sword was scanned.
Accession #: The accession number for the sword. These are based on my experience, as some are different that the accession numbers recorded in the PBF volumes.
Rivets: The number of rivets each blade has.
R1x, R1y, R1z: The xyz coordinates for rivet 1.
R2x, R2y, R2z: The xyz coordinates for rivet 2.
Tang height: The height of the tang, in mm.
Average horizontal distance between centers of concentric circles
St. dev average horizontal distance between centers of concentric circles
Average outer circle radius
Average distance between circle lines
St. dev average distance between circle lines
Average distance between parallel curves
St. dev average distance between parallel curves
Average distance between parallel straight lines
St. dev average distance between parallel straight lines
Average wave height
St. dev. of average wave height

ID	Category	Find Location	Lat	Lon	Est?
0.001	*Vollgriffschwerter*	unknown	48.4841	13.0082	x
0.002	*Vollgriffschwerter*	unknown	48.9889	9.8928	x
0.004	*Vollgriffschwerter*	unknown	48.2116	14.1053	x
0.006	*Vollgriffschwerter*	unknown	48.2278	14.0882	x
0.007	*Vollgriffschwerter*	unknown	46.9262	16.9648	x
0.008	*Vollgriffschwerter*	unknown	49.44	12.0234	x
0.009	*Vollgriffschwerter*	unknown	47.2774	14.2387	x
9.005	*Vollgriffschwerter*	Szentgál, Kom. Vesprém	47.1028	17.91	
9.006	*Vollgriffschwerter*	Tata, Kom. Komarom	47.7391	18.13	
9.015	*Vollgriffschwerter*	Komitat Szatmár	48.0395	22	
9.019	*Vollgriffschwerter*	Hungary	47.9852	14.4017	x
9.026	*Dreiwulstschwerter*	Hungary	48.3536	16.9154	x
9.027	Scheibenknaufschwert	Hungary	46.9982	17.5009	x
9.061	*Riegseeschwerter*	Budapest; aus der donau bei der Margeretheninsel	47.4979	19.04	
9.062	*Riegseeschwerter*	Bükkaranyos (ehem. Aranyos), Kom. Borsod-Abaúj-Zemplén	47.9866	20.78	
9.067	*Riegseeschwerter*	Szuhfaő, Kom. Borsod-Abaúj-Zemplén	48.2939	20.69	
9.076	Regály	Viss, Kom. Borsod-Abaúj-Zemplén	48.2614	21.5	
9.079	*Dreiwulstschwerter*	Hungary	47.465	13.867	x
9.113	*Dreiwulstschwerter*	Hungary	48.2961	12.96	x
9.136	*Dreiwulstschwerter*	Hungary	48.0714	12.0267	x
9.145	*Dreiwulstschwerter*	Hungary	47.6392	12.8421	x
9.15	*Dreiwulstschwerter*	Hungary	48.3547	11.8537	x
9.16	*Dreiwulstschwerter*	Szécsény, Kom Nógrád	48.0802	19.52	
9.17	*Dreiwulstschwerter*	Hungary	48.0238	10.4407	x
9.174	*Dreiwulstschwerter*	Hungary	47.5266	13.7386	x

ID	Category	Find Location	Lat	Lon	Est?
9.175	*Dreiwulstschwerter*	Hungary	48.0381	13.6077	x
9.199	*Schalenknaufschwerter*	Budapest, Óbuda	47.5394	19.04	
9.201	*Schalenknaufschwerter*	Keszthely, Kom. Veszprém	47.1028	17.91	
9.202	*Schalenknaufschwerter*	Szikszó, Kom. Borsod-Abaúj-Zemplén	48.2939	20.69	
9.206	*Schalenknaufschwerter*	Oradea, Rumänien	47.0465	21.92	
9.207	*Schalenknaufschwerter*	Cserépfalu, Kom Borsod-Abaúj-Zemplén	48.2939	20.69	
9.211	*Schalenknaufschwerter*	Between Pocsaj (Kom. Hajdú-Bihar) and Diosig (Bihardiószeg, Romania	47.2975	21.9	
9.223	*Schalenknaufschwerter*	Sonkád, Kom. Szabolcs-Szatmár	48.0541	22.75	
9.232	*Schalenknaufschwerter*	Between Pocsaj (Kom. Hajdú-Bihar) and Diosig (Bihardiószeg, Romania	47.2975	21.9	
9.234	*Schalenknaufschwerter*	Tiszakarád, Kom. Borsod-Abaúj-Zemplén	48.2939	20.69	
9.235	*Schalenknaufschwerter*	Hungary	48.7432	17.4501	x
9.244	*Schalenknaufschwerter*	Oradea, Rumänien	47.0465	21.92	
9.249	*Schalenknaufschwerter*	Hungary	47.163	18.3871	x
9.49	Vollgriffdolch	Simleu Silvaniei (Szilágysomlyó), Rumänien	47.2261	22.8	
9.523	*Dreiwulstschwerter*	Oradea, Rumänien	47.0465	21.92	

ID	Category	Find Location	Lat	Lon	Est?
9.524	Scheibenknaufschwert	Siebenbürgen (ehem. Kom. Szolnok-Doboka), Rumänien	46.7715	23.59	
10.003	*Vollgriffschwerter*	Matrei am Brenner, BH. Innsbruck, Tirol, Österreich; Schwermmäcker	47.1257	11.45	
10.021	*Achtkantschwerter*	Bad Wimsbach-Neydharting, BH. Wels, Oberösterreich; Traun-Alm-Eck, between Radlerstein und Haferfeldsteg	48.0632	13.9	
10.023	*Achtkantschwerter*	Gratwein, HB. Graz, Steiermark.	47.0707	15.44	
10.032	*Riegseeschwerter*	Nöfing, Gde. St. Pete am Hart, HB. Braunau, Oberösterreich.	48.2557	13.04	
10.033	*Riegseeschwerter*	Nöfing, Gde. St. Pete am Hart, HB. Braunau, Oberösterreich ; Hagland	48.2557	13.04	
10.034	*Riegseeschwerter*	Peggau, BH. Graz, Steirmark, Österreich; Innsbrucker Straße	47.2056	15.34	
10.037	*Riegseeschwerter*	Scheiben, Gde. St. Georgen ob Judenburg, BH. Judenburg, Steiermark, Österreich;	47.1683	14.66	

ID	Category	Find Location	Lat	Lon	Est?
10.048	*Dreiwulstschwerter*	Mitterndorf, BH. Liezen, Steiermark, Österreich; Rasselam.	47.9975	16.47	
10.048	*Dreiwulstschwerter*	Mitterndorf, BH. Liezen, Steiermark, Österreich; Rasselam.	47.9975	16.47	
10.065	*Dreiwulstschwerter*	Thaur, BH. Innsbruck, Tirol, Österreich	47.2692	11.4	
10.067	*Dreiwulstschwerter*	Innsbruck-Wilten, Tirol, Österreich	47.2561	11.38	
10.068	*Dreiwulstschwerter*	Innsbruck-Mühlau, BH. Innsbruck, Tirol, Österreich; Grave 54a	47.2692	11.4	
10.071	*Dreiwulstschwerter*	Unknown	47.584	11.5364	x
10.081	*Dreiwulstschwerter*	unknown	48.1224	11.8939	x
10.085	*Dreiwulstschwerter*	Aldrans, BH. Hall, Tirol, Österreich; Grab	47.2513	11.45	
10.096	*Schalenknaufschwerter*	Wörschach, BH. Leizen, Steiermark, Österreich; best 1	47.3593	14.47	
10.098	*Schalenknaufschwerter*	Judenburg, Steiermark, Österreich; bei der Ruine Oberwildon	47.1683	14.66	
10.103	*Schalenknaufschwerter*	Linz a.d. Donau, OberÖsterreich	48.3189	14.31	
10.104	*Schalenknaufschwerter*	St. Pantaleon, BH. Braunau, OberÖsterreich	48.2557	13.04	

ID	Category	Find Location	Lat	Lon	Est?
10.105	*Schalenknaufschwerter*	Lambach, BH. Wels, OberÖsterreich	48.1654	14.04	
10.147	*Vollgriffschwerter*	Helpfau-Uttendorf, BH. Braunau, OberÖsterreich; Hochpointfeld	48.1539	13.12	
11.005	*Vollgriffschwerter*	Göggenhofen, Gde. Aying, Kr. München, Bayern	48.1351	11.58	
11.011	*Vollgriffschwerter*	Münsingen, Kr. Reutlingen, Baden-Württemberg; Münsingen Hart	48.4114	9.498	
11.017	*Vollgriffschwerter*	Wangen, Stadt u. Stker. Stuttgart, Baden-Württemberg.	48.7758	9.183	
11.024	*Achtkantschwerter*	Taxöldnerner Forst, kr. Schwandorf, Bayern	49.3199	12.11	
11.026	*Achtkantschwerter*	Mägerkingen, Stadt Trochtefingen, Kr. Reutlingen, Baden Württemberg	48.5069	9.204	
11.03	*Achtkantschwerter*	Glems, Stadt Metzingen, Kr. Reutlingen, Baden-Württemberg	48.5069	9.204	
11.031	*Achtkantschwerter*	Bei Unterföhring, Kr. München, Bayern	48.1351	11.58	

ID	Category	Find Location	Lat	Lon	Est?
11.033	*Achtkantschwerter*	Hausmonig, Gde. Ainring, Kr. Berchtesgandener Land, Bayern	47.8136	12.94	
11.036	*Achtkantschwerter*	Königsdorf, Kr. Bad Tölz-Wolfratshausen, Bayern	47.9102	11.43	
11.037	*Achtkantschwerter*	Grub B. Reuth, Gde. Egglham, Kr. Rottal-Inn, Bayern	48.5292	13.05	
11.04	*Achtkantschwerter*	Wasserburg a. Inn, Kr. Rosenheim, Bayern	47.8571	12.12	
11.042	*Achtkantschwerter*	Unteriesenheim, Gde. Eisenheim, Kr. Würzburg, Bayern	49.7913	9.953	
11.051	*Achtkantschwerter*	Tauernfeld, Gde. Deining, kr. Neumarkt i.d. OPf., Bayern; Hutanger	49.2274	11.54	
11.052	*Achtkantschwerter*	Leonberg, Gde. Marktl, Kr. Altötting, Bayern	48.2246	12.68	
11.066	*Achtkantschwerter*	Ergertshausen, Gde. Egling, kr. Bad Tölz-Wolfrathausen, Bayern	47.9293	11.48	
11.072	*Achtkantschwerter*	Regensburg, Bayern	49.0134	12.1	
11.082	*Vollgriffschwerter*	Alteiselfing, Gde. Eiselfing, Kr. Rosenheim, Bayern	47.8571	12.12	

ID	Category	Find Location	Lat	Lon	Est?
11.083	*Vollgriffschwerter*	Bad Cannstatt, Stadt u. Stkr. Stuttgart, Baden-Württemburg	48.799	9.209	
11.112	*Riegseeschwerter*	Wendlingen a. Neckar, Kr. Esslingen, Baden-Würtemberg	48.6718	9.383	
11.133	*Dreiwulstschwerter*	Germering, Kr. Fürstenfeldbruck, Bayern; Haydnstr. 9-15	48.175	11.32	
11.136	*Dreiwulstschwerter*	Erlach, Stadt Simbach a. Inn, Kr. Rottal-Inn, Bayern	48.2757	13.04	
11.139	*Dreiwulstschwerter*	Rosenheim, Bayern	47.8571	12.12	
11.14	*Dreiwulstschwerter*	Kirchdorf a.d. Iller, Kr. Biberach, Baden-Württemberg	48.0951	9.79	
11.142	*Dreiwulstschwerter*	Klettham, Stadt u. Kr. erding, Bayern	48.3115	11.92	
11.145	*Dreiwulstschwerter*	Geigin, Gde. Rohrdorf, Kr. Rosenheim, Bayern	47.8571	12.12	
11.151	*Dreiwulstschwerter*	Schwaig, Stadt Neustadt a.d. Donau, Kr. Kelheim, Bayern; Grundstück Stegwiese	48.9184	11.89	
11.154	*Dreiwulstschwerter*	Lengdorf, Gde. Rott a. Inn, Kr. Rosenheim, Bayern.	47.8571	12.12	

ID	Category	Find Location	Lat	Lon	Est?
11.158	*Dreiwulstschwerter*	Ehingen (Donaue), Alb-Donau-Kries, Baden-Würtembuerg.	48.598	10.8	
11.161	*Dreiwulstschwerter*	Donauwörth, Kr. Donau-Ries, Bayern	48.8833	10.57	
11.162	*Dreiwulstschwerter*	Gegend von Berchtesgaden, Kr. Berchtesgadener Land, Bayern	47.6302	13	
11.175	*Dreiwulstschwerter*	Gegend des Cheimsees, Bayern	47.8594	12.4	
11.175A	*Dreiwulstschwerter*	Chiemgau, Bayern	48.10751	11.59892	
11.185	*Dreiwulstschwerter*	Froschau, Stadt Waldkraiburg, Kr. Müldorf a. Inn. Bayern	48.2087	12.4	
11.186	*Dreiwulstschwerter*	Mühldorf a. Inn, Kr. Mühldorf a. Inn, Bayern	48.2458	12.52	
11.188	*Schalenknaufschwerter*	Neckarweihingen, Stadt u. Kr. Ludwigsburg, Baden-Württemburg	48.9103	9.223	
11.198	*Schalenknaufschwerter*	Wolkersdorf, Gde. Kirchanschöring, kr. Traunstein, Bayern	47.8678	12.64	
11.206	*Riegseeschwerter*	Stockstadt a. Main, Kr. Aschaffenburg, Bayern	49.9807	9.136	

ID	Category	Find Location	Lat	Lon	Est?
14.231	*Dreiwulstschwerter*	Bingula-Divoš, Gde. Šid, Vojvodina (Syrmien)	45.1258	19.23	
14.234	*Dreiwulstschwerter*	Budinščina, Gde. Zlatar Bistrica, Kroatien; Flur Rebar	46.1287	16.21	
14.236	*Schalenknaufschwerter*	Otok-Privlaka, Gde. Vinkovci, Kroatien	45.2879	18.81	
14.244	*Mörigenschwerter*	Kastav, Gde. Rijka, Kroatien	45.3716	14.35	
15.478	*Mörigenschwerter*	Kehmstedt, Lkr. Nordhausen, Thüringen	51.4727	10.61	
15.479	*Mörigenschwerter*	Kehmstedt, Lkr. Nordhausen, Thüringen	51.4727	10.61	
15.481	*Mörigenschwerter*	Bothenheilingen, Unsttrut-Hainich-Kries, Thüringen	51.1865	10.62	
15.487	*Mörigenschwerter*	Kehmstedt, Lkr. Nordhausen, Thüringen	51.4727	10.61	
15.489	*Mörigenschwerter*	Bothenheilingen, Unsttrut-Hainich-Kries, Thüringen	51.1865	10.62	
15.49	*Vollgriffschwerter*	Kuckenburg, Gem. Eperstedt, Lkr. Merseburg-Quefurt, Sachsen-Anhalt; auf dem Kranberg	51.9503	11.69	
17.168	*Vollgriffschwerter*	Meckelstedt, Gem. Lintig, Ldkr. Cuxhaven	53.8593	8.688	

ID	Category	Find Location	Lat	Lon	Est?
17.176	*Vollgriffschwerter*	Himmelpforten, Ldkr. Stade	53.6164	9.31	
17.186	*Dreiwulstschwerter*	Westerwanna, Gem. Wanna Ldkr. Cuxhaven	53.8593	8.688	

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
0.001	-	-	-	Hungarian National Museum	855/35.1
0.002	-	-	-	Tiroler Landesmuseum Ferdinandeum	1
0.004	-	-	-	Tiroler Landesmuseum Ferdinandeum	18.262
0.006	-	-	-	Tiroler Landesmuseum Ferdinandeum	19.302
0.007	-	-	-	Landesmuseum d. Stiermark Joanneum	6135
0.008	-	-	-	Prahistorische Stattssammlung	1897.191
0.009	-	-	-	Prahistorische Stattssammlung	19,853,000
9.005	single find	19.9	no	Hungarian National Museum	52.32.01
9.006	Single find	10.8	yes	Hungarian National Museum	65/1892.3
9.015	unknown	50	no	Hungarian National Museum	77/1857
9.019	unknown	11.6	yes	Hungarian National Museum	52.29.748
9.026	unknown	61.4	yes	Hungarian National Museum	76/1886
9.027	unknown	47.7	no	Hungarian National Museum	52.29.758
9.061	river	68.1	no	Hungarian National Museum	18.1893.2
9.062	hoard	57.8	no	Hungarian National Museum	43/1895.5
9.067	hoard	62.3	no	Hungarian National Museum	60/1903
9.076	hoard	58.2	no	Hungarian National Museum	74.6.2
9.079	unknown	3.4	yes	Hungarian National Museum	39.1917.1
9.113	unknown	61.4	no	Hungarian National Museum	61.16.78

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
9.136	unknown	56.9	yes	Hungarian National Museum	56/1879.1
9.145	unknown	60.4	no	Hungarian National Museum	62.43.65
9.15	unknown	15.5	yes	Hungarian National Museum	50.1875.15
9.16	unknown	51.8	yes	Hungarian National Museum	81.187
9.17	unknown	68.5	no	Hungarian National Museum	83.32.2
9.174	unknown	51.8	yes	Hungarian National Museum	23/1883.2
9.175	unknown	40.4	no	Hungarian National Museum	62.3.225
9.199	Single find	16.7	yes	Hungarian National Museum	171/1874/4
9.201	Single find	60.8	no	Hungarian National Museum	60.1951.10
9.202	Single find	60.6	no	Hungarian National Museum	25_1944
9.206	hoard	63.2	no	Hungarian National Museum	91/1870.1
9.207	single find	63.5	no	Hungarian National Museum	52.32.69
9.211	hoard	11	yes	Hungarian National Museum	45/1983.2
9.223	Single find	63.3	no	Hungarian National Museum	7.1891
9.232	hoard	20.3	yes	Hungarian National Museum	45/1893.1
9.234	hoard	27.9	yes	Hungarian National Museum	245/1875.1
9.235	unknown	60.2	no	Hungarian National Museum	60.951.11
9.244	hoard	60.4	yes	Hungarian National Museum	91/1870.2
9.249	unknown	69.3	no	Hungarian National Museum	70.2.1
9.49	single find	-	no	Hungarian National Museum	104/1889.2
9.523	Single find	-	-	Hungarian National Museum	62/1907

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
9.524	unknown	-	-	Hungarian National Museum	1.1907.34
10.003	construction	54.5	no	Tiroler Landesmuseum Ferdinandeum	8.934
10.021	river	70.2	no	Oberosterreichisches Landesmuseum	A4332
10.023	plow	60	no	Landesmuseum d. Stiermark Joanneum	8977
10.032	unknown	27	yes	Oberosterreichisches Landesmuseum	A599
10.033	cremation	62.5	yes	Oberosterreichisches Landesmuseum	A607
10.034	unknown	65.5	no	Landesmuseum d. Stiermark Joanneum	16910
10.037	river	-	no	Landesmuseum d. Stiermark Joanneum	6138
10.048	opportunity	60	no	Landesmuseum d. Stiermark Joanneum	4297
10.065	cremation	-	yes	Tiroler Landesmuseum Ferdinandeum	18.757a0d
10.067	near urnfield	65	yes	Tiroler Landesmuseum Ferdinandeum	18596
10.068	cremation	57	no	Tiroler Landesmuseum Ferdinandeum	110
10.071	unknown	27.2	yes	Tiroler Landesmuseum Ferdinandeum	18.093
10.081	unknown	72.7	no	Tiroler Landesmuseum Ferdinandeum	18.506
10.085	grave	67.5	no	Tiroler Landesmuseum Ferdinandeum	109
10.096	cremation	27	yes	Landesmuseum d. Stiermark Joanneum	16167

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
10.098	near ruin	63	no	Landesmuseum d. Stiermark Joanneum	6137
10.103	river	56.6	no	Oberosterreichisches Landesmuseum	A606
10.104	drainage	68	no	Oberosterreichisches Landesmuseum	A04483
10.105	river	68.4	no	Oberosterreichisches Landesmuseum	A609
10.147	-	29	yes	Oberosterreichisches Landesmuseum	A611
11.005	Grave mound	51.6	no	Prahistorische Stattssammlung	1911.874
11.011	grave mound	61.9	no	Wurttemburgisches Landesmuseum	10504
11.017	river	64	yes	Wurttemburgisches Landesmuseum	11333
11.024	grave mound / cremation	58	no	Prahistorische Stattssammlung	NM 3548
11.026	grave mound	66.9	no	Wurttemburgisches Landesmuseum	11433
11.03	plow	67	no	Wurttemburgisches Landesmuseum	V54,23
11.031	river	67.5	no	Prahistorische Stattssammlung	1920.17
11.033	unknown	61	no	Prahistorische Stattssammlung	1937, 50
11.036	river	63.9	no	Prahistorische Stattssammlung	HV80
11.037	field	56	yes	Prahistorische Stattssammlung	1963, 330
11.04	unknown	64.7	no	Prahistorische Stattssammlung	IV570
11.042	river	64.3	no	Wurttemburgisches Landesmuseum	A733
11.051	grave mound	68.5	no	Prahistorische Stattssammlung	IV147

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
11.052	grave mound	66.5	no	Prahistorische Stattssammlung	HV79
11.066	river	63.5	yes	Prahistorische Stattssammlung	1927.54
11.072	river	63.6	no	Prahistorische Stattssammlung	1922.1
11.082	plow	66.4	yes	Prahistorische Stattssammlung	IV128
11.083	river	69.5	no	Wurttemburgisches Landesmuseum	8903
11.112	river	63.5	yes	Wurttemburgisches Landesmuseum	11514
11.133	construction	70.8	no	Prahistorische Stattssammlung	1964, 1021
11.136	river	69.3	no	Prahistorische Stattssammlung	1/1/1903
11.139	river	69.7	no	Prahistorische Stattssammlung	1937.53
11.14	river	68	no	Wurttemburgisches Landesmuseum	A541
11.142	field	51.6	no	Prahistorische Stattssammlung	1969, 246
11.145	field	69.5	no	Prahistorische Stattssammlung	1982, 129
11.151	drainage channel	65	no	Prahistorische Stattssammlung	1921.11
11.154	river	49.3	yes	Prahistorische Stattssammlung	1958.549
11.158	grave	78	no	Wurttemburgisches Landesmuseum	A249
11.161	river	67.5	no	Prahistorische Stattssammlung	1934.3
11.162	unknown	26.9	yes	Prahistorische Stattssammlung	1960.795
11.175	unknown	14.6	yes	Prahistorische Stattssammlung	1954.1
11.175A	construction	-	-	Prahistorische Stattssammlung	1,982,130
11.185	river	69.5	no	Prahistorische Stattssammlung	1936.3

ID	Find Type	Length (in cm)	Frag?	Museum	Accession #
11.186	river	66	no	Prahistorische Stattssammlung	1950.9
11.188	river	54.7	no	Wurttemburgisches Landesmuseum	11148
11.198	river	63.4	no	Prahistorische Stattssammlung	3763
11.206	river	63.9	no	Prahistorische Stattssammlung	NM 1923.12
14.231	hoard	22.3	yes	Arheoloski Muzej	3923
14.234	hoard	16.3	yes	Arheoloski Muzej	10769
14.236	hoard	12.5	yes	Arheoloski Muzej	2195
14.244	grave	46.4	no	Arheoloski Muzej	10468
15.478	hoard	66	no	Landesmuseum Halle Salle	9392
15.479	hoard	55	no	Landesmuseum Halle Salle	9393
15.481	hoard	80.5	no	Landesmuseum Halle Salle	3101428a
15.487	hoard	70	no	Landesmuseum Halle Salle	9391
15.489	hoard	65	no	Landesmuseum Halle Salle	3101428d
15.49	hoard	45.6	no	Landesmuseum Halle Salle	7965
17.168	grave	67.2	no	Niedersachsisches Landesmuseum	15555
17.176	unknown	65.6	no	Niedersachsisches Landesmuseum	5430
17.186	unknown	25.1	yes	Niedersachsisches Landesmuseum	5431

ID	Rivets	R1x	R1y	R1z	R2x	R2y	R2z	Tang Height
0.001	2	3.286	4.404	17.309	4.032	3.6043	16.76	7.5206
0.002	2	7.833	2.756	17.87	7.7	3.6148	18.17	4.5896
0.004	2	5.527	3.608	17.471	7.578	7.6823	17.18	6.7821
0.006	2	9.659	7.391	18.964	8.101	7.0283	16.09	7.2489
0.007	2	5.739	4.608	17.495	4.222	3.9505	16.02	9.2427
0.008	2	9.097	6.328	16.473	3.538	4.382	17.36	7.8163
0.009	2	5.778	3.981	15.215	5.33	3.5469	15.87	7.914
9.005	2	7.262	2.119	16.721	6.454	1.8344	18.79	8.0192
9.006	-	-	-	-	-	-	-	-
9.015	4	6.281	4.301	16.859	6.98	3.5021	15.23	5.3474
9.019	2	5.176	4.189	17.209	4.842	3.5882	17.1	9.801
9.026	-	-	-	-	-	-	-	7.2356
9.027	2	5.544	3.794	18.876	6.485	3.7706	23.09	7.9933
9.061	2	4.296	5.534	17.019	5.054	5.6815	17.52	7.3807
9.062	2	4.654	2.341	19.168	4.801	4.5828	13.95	7.2969
9.067	2	8.145	4.43	16.245	6.059	4.6666	14.73	7.3906
9.076	2	8.37	5.497	14.584	7.371	5.4229	15.17	7.0859
9.079	2	4.3	2.589	19.149	3.535	2.8921	18.61	7.6795
9.113	2	5.717	5.891	18.371	5.462	6.1878	15.53	6.9137
9.136	2	5.925	3.079	14.559	7.312	4.2097	14.82	7.2904
9.145	3	-	-	-	-	-	-	6.6367
9.15	2	4.441	5.207	17.958	5.762	4.9966	17.04	9.4128
9.16	-	-	-	-	-	-	-	5.2699
9.17	2	5.871	1.635	17.863	5.743	1.2951	19	7.6384
9.174	2	6.729	4.151	16.057	5.464	3.8387	16.57	6.1955
9.175	5	5.292	5.144	17.617	5.745	5.0588	18.06	5.034
9.199	2	6.33	3.306	19.723	6.496	2.3488	16.13	7.4355
9.201	2	7.934	2.403	19.783	5.827	2.8655	16.35	3.4685
9.202	2	7.963	4.504	19.289	6.424	2.7765	13.67	8.9235
9.206	2	7.669	4.376	20.314	6.229	3.5474	14.8	9.0097
9.207	2	5.426	2.842	19.242	5.731	2.7759	19.74	7.4551
9.211	2	8.248	1.028	18.224	6.574	1.3415	14.2	8.0516
9.223	2	7.636	1.735	17.276	8.141	3.0335	18.51	9.0518
9.232	2	6.176	2.034	21.482	10.16	3.6201	25.83	10.3257
9.234	2	8.034	2.884	19.462	6	2.6854	18.44	8.1549
9.235	2	4.919	4.78	18.097	8.052	2.601	22.34	40.8474

ID	Rivets	R1x	R1y	R1z	R2x	R2y	R2z	Tang Height
9.244	2	5.276	3.257	16.766	6.077	7.1064	18.23	8.6762
9.249	2	4.405	3.54	15.668	7.197	1.7859	22.57	7.3025
9.49	3	6.337	4.034	11.676	5.857	4.6442	12.91	5.4389
9.523	-	-	-	-	-	-	-	7.5322
9.524	3	6.446	7.063	18.266	6.602	3.657	19.37	7.9215
10.003	2	7.24	3.826	16.466	7.858	2.45	17.1	4.9859
10.021	2	7.258	3.996	17.306	7.315	3.2222	20.56	6.7346
10.023	2	8.294	4	16.777	9.099	3.1438	20.8	5.4795
10.032	2	6.551	2.162	18.964	8.71	6.2468	16.71	7.208
10.033	2	6.805	3.165	16.294	7.094	3.143	18.42	6.9448
10.034	2	6.753	3.762	15.76	7.639	3.086	16.74	6.7633
10.037	2	8.91	2.929	16.949	8.016	2.5599	18.72	7.2296
10.048	2	3.268	5.415	15.695	3.286	4.7025	18.12	9.1452
10.065	2	9.426	2.895	16.861	7.402	0.4134	16.66	8.5088
10.067	2	8.367	3.276	15.967	7.997	4.4303	15.91	36.5726
10.068	2	9.625	2.592	17.446	8.175	3.5039	12.74	7.2832
10.071	2	5.8	2.889	17.929	5.404	3.0021	18.44	8.0148
10.081	2	7.594	0.86	18.389	7.31	4.4482	16.79	8.9689
10.085	2	5.043	4.605	16.768	7.197	5.1578	16.71	9.5055
10.096	2	3.981	3.856	18.58	6.261	4.3628	19.6	9.6883
10.098	2	7.328	5.029	18.339	6.219	3.0909	14.44	8.9751
10.103	2	7.169	2.129	17.141	6.569	2.1603	16.57	7.1998
10.104	2	7.209	4.362	19.753	7.017	4.6204	19.92	7.6732
10.105	2	3.842	3.335	15.256	5.441	1.2276	17.31	10.1297
10.147	2	8.066	4.164	12.111	7.084	4.446	10.51	5.4285
11.005	2	8.799	5.092	16.053	9.722	4.4909	15.47	4.8559
11.011	4	8.008	4.477	16.917	8.252	3.7439	16.93	4.5693
11.017	-	-	-	-	-	-	-	8.0219
11.024	2	10.17	3.287	16.092	9.726	3.8789	18.45	3.8642
11.026	2	9.368	4.866	19.381	8.734	4.6367	18.18	4.6092
11.03	2	9.809	6.219	20.28	8.791	6.6291	17.56	7.2854
11.031	2	8.402	5.289	19.195	8.332	4.7712	18.43	5.1206
11.033	2	9.923	5.266	18.068	10.76	4.9031	19.2	6.976
11.036	2	10.4	4.995	18.186	9.271	7.2905	19.83	6.7397
11.037	2	6.057	5.628	16.003	5.937	6.3059	17.37	6.171
11.04	2	10.85	6.556	16.984	9.545	9.3286	18.34	7.0564
11.042	2	7.208	5.556	19.114	7.399	5.7807	16.81	6.0313

ID	Rivets	R1x	R1y	R1z	R2x	R2y	R2z	Tang Height
11.051	2	5.59	4.558	20.325	7.5	3.9941	15.03	6.4498
11.052	2	5.985	6.007	17.669	8.832	5.5509	17.43	7.426
11.066	2	10.16	5.53	18.248	11.69	5.4196	17.1	6.0637
11.072	2	9.287	4.65	17.786	9.102	5.0466	14.98	5.9298
11.082	2	3.443	4.706	17.003	5.08	4.4146	18.69	10.4867
11.083	2	4.006	3.687	16.649	4.653	3.5846	18.34	8.2873
11.112	2	5.784	4.561	16.552	8.166	3.1319	20	6.2036
11.133	2	7.21	4.395	15.619	9.02	4.8569	18.99	8.4863
11.136	2	8.17	4.118	16.754	6.652	5.4805	14.4	8.1202
11.139	2	8.092	3.208	17.136	8.298	1.7143	17.38	3.7953
11.14	2	9.437	4.977	15.535	8.102	3.0282	18.23	7.4717
11.142	2	3.735	2.773	17.168	4.131	3.27	16.68	5.242
11.145	2	9.199	5.01	18.344	8.097	5.4748	17.5	9.787
11.151	2	6.253	3.45	19.615	7.913	3.6937	18.72	7.3544
11.154	2	4.617	3.755	17.388	6.429	3.3816	18.08	8.1616
11.158	2	5.527	3.737	17.98	6.267	4.0142	17.09	9.3303
11.161	2	5.571	3.421	18.626	6.753	1.7748	15.13	6.9438
11.162	2	9.232	3.989	16.632	9.407	5.0252	20.63	9.8246
11.175	2	2.212	2.875	16.464	3.218	2.7099	15.9	8.4826
11.175A	2	5.904	3.597	16.914	5.371	4.4195	18.83	7.3369
11.185	2	5.887	2.456	16.364	6.227	3.0876	20.3	6.1057
11.186	2	6.734	4.568	14.752	6.465	3.56	17.49	6.2781
11.188	2	4.805	3.547	15.599	3.982	3.5845	16.01	5.1168
11.198	2	7.172	2.897	17.108	9.265	3.8955	16.25	7.2312
11.206	2	8.187	4.562	19.597	8.992	4.882	17.81	8.6156
14.231	2	9.893	3.012	16.822	11.7	3.0638	17	5.7816
14.234	-	-	-	-	-	-	-	6.3483
14.236	2	12.12	3.031	17.643	11.23	4.9606	18.08	6.1839
14.244	2	6.443	4.12	15.38	6.438	4.2319	15.1	17.546
15.478	-	-	-	-	-	-	-	7.0111
15.479	-	-	-	-	-	-	-	7.9798
15.481	-	-	-	-	-	-	-	8.0718
15.487	-	-	-	-	-	-	-	7.4884
15.489	-	-	-	-	-	-	-	5.6994
15.49	-	-	-	-	-	-	-	7.3027
17.168	2	9.302	5.5	17.684	6.456	5.5672	17.67	6.0068
17.176	2	7.589	5.605	18.095	10.13	6.9519	19	7.3754

ID	Rivets	R1x	R1y	R1z	R2x	R2y	R2z	Tang Height
17.186	4	11.74	4.896	13.622	21.01	2.9403	7.117	4.3603

ID	Average horizontal distance between centers of concentric circles	St. dev average horizontal distance between centers of concentric circles	Average outer circle radius	St. dev average outer circle radius
0.001	10.8309	1.0644	3.7515	0.0275
0.002	12.6623	1.7405	4.8814	0.2485
0.004	10.466725	0.1915	3.963	0.5795
0.006	15.1163	-	2.936	0.0719
0.007	-	-	-	-
0.008	-	-	-	-
0.009	-	-	-	-
9.005	-	-	-	-
9.006	-	-	-	-
9.015	-	-	-	-
9.019	-	-	-	-
9.026	-	-	-	-
9.027	-	-	-	-
9.061	-	-	-	-
9.062	-	-	-	-
9.067	9.0989	0.5907	3.7709	0.1382
9.076	-	-	-	-
9.079	-	-	-	-
9.113	-	-	-	-
9.136	-	-	-	-
9.145	-	-	-	-
9.15	-	-	-	-
9.16	-	-	-	-
9.17	-	-	-	-
9.174	-	-	-	-
9.175	-	-	-	-
9.199	-	-	-	-
9.201	5.5731	0.2334	2.473	0.0803
9.202	-	-	-	-
9.206	-	-	-	-
9.207	3.8653	0.6482	1.7979	0.6812
9.211	5.3162	0.6143	2.2626	0.0455
9.223	9.6185	1.1753	4.6183	0.6877

ID	Average horizontal distance between centers of concentric circles	St. dev average horizontal distance between centers of concentric circles	Average outer circle radius	St. dev average outer circle radius
9.232	10.9335	0.7001	4.4868	1.5557
9.234	-	-	-	-
9.235	11.5013	0.9707	4.6716	1.6248
9.244	-	-	-	-
9.249	-	-	-	-
9.49	-	-	-	-
9.523	-	-	-	-
9.524	-	-	-	-
10.003	-	-	-	-
10.021	-	-	-	-
10.023	-	-	-	-
10.032	9.8223	2.4801	3.842	0.3683
10.033	12.2692	-	4.774	0.1139
10.034	11.094	-	4.61	0.9241
10.037	-	-	-	-
10.048	-	-	-	-
10.065	-	-	-	-
10.067	16.3498	-	3.12506	0.2393
10.068	-	-	-	-
10.071	-	-	-	-
10.081	-	-	-	-
10.085	-	-	-	-
10.096	10.5971	0.6409	4.9406	0.2961
10.098	9.2492	0.4811	4.3363	0.2802
10.103	-	-	-	-
10.104	-	-	-	-
10.105	-	-	-	-
10.147	-	-	-	-
11.005	-	-	-	-
11.011	-	-	-	-
11.017	-	-	-	-
11.024	-	-	-	-
11.026	-	-	-	-
11.03	8.4812	0.6925	3.592	0.3928

ID	Average horizontal distance between centers of concentric circles	St. dev average horizontal distance between centers of concentric circles	Average outer circle radius	St. dev average outer circle radius
11.031	-	-	-	-
11.033	8.4168	0.7238	3.007	0.6163
11.036	7.8622	0.5905	2.8208	0.2515
11.037	8.1698	0.7861	3.3111	0.4878
11.04	4.4982	1.0024	3.1128	0.8129
11.042	8.2947	1.0563	3.1782	0.5205
11.051	-	-	-	-
11.052	14.5642	-	5.9735	0.1467
11.066	-	-	-	-
11.072	-	-	-	-
11.082	-	-	-	-
11.083	-	-	-	-
11.112	-	-	-	-
11.133	-	-	-	-
11.136	-	-	-	-
11.139	-	-	-	-
11.14	-	-	-	-
11.142	-	-	-	-
11.145	-	-	-	-
11.151	16.7577	-	3.0763	0.0595
11.154	-	-	-	-
11.158	16.1413	-	2.6506	0.0907
11.161	-	-	-	-
11.162	18.3811	-	1.9888	0.1733
11.175	-	-	-	-
11.175A	-	-	-	-
11.185	-	-	-	-
11.186	-	-	-	-
11.188	-	-	-	-
11.198	8.7658	0.9249	4.5844	0.5155
11.206	13.9273	0.2291	3.3045	0.0722
14.231	-	-	-	-
14.234	13.0849	0.644	3.1145	0.3646
14.236	-	-	-	-

ID	Average horizontal distance between centers of concentric circles	St. dev average horizontal distance between centers of concentric circles	Average outer circle radius	St. dev average outer circle radius
14.244	-	-	-	-
15.478	-	-	-	-
15.479	-	-	-	-
15.481	-	-	-	-
15.487	-	-	-	-
15.489	-	-	-	-
15.49	-	-	-	-
17.168	-	-	-	-
17.176	8.283	0.7624	3.2531	0.3279
17.186	-	-	-	-

ID	Average distance between circle lines	St. dev average distance between circle lines	Average distance between parallel curves	St. dev average distance between parallel curves
0.001	0.8897	0.0711	1.6047	1.022
0.002	0.5839	0.1229	-	-
0.004	1.1993	0.3597	-	-
0.006	1.1145	0.1853	2.3344	0.2502
0.007	-	-	-	-
0.008	-	-	-	-
0.009	-	-	-	-
9.005	-	-	0.5469	0.1039
9.006	-	-	-	-
9.015	-	-	-	-
9.019	-	-	-	-
9.026	-	-	-	-
9.027	-	-	-	-
9.061	-	-	-	-
9.062	-	-	-	-
9.067	0.9752	0.2097	-	-
9.076	-	-	-	-
9.079	-	-	-	-
9.113	-	-	0.9226	0.1286
9.136	-	-	0.8202	0.22
9.145	-	-	-	-
9.15	-	-	-	-
9.16	-	-	-	-
9.17	-	-	-	-
9.174	-	-	-	-
9.175	-	-	-	-
9.199	-	-	0.5212	0.105
9.201	0.3917	0.0878	0.4535	0.0895
9.202	-	-	-	-
9.206	-	-	1.006	0.1611
9.207	0.4478	0.0915	0.4584	0.0845
9.211	0.5102	0.1243	0.4654	0.1107
9.223	0.5489	0.1174	0.5192	0.1105

ID	Average distance between circle lines	St. dev average distance between circle lines	Average distance between parallel curves	St. dev average distance between parallel curves
9.232	0.7923	0.1307	0.8324	0.1797
9.234	-	-	-	-
9.235	0.4652	0.0904	-	-
9.244	-	-	-	-
9.249	-	-	-	-
9.49	-	-	-	-
9.523	-	-	-	-
9.524	-	-	-	-
10.003	-	-	-	-
10.021	-	-	-	-
10.023	-	-	-	-
10.032	0.7244	0.1217	-	-
10.033	0.9803	0.1551	-	-
10.034	0.9379	0.2144	-	-
10.037	-	-	-	-
10.048	-	-	-	-
10.065	-	-	-	-
10.067	1.271	0.3302	1.4133	0.203
10.068	-	-	-	-
10.071	-	-	-	-
10.081	-	-	0.6823	0.2067
10.085	-	-	0.6179	0.0993
10.096	0.4937	0.1051	0.4567	0.0918
10.098	0.4374	0.1285	0.5607	0.1057
10.103	-	-	-	-
10.104	-	-	-	-
10.105	-	-	-	-
10.147	-	-	-	-
11.005	-	-	-	-
11.011	-	-	-	-
11.017	-	-	-	-
11.024	-	-	-	-
11.026	-	-	-	-
11.03	0.837	0.217	-	-

ID	Average distance between circle lines	St. dev average distance between circle lines	Average distance between parallel curves	St. dev average distance between parallel curves
11.031	-	-	-	-
11.033	0.9737	0.1692	-	-
11.036	0.8474	0.1176	-	-
11.037	0.8797	0.1682	-	-
11.04	1.1043	0.2755	-	-
11.042	0.902	0.1772	-	-
11.051	-	-	-	-
11.052	0.9157	0.1913	-	-
11.066	-	-	-	-
11.072	-	-	-	-
11.082	-	-	-	-
11.083	-	-	-	-
11.112	-	-	-	-
11.133	-	-	-	-
11.136	-	-	2.426	0.3207
11.139	-	-	-	-
11.14	-	-	-	-
11.142	-	-	-	-
11.145	-	-	-	-
11.151	1.148	0.0942	1.4156	0.2118
11.154	-	-	-	-
11.158	1.0239	0.1779	0.8534	0.1534
11.161	-	-	0.8002	0.2428
11.162	0.639	0.178	0.5867	0.1418
11.175	-	-	-	-
11.175A	-	-	0.8291	0.1914
11.185	-	-	-	-
11.186	-	-	-	-
11.188	-	-	-	-
11.198	0.7783	0.2727	-	-
11.206	0.7508	0.1739	-	-
14.231	-	-	-	-
14.234	1.3602	0.3996	-	-
14.236	-	-	-	-

ID	Average distance between circle lines	St. dev average distance between circle lines	Average distance between parallel curves	St. dev average distance between parallel curves
14.244	-	-	0.9923	0.2539
15.478	-	-	-	-
15.479	-	-	-	-
15.481	-	-	-	-
15.487	-	-	-	-
15.489	-	-	-	-
15.49	-	-	-	-
17.168	-	-	-	-
17.176	0.9074	0.2237	-	-
17.186	-	-	-	-

ID	Average distance between parallel straight lines	St. dev average distance between parallel straight lines	Average wave height	St. dev. of average wave height
0.001	-	-	-	-
0.002	0.6699	0.197	-	-
0.004	2.999	0.2858	10.0505	0.2286
0.006	-	-	7.3435	0.2934
0.007	0.4519	0.0478	-	-
0.008	-	-	-	-
0.009	1.3059	0.2646	7.7037	0.9757
9.005	0.4934	0.1095	-	-
9.006	-	-	-	-
9.015	1.2872	0.2841	-	-
9.019	1.1356	0.2064	-	-
9.026	-	-	-	-
9.027	0.4562	0.0804	12.631	0.5357
9.061	1.369	0.1756	-	-
9.062	2.8182	0.2313	-	-
9.067	2.6672	0.8311	-	-
9.076	2.8823	0.1788	-	-
9.079	-	-	-	-
9.113	-	-	-	-
9.136	1.0563	0.1588	-	-
9.145	0.7096	0.2181	-	-
9.15	-	-	-	-
9.16	-	-	-	-
9.17	-	-	-	-
9.174	-	-	-	-
9.175	-	-	-	-
9.199	0.5718	0.0949	-	-
9.201	0.4239	0.1164	10.044	0.8974
9.202	0.6073	0.0624	-	-
9.206	-	-	8.4591	1.1002
9.207	0.4604	0.0821	11.2847	0.902
9.211	0.6257	0.1107	11.2096	0.8319
9.223	0.4813	0.0745	-	-

ID	Average distance between parallel straight lines	St. dev average distance between parallel straight lines	Average wave height	St. dev. of average wave height
9.232	0.6902	0.1604	-	-
9.234	0.6029	0.1158	-	-
9.235	0.4963	0.1002	-	-
9.244	0.5217	0.1098	-	-
9.249	-	-	-	-
9.49	-	-	-	-
9.523	-	-	-	-
9.524	-	-	-	-
10.003	-	-	-	-
10.021	-	-	-	-
10.023	-	-	-	-
10.032	1.0847	0.4574	-	-
10.033	1.2577	0.2507	-	-
10.034	1.9148	0.5189	-	-
10.037	-	-	-	-
10.048	-	-	-	-
10.065	1.0488	0.1304	9.814	0.5515
10.067	1.5259	0.2232	9.7165	0.5773
10.068	1.021	0.2203	-	-
10.071	1.0643	0.2183	-	-
10.081	0.6372	0.1399	-	-
10.085	0.6191	0.1205	9.5848	0.8979
10.096	0.4106	0.0777	-	-
10.098	0.501	0.1012	-	-
10.103	-	-	-	-
10.104	-	-	-	-
10.105	-	-	-	-
10.147	1.3769	0.2175	-	-
11.005	1.0758	0.1834	-	-
11.011	1.5753	0.4121	-	-
11.017	-	-	-	-
11.024	-	-	-	-
11.026	0.7147	0.0497	-	-
11.03	1.0173	0.2684	-	-

ID	Average distance between parallel straight lines	St. dev average distance between parallel straight lines	Average wave height	St. dev. of average wave height
11.031	1.122	0.3399	-	-
11.033	1.8379	0.2807	-	-
11.036	0.8728	0.1658	-	-
11.037	0.8054	0.1304	-	-
11.04	0.8813	0.1701	-	-
11.042	0.7988	0.1463	-	-
11.051	0.8088	0.1957	-	-
11.052	0.6313	0.1438	6.505	0.4091
11.066	-	-	-	-
11.072	-	-	-	-
11.082	1.311	0.2829	-	-
11.083	-	-	-	-
11.112	-	-	-	-
11.133	1.229	0.201	9.0722	0.5614
11.136	2.8431	0.103	9.3931	0.5615
11.139	1.4394	0.3426	7.4828	0.6451
11.14	-	-	-	-
11.142	1.7216	0.19535	7.4477	0.3447
11.145	1.6515	0.1148	9.4854	0.3453
11.151	-	-	-	-
11.154	1.5615	0.4274	9.285	0.7738
11.158	0.8985	0.1315	7.3781	0.2208
11.161	0.8917	0.1921	7.9204	0.7507
11.162	0.7113	0.1691	10.8272	0.9565
11.175	0.9065	0.1169	-	-
11.175A	1.3144	0.1286	-	-
11.185	-	-	-	-
11.186	-	-	-	-
11.188	-	-	-	-
11.198	0.8376	0.333	-	-
11.206	0.8545	0.1657	-	-
14.231	-	-	-	-
14.234	-	-	-	-
14.236	-	-	-	-

ID	Average distance between parallel straight lines	St. dev average distance between parallel straight lines	Average wave height	St. dev. of average wave height
14.244	0.7805	0.1008	-	-
15.478	-	-	-	-
15.479	-	-	-	-
15.481	-	-	-	-
15.487	-	-	-	-
15.489	-	-	-	-
15.49	-	-	-	-
17.168	0.9399	0.2497	-	-
17.176	0.8073	0.1644	-	-
17.186	-	-	-	-

ID	Average wave width	St. dev. of average wave width	Average distance between wave centers	St. dev. average distance between wave centers	Average dash length
0.001	-	-	-	-	-
0.002	-	-	-	-	-
0.004	6.7556	0.2084	10.4667	0.1915	1.347
0.006	5.6896	0.2982	8.0812	0.6473	1.562
0.007	-	-	-	-	1.0249
0.008	-	-	-	-	-
0.009	6.8737	1.0177	9.1492	0.7884	-
9.005	-	-	-	-	2.032
9.006	-	-	-	-	-
9.015	-	-	-	-	-
9.019	-	-	-	-	-
9.026	-	-	-	-	-
9.027	9.4581	0.5376	-	-	-
9.061	-	-	-	-	-
9.062	-	-	-	-	-
9.067	-	-	-	-	1.1723
9.076	-	-	-	-	2.6528
9.079	-	-	-	-	-
9.113	-	-	-	-	3.6026
9.136	-	-	-	-	5.5967
9.145	-	-	-	-	-
9.15	-	-	-	-	-
9.16	-	-	-	-	-
9.17	-	-	-	-	-
9.174	-	-	-	-	-
9.175	-	-	-	-	-
9.199	-	-	-	-	1.7012
9.201	10.0443	0.8974	9.7603	1.4815	2.6768
9.202	-	-	-	-	-
9.206	7.8376	0.882	9.994	0.6075	3.1512
9.207	9.6464	0.9028	10.504	1.1519	1.2431
9.211	9.5367	0.8357	10.1901	0.7044	1.9764

ID	Average wave width	St. dev. of average wave width	Average distance between wave centers	St. dev. average distance between wave centers	Average dash length
9.223	-	-	-	-	1.7471
9.232	-	-	-	-	2.0416
9.234	-	-	-	-	-
9.235	-	-	-	-	2.1373
9.244	-	-	-	-	2.2301
9.249	-	-	-	-	-
9.49	-	-	-	-	-
9.523	-	-	-	-	-
9.524	-	-	-	-	-
10.003	-	-	-	-	-
10.021	-	-	-	-	-
10.023	-	-	-	-	-
10.032	-	-	-	-	1.8101
10.033	-	-	-	-	-
10.034	-	-	-	-	-
10.037	-	-	-	-	-
10.048	-	-	-	-	-
10.065	8.788	1.7504	11.2671	0.258	-
10.067	6.9316	1.122	10.2317	0.649	2.0243
10.068	-	-	-	-	-
10.071	-	-	-	-	-
10.081	-	-	-	-	-
10.085	8.69	0.7864	-	-	1.6208
10.096	-	-	-	-	-
10.098	-	-	-	-	1.4616
10.103	-	-	-	-	-
10.104	-	-	-	-	-
10.105	-	-	-	-	-
10.147	-	-	-	-	-
11.005	-	-	-	-	-
11.011	-	-	-	-	-
11.017	-	-	-	-	-
11.024	-	-	-	-	-
11.026	-	-	-	-	-

ID	Average wave width	St. dev. of average wave width	Average distance between wave centers	St. dev. average distance between wave centers	Average dash length
11.03	-	-	-	-	-
11.031	-	-	-	-	-
11.033	-	-	-	-	-
11.036	-	-	-	-	-
11.037	-	-	-	-	1.2324
11.04	-	-	-	-	-
11.042	-	-	-	-	-
11.051	-	-	-	-	-
11.052	6.0458	0.4516	8.2969	0.826	-
11.066	-	-	-	-	-
11.072	-	-	-	-	-
11.082	-	-	-	-	-
11.083	-	-	-	-	-
11.112	-	-	-	-	-
11.133	7.4781	0.3502	9.9102	1.06	-
11.136	7.1808	0.754	10.4714	0.7526	-
11.139	6.4514	1.077	9.3023	0.5122	-
11.14	-	-	-	-	-
11.142	6.9287	1.4796	7.7152	0.1504	-
11.145	7.9791	1.0911	10.3302	2.424	-
11.151	-	-	-	-	-
11.154	8.7302	2.1814	9.9229	1.2149	-
11.158	8.07	2.7992	10.4821	2.6871	-
11.161	0.8022	0.5433	7.5359	1.8191	-
11.162	9.5431	1.3757	9.4249	1.6303	1.8852
11.175	-	-	-	-	1.8122
11.175A	-	-	-	-	-
11.185	-	-	-	-	-
11.186	-	-	-	-	-
11.188	-	-	-	-	-
11.198	-	-	-	-	-
11.206	-	-	-	-	-
14.231	-	-	-	-	-
14.234	-	-	-	-	-

ID	Average wave width	St. dev. of average wave width	Average distance between wave centers	St. dev. average distance between wave centers	Average dash length
14.236	-	-	-	-	1.2775
14.244	-	-	-	-	-
15.478	-	-	-	-	-
15.479	-	-	-	-	-
15.481	-	-	-	-	-
15.487	-	-	-	-	-
15.489	-	-	-	-	-
15.49	-	-	-	-	-
17.168	-	-	-	-	-
17.176	-	-	-	-	-
17.186	-	-	-	-	-

ID	St. dev. average dash length	Average distance between dashes	St. dev. average distance between dashes
0.001	-	-	-
0.002	-	-	-
0.004	0.2975	0.7713	0.2373
0.006	0.2478	1.0211	0.1387
0.007	0.1939	0.9133	0.1982
0.008	-	-	-
0.009	-	-	-
9.005	0.6153	0.7555	0.1604
9.006	-	-	-
9.015	-	-	-
9.019	-	-	-
9.026	-	-	-
9.027	-	-	-
9.061	-	-	-
9.062	-	-	-
9.067	0.2498	0.6032	0.1621
9.076	0.5064	1.8507	0.4319
9.079	-	-	-
9.113	0.5039	0.582	0.179
9.136	0.8743	0.7645	0.1028
9.145	-	-	-
9.15	-	-	-
9.16	-	-	-
9.17	-	-	-
9.174	-	-	-
9.175	-	-	-
9.199	0.2894	0.77556	0.1086
9.201	0.8272	0.5254	0.1057
9.202	-	-	-
9.206	0.7777	0.8812	0.14
9.207	0.2425	0.8069	0.2351
9.211	0.3486	0.7721	0.1782
9.223	0.2526	0.6623	0.1355
9.232	0.3603	1.0195	0.2022

ID	St. dev. average dash length	Average distance between dashes	St. dev. average distance between dashes
9.234	-	-	-
9.235	1.4426	0.9517	0.2745
9.244	0.5201	0.5005	0.1252
9.249	-	-	-
9.49	-	-	-
9.523	-	-	-
9.524	-	-	-
10.003	-	-	-
10.021	-	-	-
10.023	-	-	-
10.032	0.3919	0.5982	0.1134
10.033	-	-	-
10.034	-	-	-
10.037	-	-	-
10.048	-	-	-
10.065	-	-	-
10.067	0.5171	1.1238	0.2526
10.068	-	-	-
10.071	-	-	-
10.081	-	-	-
10.085	0.3818	0.6371	0.1216
10.096	-	-	-
10.098	0.7029	0.6239	0.1855
10.103	-	-	-
10.104	-	-	-
10.105	-	-	-
10.147	-	-	-
11.005	-	-	-
11.011	-	-	-
11.017	-	-	-
11.024	-	-	-
11.026	-	-	-
11.03	-	-	-
11.031	-	-	-
11.033	-	-	-

ID	St. dev. average dash length	Average distance between dashes	St. dev. average distance between dashes
11.036	-	-	-
11.037	0.2362	0.5711	0.1265
11.04	-	-	-
11.042	-	-	-
11.051	-	-	-
11.052	-	-	-
11.066	-	-	-
11.072	-	-	-
11.082	-	-	-
11.083	-	-	-
11.112	-	-	-
11.133	-	-	-
11.136	-	-	-
11.139	-	-	-
11.14	-	-	-
11.142	-	-	-
11.145	-	-	-
11.151	-	-	-
11.154	-	-	-
11.158	-	-	-
11.161	-	-	-
11.162	0.4061	0.7909	0.2667
11.175	0.2808	1.0189	0.1641
11.175A	-	-	-
11.185	-	-	-
11.186	-	-	-
11.188	-	-	-
11.198	-	-	-
11.206	-	-	-
14.231	-	-	-
14.234	-	-	-
14.236	0.217	1.9186	0.3606
14.244	-	-	-
15.478	-	-	-
15.479	-	-	-

ID	St. dev. average dash length	Average distance between dashes	St. dev. average distance between dashes
15.487	-	-	-
15.489	-	-	-
15.49	-	-	-
17.168	-	-	-
17.176	-	-	-
17.186	-	-	-

Appendix F: Clustered groups and communities

The following table includes the clusters to which each blade belongs. Data can be downloaded in .csv format from the DRUM service at http://hdl.handle.net/11299/180367 in the Statistics folder. The file name is LocationAndClusterData.csvAbbreviations are as follows, with the number to the right being the number of groups for each clustering option:

LC = Location clusters: 6 (Note that estimated locations were not used for this analysis.)
BC = Blade clusters: 12
HC = Hilt clusters: 10
CC = Concentric circle clusters: 3
DC = Dash clusters: 5
CPC = Curved Parallel Clusters: 4
SPC = Straight Parallel Clusters: 8
CD1 = Community Detection with a resolution of 1: 5
CD.8 = Community Detection with a resolution of .8: 12

Id	LC	BC	HC	CC	DC	CPC	SPC	CD1	CD.8
0.001			4	1		3		2	3
0.002			1	2			3	2	7
0.004			1	1	1		6	4	3
0.006			1	3	2	4		1	6
0.007			1		2		5	2	7
0.008			1					1	2
0.009			1				2	1	0
9.005	1		4		1	1	5	2	7
9.006	1		4					0	1
9.015	1		7				2	3	4
9.019			7				1	1	2
9.026			7					1	2
9.027		6	2				5	2	7
9.061	1	2	1				2	3	5
9.062	1	6	1				6	4	3
9.067	1	4	1	1	3		6	4	3
9.076	1	6	1		4		6	1	2
9.079			1					1	2
9.113		11	1		3	2		1	0
9.136			1		5	2	1	1	2
9.145		5	5				3	1	7
9.15			7					3	4

Id	LC	BC	HC	CC	DC	CPC	SPC	CD1	CD.8
9.16	1		5					1	2
9.17		8	2					1	0
9.174			2					1	0
9.175			3					2	7
9.199	1		1		1	1	3	2	7
9.201	1	11	1	1	3	1	5	2	7
9.202	1	7	1				3	2	7
9.206	1		3		2	2		2	7
9.207	1	7	1	1	1	1	5	2	7
9.211	1		1	1	1	1	3	2	7
9.223	1	7	1	2	3	1	5	2	7
9.232	1		1	2	2	2	3	2	7
9.234	1		1				3	2	7
9.235		5	1	2	2		5	2	7
9.244	1		2		3		5	2	7
9.249		7	1					2	7
9.49	1		1					3	4
9.523	1		1					1	2
9.524	4		1					2	7
10.003	2	4	1					3	4
10.021	2	1	1					1	4
10.023	2		1					3	4
10.032	2		1	2	3		1	1	2
10.033	2		1	2			2	1	0
10.034	2	1	1	2			8	1	4
10.037	2	4	1					1	0
10.048	1	10	1					1	6
10.065	2		4				1	2	4
10.067	2		7	3	2	3	7	1	6
10.068	2	8	3				1	1	2
10.071			6				1	1	2
10.081		12	6			2	3	1	7
10.085	2	11	6		3	1	3	2	7
10.096	2		10	2		1	5	2	7
10.098	2	3	2	2	3	1	5	2	7
10.103	2	5	9					2	7
10.104	2		1					3	4
10.105	2	7	6					2	7
10.147	2		7				2	3	5
11.005	2		1				1	3	4

Id	LC	BC	HC	CC	DC	CPC	SPC	CD1	CD.8
11.011	3	10	1				7	3	4
11.017	3		11					2	4
11.024	3	9	1					3	4
11.026	3	1	2				3	2	7
11.03	3	4	2	1			1	4	3
11.031	2	6	2				1	1	2
11.033	2	4	2	1			8	4	3
11.036	2	10	2	1			4	4	3
11.037	2		2	1	3		4	4	3
11.04	2	3	2	1			4	4	3
11.042	3	3	2	1			4	4	3
11.051	3	3	2				4	4	3
11.052	2	2	2	2			3	3	7
11.066	2	11	2					1	2
11.072	3	2	3					3	5
11.082	2		8				2	3	4
11.083	3	2	8					3	4
11.112	3		2					1	4
11.133	2	2	4				2	3	5
11.136	2	2	4			4	6	3	5
11.139	2	2	3				2	3	5
11.14	3	2	4					3	5
11.142	2	6	3				7	1	6
11.145	2	2	3				7	3	5
11.151	3	6	3	3		3		1	6
11.154	2		3				7	1	6
11.158	3	8	4	3		2	4	1	6
11.161	3	2	4			2	4	3	5
11.162	2		3	3	1	1	3	2	7
11.175	2		4		2		4	1	6
11.175A	2					2	2	3	0
11.185	2	9	4					1	0
11.186	2	8	4					1	0
11.188	3	7	2					1	0
11.198	2	11	5	2			4	2	7
11.206	3	12	9	3			4	4	6
14.231	6		8					3	4
14.234	6		3	3				1	6
14.236	6		3		4			1	2
14.244	6	5	3			2	4	2	7

Id	LC	BC	HC	CC	DC	CPC	SPC	CD1	CD.8
15.478	4	2	7					3	5
15.479	4	10	7					3	5
15.481	4	2	7					3	5
15.487	4	2						3	5
15.489	4	2	10					3	5
15.49	4		10					3	0
17.168	5	3	1				4	4	3
17.176	5		2	1			4	4	3
17.186	5		11					2	4