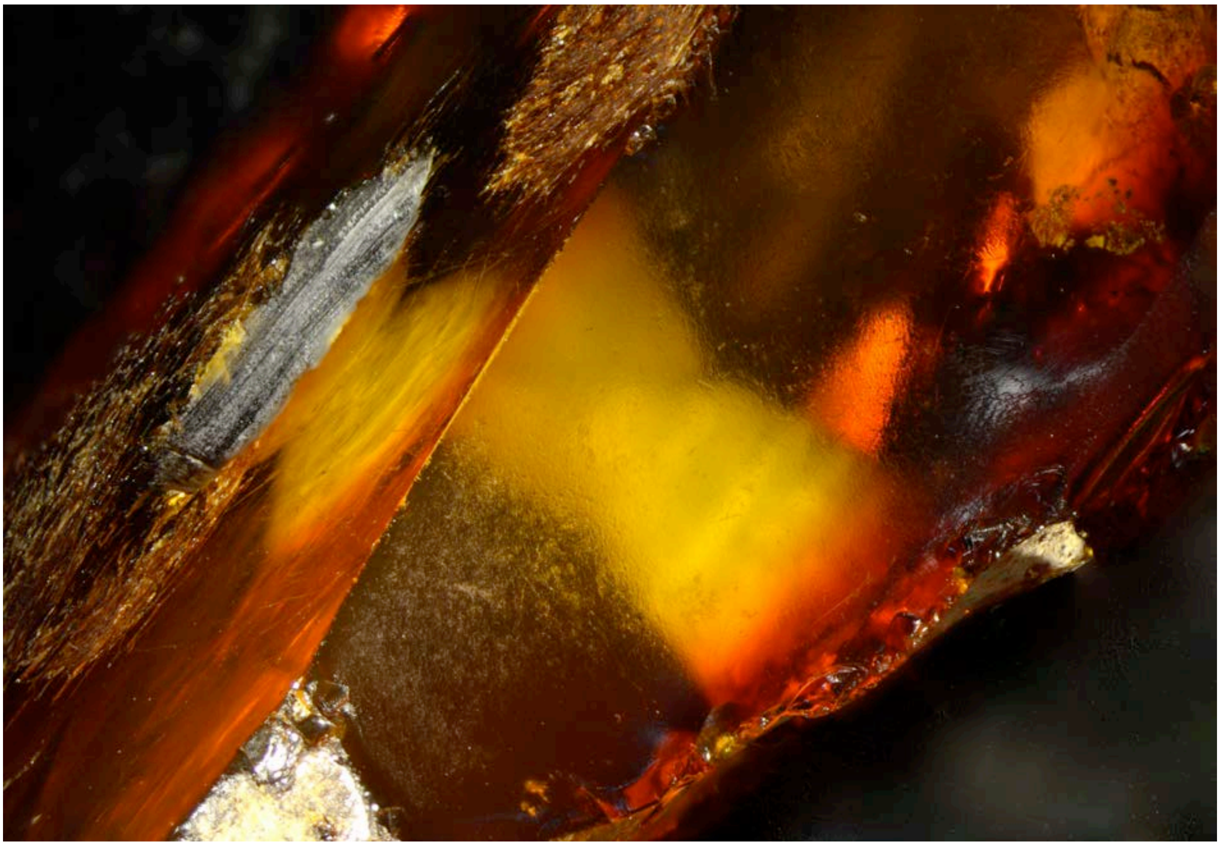
The Marks of Metal

An experimental project using microwear analysis to investigate prehistoric amber beads from the northern Netherlands



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An experimental project using microwear analysis to investigate prehistoric amber beads from the northern Netherlands

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Chapter 1: Introduction to the thesis project

1.1. Aims and central research questions

The primary aim of this thesis is to investigate the production process of amber beads, focusing on whether it is possible to determine which tool material was used based on the production traces present in the finished bead. This question relates to the overarching question of when metal was first used as a material for functional tools in past societies.

It is hypothesised that the earliest metal objects would not have been used as functional tools and, even if they were, had no superiority to previous materials such as bone or flint in terms of strength or ease of production ((Kienlin 2008; Kuijpers 2008). At some point in the past, however, metallurgy as a technological practise became inherently related to everyday social interactions, and since that point has been an essential material within society (Vandkilde 1996). How, then, can archaeologists see this transformation in relationship between metallurgy and society? The earliest metal found in the archaeological record is usually associated with ritual depositions, and thus provides no evidence for the daily use of functional metal objects, but only shows that metal as a material was present within society at that time (Vandkilde 1996; Kuijpers 2012). Due to the easy recyclability of metal (Bray and Pollard 2012), it is suggested that everyday metal objects would have been re-melted after use, and thus were not discarded in a convenient and dateable stratigraphic layer (Kuijpers 2012). Alternative methods of identifying the functional use of metal in prehistoric societies have therefore been proposed. One suggested method is through indirect investigation; by examining and consequently dating the traces that metal tools leave on objects that they have created (cf. Christidou 2008). Experimental archaeology and microwear analysis can contribute to this investigation. By documenting when and where metal has been used to create other objects made from different materials, rather than deposited in a ritual context, it could be possible to see the spread of metallurgy as it started to be used as an essential functional material within the prehistoric technological system (Greenfield 2008). In order to conduct this investigation, several studies have utilised experimental archaeology complemented by microwear analysis to determine which production marks are left by metal tools versus tools made from different materials.

The first experimental studies that addressed this idea considered the morphological characteristics of butchering tool marks on bones, and suggested that it was possible to see a difference between grooves left by metal versus stone tools (Walker and Long 1977; Greenfield 1999; Greenfield 2008). Similar experiments on bone were also carried out by Christidou (2008), but rather than looking at butchery marks, the author examined the differences between intentionally carved marks left by bronze, iron, and steel tools. Christidou (2008) argued that there was a definite difference between those marks left by bronze and iron, and those left by steel. The two most relevant case studies for this thesis were carried out by John Gwinnet and Leonard Gorelick (Gwinnet and Gorelick 1987; Gwinnet and Gorelick 1991). Through various experiments, they showed that differences can be seen in the manufacturing traces of beads and seals when different materials are used for the drill-bit (Gwinnet and Gorelick 1981). Their attempt to determine when a change from stone to copper drills might have occurred in Mesopotamia produced a range of comparable experimental pieces. These pieces not only showed a difference in morphological characteristics of the manufacturing traces between different materials, but were also able to be directly compared with the archaeological record (Gwinnet and Gorelick 1987).

The results of all of these case studies show that, through experimental archaeology complemented by microwear analysis, differences can be seen in the manufacturing traces of tools made from different materials. This is particularly relevant for this thesis, as it suggests that a distinction could be made between the different tool materials used to produce, for example, amber beads. By looking at the morphological characteristics of metal versus flint and antler tools on the experimentally produced amber beads, it is therefore possible to contribute to the ongoing discussion of when metal started to be used in the past. The reason for using amber beads as a specific case study for the current research project was due to their presence within the majority of Late Neolithic and Bronze Age sites in the geographic region of the northern Netherlands (Waterbolk and Waterbolk 1991) where this thesis is based. This then allowed a high level of accessibility to the required archaeological collections, the contexts of which are provided in section 2.1.3.

Based on the research methodology of previous studies investigating the spread of metallurgy by examining the production marks left by different tool materials, this thesis project used experimental archaeology complemented by microwear analysis. First, an experimental collection of cut and drilled amber nodules were created. The cutting and drilling stages of the bead production process were chosen as a focus for the current study, as these are the only two stages that could have involved the use of metal tools, as will be further described in section 3.2. These experimentally produced pieces were then microscopically examined, and a list of microwear traces characteristic for each tool material was created. These characteristic traces were then compared against those traces identified on beads from the archaeological collections, in order to attempt to determine which tool materials may have been used to create those beads. The importance of this research relates to the significant changes that occurred within prehistoric society, which were essential to our progression into modern society and yet the full details of which we still do not know. The onset of metallurgy was an essential technological innovation, without which we would certainly not be the society that we are today. In order to gain a greater understanding of how this prehistoric innovation occurred, further research must therefore be conducted investigating different methods of identifying metal use in the past. The aim of this thesis is not to conclusively say when metal started to be used as a functional material in the Northern Netherlands, as such as broad question cannot be answered in a Master's thesis project. In contributing to the information gathered as part of previous studies such as those mentioned above, however, it can provide a further data set towards the investigation of metallurgical practices in prehistory.

1.2. Structure of the thesis project

The second chapter of this thesis provides the wider archaeological context of the research project. It considers the archaeological context of the amber beads studied, as well as the material properties and wider significance of amber for prehistoric societies. In addition, this chapter focuses on the social significance of bead making and a brief introduction to the *chaîne opératoire* utilised in previous experimental studies.

The third chapter then provides a more detailed overview of the various stages of bead production, particularly those stages which were addressed within the present study, namely cutting of the raw nodule and perforation through drilling. The cutting experiments were completed using a bronze knife and copper saw. The drilling experiments were completed using drill-bits made from flint, antler, malachite, copper, and bronze, utilising both a bow-drill and a hand-drill technique. In addition, Chapter 3 discusses the methodological approaches utilised in the present study, namely experimentation and microwear analysis, with a focus on the benefits but also the potential issues of both techniques.

Chapter 4 presents the analysis from the experimental aspect of the research project. This includes the results of the blind test, a description of the traces created by the cutting experiments, and an overview of the characteristic production traces created during the drilling experiments.

Chapter 5 then applies these results to the analysis of the three archaeological collections that were investigated during the thesis. The results from both of these chapters are then discussed in detail in chapter 6, and concluding remarks and directions for future research are presented in the seventh and final chapter.

1.3. Conclusion

A current assumption within archaeological discourse is that the origin of metalworking in the past cannot be based on the presence of metal objects within the archaeological record due to their recyclable properties. In order to address this problem, several studies have instead investigated the traces left by different tool materials in order to determine whether certain traces can be considered characteristic of metal tool use. The present study utilises experimental archaeology complemented by microwear analysis to investigate traces created by stone, antler, and metal tools during the production of amber beads, focusing particularly on the cutting and drilling stages of bead production.

Chapter 2: Archaeological context and previous research studies

Before describing the methodology used in this research, it is first important to provide some information about the archaeological and wider research context of this thesis. It should be stressed that the applicability of the current research is not limited to a single past cultural group. The location of the researcher at Leiden University facilitated the examination of archaeological collections from the modern geographical region of the Netherlands. The three sites from which the archaeological collections originated (Kolhorn, Emmerdennen, and Hijken Hooghalen) are presented in section 2.1.3. The research methodology developed for the current thesis can however be applied universally to all studies concerning the production of amber beads. A more detailed discussion of the general points of amber processing are therefore also provided below, as well as the significance of amber in the past, and the principles and *chaîne opératoire* of bead production.

2.1. Background to the archaeological collections

2.1.1. Amber in Dutch prehistory

Amber objects have been discovered in many archaeological excavation in the Netherlands, particularly within the context of graves and hoards (Butler 1990). The raw amber nodules (*succinite*) used to produce objects in prehistory are believed to have originated mainly in Baltic deposits (Sprincz and Beck 1981; Kars and Boon 1993; Van Gijn 2006). Amber then became available to societies living in the Northern European lowlands through two possible ways: trade through eastern Europe (Todd *et al* 1976; Sprincz and Beck 1981) or transportation by tidal streams through the North Sea, where it was then collected on beaches along the northern shores (Van Gijn 2006). Amber beads in particular can be found at Dutch sites ranging throughout the whole of the prehistoric period, although are most plentiful in sites dating to the Middle Bronze Age (Kars and Boon 1993). The identification of prehistoric production sites and the analysis of trade routes has led Dutch archaeologists to suggest that amber beads discovered in the modern region of the Netherlands were produced and circulated on a local level (Butler 1990; Van Gijn 2014a). The three different sites used within this research ranging from the Late Neolithic to the Middle Bronze Age, described in section 2.1.3, provide a sufficient chronological variation against which to compare the experimentally produced beads, and also hopefully account for any variations in production techniques and tool materials used throughout this time period. This is particular relevant considering the cultural differences evident throughout the Netherlands up until the start of the Bell Beaker Culture (Fokkens 2005), which may have also led to differences in craft production activities, for example that of bead making.

2.1.2. An overview of the prehistory of the Netherlands

Before providing a description of the archaeological collections that were examined in the context of this research, a brief cultural background to the prehistory of the geographic region currently defined as the Netherlands should first be presented. The Early Neolithic saw the emergence of famously homogenous LBK society, which then disintegrated into smaller units c.4200BC, such as the Swifterbant culture in the Northern Netherlands and the Hazendonk culture in the South (Van Gijn and Louwe Kooijmans 2005). Settlements and subsistence practices associated with the beginning of agriculture then emerged with the onset of the Funnel Beaker and Vlaardingen cultures after around 3400BC (Van Gijn & Louwe Kooijmans 2005, 211). The oldest archaeologist collection of amber beads that were studied in this thesis, however, is associated with a site from the Single Grave Culture, which is believed to have emerged from the Funnel Beaker Culture in the Late Neolithic in the north of Holland c.2900BC (Van Gijn 2014a). The Single Grave Culture, which as the name implies is defined by the presence of individual burials as opposed to group graves, then dissipated in the Early Bronze Age to make way for the Bell Beaker Culture, which is believed to have emerged from the Vlaardingen Culture (Van Gijn and Louwe Kooijmans 2005, 211). Unlike previous cultural groups, which had inhabited regions along an approximate north/south divide, the Bell Beaker Culture is particularly important within Dutch archaeology because it covered the entirety of the lowland area (Fokkens 2005, 359; Van Gijn 2010). It is also a significant cultural group in terms of the main aim of the current research, as it is the first in the prehistory of the Netherlands to exhibit evidence of metalworking (Butler 1966; Butler and Fokkens 2005, 377). Any archaeological amber bead collections dating from the Early Bronze Age onwards, for example those from Emmerdennen and Hijken Hooghalen described below, could therefore contain microwear traces created by metal tools.

It should be noted that the list of cultures provided above does not imply, for example, that all evidence of the Single Grave Culture stopped directly at the onset of the Bell Beaker Culture.

Instead, prehistoric society was a fluid and dynamic mixture of cultural influences, through which it is possible to see a steady progression in terms of, for example, the emergence of agriculture and the use of metal.

2.1.3. An overview of the archaeological collections analysed

Due to the time restrictions of the thesis project, and the focus on the experimentation, only three archaeological collections were selected for direct analysis. The consequences of these limitations and how they can be avoided in future expansions of this thesis project will be discussed in further detail in Chapter 5. The geographic location of all three sites can be seen on the map below (fig. 1). These three collections, although relatively small in terms of sample size, were considered sufficient to provide an archaeological data set against which to compare the experimentally produced beads within the current research, particularly when complimented by references to similar analyses previously conducted on prehistoric amber beads in the Netherlands.

Figure 1. Map of the Netherlands showing the origin of the three archaeological collections

Kolhorn

The settlement site of Kolhorn was excavated between 1979 and 1986 and was dated to c.2600-2450BC and so associated with the late Single Grave Culture (Drenth and Kars 1990, 21). Other Single Grave Culture sites in the same region show a relative level of uniformity in their subsistence patterns and built landscape. The sites of Mienakker (Kleijne *et al* 2013) and Zeewijk (Theunissen *et al* 2014), for example, both show evidence that they were inhabited throughout the year but with seasonal variation in their subsistence practices, most of which were focused on the breeding of stock. From this evidence, it is safe to say that by the Late Neolithic these societies were all firmly established in a dominantly agricultural lifestyle. Hunting did not play a major role at Mienakker (Kleijne *et al* 2013, 252), and only wild boar were hunted with any regularity at Zeewijk (Theunissen *et al* 2014, 260), however both sites show evidence that cattle were kept close to the settlement and crops were cultivated and processed on site. This provides further evidence of a permanent settlement, where food-processing and crafting activities were initiated and carried out at the settlement location. Considering this self-sufficient and settlement-based lifestyle, it might be suggested that while trade may have already been a major part of Late Neolithic life in this region, it was perhaps not essential. Based on this suggestion, the analysis of beads from any of these Single Grave Culture sites is therefore likely to reveal evidence only of what particular production processes were being conducted at each specific site, rather than as objects that were potentially traded between sites. Despite this assumption, there do appear to be similarities between previously investigated Single Grave Culture sites from the region of Kolhorn in terms of the amber production waste evident, for example Aartswoud (Piena and Drenth 2001), Mienakker (Garcia Diaz 2013), and Zeewijk (van Gijn 2014a). This strongly suggests that, while the amber beads may not have been directly traded between settlements, there was an exchange of ideas and thus a high level of interaction between the different communities.

Based on their high preservation and visibility of production traces, 23 beads from a total of 40 were examined from Kolhorn. It is believed that the beads were produced on site, as can be seen from the presence of production waste and half products (Drenth and Kars 1990). This can also be seen at other Single Grave Culture sites such as those mentioned above. As well as production waste, the Kolhorn material also contains many examples of broken beads and demonstrates variation in both amber and bead types (fig. 2).

Figure 2. Examples of beads from the archaeological collection from Kolhorn

Emmerdennen

The site of Emmerdennen consisted of a cemetery of twelve tumuli, which were excavated in 1932 (Bursch 1936, cited in Butler 1990, 58). One of the tumuli, referred to as tumulus 11, comprised of a sod-built mound dated to the Middle Bronze Age B, approximately 1500-1050 BC (Arnoldussen and Scheele 2011). The Middle Bronze Age in the Netherlands is characterised by a structured organisation of the landscape, particularly burial patterns such as the Emmerdennen tumuli, which have been suggested to provide evidence for a cyclic relationship between Middle Bronze Age society and landscapes associated with their past (Arnoldussen and Fontijn 2006, 308). This idea of Middle Bronze Age society being not only aware of their ancestry but also actively interacting with their past can also be seen through the re-use of barrows and tumuli (Arnoldussen and Fontijn 2006; Arnoldussen and Scheele 2011). Considering this point, it is possible to assume that grave goods, such as amber beads, were deposited alongside the deceased with a particular purpose, and could indeed have been specially produced or at least prepared for such an occasion, as already suggested in Funnel Beaker burial practices (Van Gijn 2014b, 698).

Tumulus 11 from Emmerdennen contained two coffin burials, one of which held no grave goods but the second of which included two pottery vessels, bronze and flint splinters, and a necklace consisting of 26 amber beads (Bursch 1936, cited in Butler 1990, 58). As yet, the individual within the grave is of unknown origin and status. A random selection of 13 of the amber beads were examined, as it was not possible to investigate the complete necklace. The beads are all disc-shaped and range from a diameter of 4.8cm and a thickness of 1.25cm to a diameter of 1.35cm and a thickness of 0.55cm (fig. 3). According to a review of the site by Butler (1990), it was first believed that the beads originated as part of a necklace which was worn by the individual buried within the grave. According to Butler, however, the apparent disarray of the beads on their discovery and the presence of double-perforated beads "hardly seems an adequate basis” for decided that the beads were worn as a necklace (Butler 1990, 58). An alternative option could be that they were worn on a headband, as suggested from a Bell Beaker grave at Hanzelijn (Drenth *et al* 2011, 214). Further analysis and a more detailed discussion of their potential wear and use is provided in section 5.2.

Figure 3. Examples of beads from the archaeological collection from Emmerdennen

Hijken Hooghalen

A full review of the excavation of the Hijken Hooghalen tumuli, which took place between 1952 and 1953, was provided by Van der Veen and Lanting (1989). The site consists of a total of sixteen barrows dating from the beginning of the Late Neolithic Singe Grave period to the end of the Middle Bronze Age, with a secondary period covering the Middle and Late Iron Age. Those graves from containing amber beads were situated in tumuli 6, 10, and 9, which were all dated to the Middle Bronze Age and consisted of sand and turf mounds surrounded by a ditch or post circle. All of the beads excavated from the site were examined. Those from tumulus 9 consist of a hypothesised necklace of 16 complete disc-shaped beads ranging from a diameter of 1cm and a thickness of 0.5cm to a diameter of 2cm and a thickness of 1cm. The 8 remaining beads from the other two tumuli are perforated but appear to be unshaped, and so an average thickness and diameter cannot be provided here. This range of bead shape and size can be seen below (fig. 4).

In addition to the similarity of being a structured burial landscape suggesting a strong link between prehistoric society and their past, as mentioned above (Arnoldussen and Fontijn 2006), the amber beads from the tumuli at Hijken Hooghalen are remarkably similar to those discovered at Emmerdennen. This is hardly surprising considering their close geographical proximity (fig.1). Geological and environmental changes from the Late Neolithic to the Middle Bronze Age restricted accessibility between different regions of the Netherlands, thus leading to the formation of regionally specific cultural groups (Fokkens 2005, 357). Despite this regional identity, however, the similarity in form between those beads at Hijken Hooghalen and Emmerdennen strongly suggest a link between the two regions, either in terms of cultural identity and social structure, or of exchange through trade.

Figure 4. Examples of beads from the archaeological collection from Hijken Hooghalen

2.2. The properties and significance of amber

Amber has been used in the creation of ornaments from the Palaeolithic until the present day (King 2007). The earliest known example of the intentional working of amber was a perforated and engraved nodule from the Palaeolithic site of Meiendorf in northern Germany (Waterbolk and Waterbolk 1991). In terms of physical and geological classification, amber is an organic substance. It originates as tree resin, which is transported by natural means to become submerged in sediments known as 'gley' where it then fossilizes to become the material that modern scientists classify as amber (King 2006). Several of its properties, however, mean that it is often mistaken for an inorganic mineral. For example, it has an average hardness of 2.15 on the Mohs scale, breakages exhibiting conchoidal fracture, variation in lustre, and occasional fluorescence beneath ultraviolet light (King 2006). Is it therefore possible that prehistoric societies might have seen amber as another type of stone and used it accordingly. This can be implied through many archaeological contexts, for example in the amber elk from northern Germany that was carved in the same style as other elk statues carved from stone (Veip *et al* 2012), or in amber beads from Britain and the Netherlands carved in a similar style as beads made from jet (Woodward 2002; Van Gijn 2006).

However, the names used for amber in classical and historical periods suggests that several of amber's properties were already known from prehistory onwards. For example, the Greek word 'λέκτρον', meaning both 'amber' and 'electricity', refers to the material's electrostatic properties, and the Spanish word 'ámbar', originating from the Arabic 'عنبر', meaning "which floats on the sea", refers to amber's low relative density (Murillo-Barroso and Martinón-Torres 2012, 187). How far back were these properties known? Were prehistoric societies therefore also aware of the differences between amber and other materials such as minerals? More importantly; how does this physical classification affect the interpretation of archaeological amber artefacts? Although it is easier in terms of categorisation to use modern definitions when identifying archaeological materials, we should not assume that people in the past also used these definitions (Hurcombe 2007; Kuijpers 2008). In other words, we should not enforce our modern classification of materials onto past societies. For example, many archaeologists categorise amber objects separately from objects made from other materials such as stone when conducting archaeological reports. This distinction then subconsciously implies that amber objects were also categorised differently in prehistoric societies, which may not in fact have been the case. It should be noted that the ideas put forth here are not meant to imply that archaeologists should always classify amber within the same grouping as stone objects. Instead, archaeologists should simply always consider the possibility that amber was not necessarily seen as a distinct and special material throughout prehistory. The symbolic importance of amber can, however, also be seen through, for example, the Chinese myth that describes it as the soul of deceased tigers, or the fact that in ancient Rome an amber talisman was more expensive than a healthy slave (King 2006). Even in prehistory, Woodward (2002) suggests that amber beads may have performed a more symbolic function as heirlooms or relics. Whether amber was indeed a symbolic material is a subject of some contention amongst material analysts. As mentioned above, it is important to consider every possibility, and understand that prehistoric societies may have had a range of attitudes and ideas concerning amber as a material.

2.3. An introduction to bead making in the past

2.3.1. The social significance of bead making

"The study of bead manufacture and changing styles of beaded ornaments is an important method for investigating the social and economic developments of a society" (Kenoyer 2005). This quotation perfectly encapsulates the reason why beads remain an important subject of analysis within archaeology. Beads can be found in nearly every society from the Palaeolithic until the modern day (Childe 1955). As a form of ornamentation, they held and continue to hold a certain value as they were meant to reflect the personhood of the person who wore them (Van Gijn 2010). In other words, their creation was not stimulated by functional requirements, as can be the case with other objects such as tools, but was instead more strongly influenced by cultural ideologies. This is not to say that the creation of tools cannot be influenced in a similar way (Sillar and Tite 2000), more that beads are usually not associated with functionality. Because of this, ornamentation such as beads are therefore seen as a fundamental part of understanding prehistoric society (Thomas 2011) and can thus be used to examine the changes within past societies in terms of economic and social developments, as described below.

For example, the introduction of stone beads in the Levant in the early Neolithic, compared to previous beads made from organic materials such as bone, shell, and antler, appears to coincide with the adoption of agriculture (Groman-Yaroslavski and Bar Yosef Mayer 2015). This suggests that the related technical innovations associated with agriculture, for example ground stone tools with sharper cutting edges, would perhaps have also enabled the cutting and drilling of harder stone beads (Leakey 1955). Although softer amber material would not require such improved tools, this example is provided here to show how changes in technology can affect the production of beads. As well as practical technological influences, transformations in social ideologies could also have affected the bead making process. For example, evidence from the site of Hajar in Yemen suggests that hard stones were often chosen instead of soft stones as they reflected a higher social status, despite the easier workability of the latter (Gwinnet and Gorelick 1991). In a similar way, African societies imitated the ritually significant and socially identifying styles and colours of earlier stone beads when making glass beads, despite the technical difficulty involved (Labelle 2005). From a more theoretical viewpoint, Isazá Aizpurúa and McAnany (1999) have suggested that the presence of beads and other ornamentation in graves implies that those involved in the funeral rites believed that the deceased should be prepared for beyond death, which then suggests a belief in some sort of afterlife, therefore providing information on the cosmological viewpoint of the society involved. An alternative suggestion, based on evidence from Funnelbeaker burials, is that beads were specially re-worked and deposited in graves in order to be removed from circulation, as had the person with whom they were associated (Van Gijn 2014b). Regarding the changes over time in the materials used to make beads, one potential explanation relates to the wider variety of ornamentation possible (Wright and Garrard 2003). As beads are a form of ornamentation, they are seen as expressing the wearer's identities (Van

Gijn 2006). A greater variation in bead types and materials therefore provides a wider range of 'expressions' for an individual.

In summary, through the investigation of changes in bead production it is also possible to see developments within a society, for example technological progressions or changes in social ideologies.

2.3.2. The *chaîne opératoire* of bead making

The precise *chaîne opératoire* used in bead making depends on the materials used, however it is possible to see some universal consistency in the general production process. First, the raw material required for making the beads must be sourced. This is done either through passive methods such as collection from above ground in the case of shells, amber, and some stones (Waterbolk and Waterbolk 1991; Isazá Aizpurúa and McAnany 1999), or else more active methods such as hunting or trading in the case of ivory and antler (Thomas 2011), or quarrying in the case of some stones (Wright *et al* 2008). The next stages vary considerably depending on the material. Considering that the focus of this thesis is on amber, mineral materials of similar hardness on the Mohs scale, such as different types of stone, were considered rather than organic materials such as shell and bone (Wright *et al* 2008). To demonstrate the variation with which such materials were worked into beads in the past, the general stages of the *chaîne opératoire* are presented below alongside several case studies. It should be noted that the following overview is meant only to provide a short introduction to the bead making process. A full description of the methodology that was used in the current research project is presented in section 3.4.

Shaping

The first stage of shaping the bead varied considerably even within a society. Remains from Early Neolithic bead making activities at a site in Southern Jordan suggest that sourced amazonite fragments were first flaked and then either shaped through grinding, perforated through drilling with a flint borer, and polished, or else were perforated before shaping and then polished (Fabiano *et al* 2001). In the Indian region of Khambhat, however, ethnographic evidence suggests that the original nodules of agate were not flaked but were instead sawn in order to conserve the raw materials (Kenoyer *et al* 2011). Similarly, in North-western Costa Rica, evidence has been found of string sawing used to split nodules of jade into appropriate sizes, the oldest evidence of which can be seen on a figurine from the Olmec culture (Lothrop 1955). Suggestions have been made that amber could also have been cut using this method of string sawing, based on evidence from amber beads found at Aartswoud (Bulten 2001, cited in Verschoof 2010, 43). Once the initial blank had been prepared through either flaking or sawing, it was then shaped further using either rough abrasive materials such as coarse stone, or else softer materials enhanced with abrasives such as basalt and quartz sand, as was used on carnelian beads from the Levant (Groman-Yaroslavski and Bar-Yosef Mayer 2015). Considering these case studies, it is possible to see a general pattern amongst the variation. This shaping and grinding is the first major stage in the production of a bead.

Drilling

Another important stage in a bead's *chaîne opératoire* is the drilling of the perforation. The earliest evidence of perforated objects comes from the Upper Palaeolithic (Leakey 1955). The first perforating technique is thought to have been using the method of percussion, although evidence of awls and borers accompanied by finer perforations suggests that ancient man soon improved their technique (Childe 1955). It is now instead generally agreed that most if not all prehistoric perforations were made using a rotating drill as opposed to percussive techniques (Thomas 2011), however variety can be seen not only in terms of the material used as a drill-bit but also in terms of the technological method employed. This latter variation can often be seen by looking at the shape of the perforations themselves (Wright *et al* 2008). For example, a biconical perforation suggests that the bead was drilled halfway through on one side, and then from the other side until the two perforations met to become one (Groman-Yaroslavski and Bar-Yosef Mayer 2015). From this, it can therefore be assumed that a conical perforation is achieved by drilling only from one side. Further experimental research has shown that cylindrical perforations are produced when using a hollow drill bit, such as those made from copper in South America (Childe 1955) or suggested bird bone in the Netherlands (Piena and Drenth 2001; Van Gijn 2006).

The material of the drill bit can also be seen by looking not only at the shape of the perforation, but also at the microwear traces within it. Previous studies have already suggested that this is possible based on a combination of experimental and analytical research, as described in the previous chapter. The complete methodological framework used for such studies, and which was used for the current research project, is described in detail in section 3.2. Previous research, however, has already suggested that a conical perforation with irregular striations could have been caused by a flint drill-bit (Van Gijn 2006), while more regularly spaced scratches could have been left by organic materials such as wood or antler (Van Gijn 2014a), and a narrower, smoother perforation could suggest a harder material allowing a sharper edge, such as metal (Thomas 2011).

Further variation evident within the perforation stage of the bead production process relates to the way the drill was used, which often depends on the bead material. For example, experimental research on the production of carnelian beads from the Levant showed that a hand-held palm drill was insufficient to pierce the material, and instead a pump-drill was used along with an abrasive made from sand (Groman-Yaroslavski and Bar-Yosef Mayer 2015). The use of hand drilling was, however, able to pierce Dabba marble, as suggested from microscopic and experimental analysis from a Neolithic site in Eastern Jordan (Wright *et al* 2008). Another technology is the bow-drill, which is believed to fall between the hand- and pump-drills in terms of technological development, although all three are still used today for various activities by different indigenous groups (Childe 1955).

Polishing

Polishing of beads usually involves soft abrasion and an accompanying polishing lubricant, for example using leather or wood with oil or animal fat (Groman-Yaroslavski and Bar-Yosef Mayer 2015). Other possible options, similar to modern-day techniques of polishing, include the use of progressively finer abrasives until all manufacturing traces are erased (Gwinnet and Gorelick 1991). A similar option demonstrated through ethnographic studies is that of 'tumbling', which involves placing the beads to be polished into a bag along with an abrasive and lubricant, and shaking until completely polished (Wright *et al* 2008).

2.4. Conclusion

The methodological aim of this thesis was to determine whether microwear traces created when producing amber beads can provide information on the tool materials used during production. In order to investigate this, a collection of experimentally produced beads were compared against an archaeological collection consisting of beads from three sites within the modern geographic region known as the Netherlands. These sites were a Late Neolithic settlement in Kolhorn, a Middle Bronze Age grave in Emmerdennen, and Middle Bronze Age tumuli in Hijken Hooghalen. Amber beads as a research material were chosen due to their status as ornamental objects, through which archaeologists are able to see technological, economic, and social developments in prehistoric societies. The social significance of amber remains a subject of some contention. While it is important for archaeologists to see the connection between different materials and never assume that they were classified separately in the same way that they are today, historic evidence suggests that amber was indeed considered 'special' in the past. Although a more detailed investigation of the *chaîne opératoire* of amber beads is presented in section 3.2, a brief overview of the three basic stages involved in the production of beads, as seen through other case studies, was provided above. These stages included shaping through flaking or grinding, drilling using various methodologies and technologies, and polishing using soft abrasion.

Chapter 3: Research Project Methodology

The two methodological approaches employed in this research are that of experimental archaeology and microwear analysis. An outline of these two methodologies is provided below, including any associated disadvantages and limitations. The methodology followed in other similar studies focusing on the production of beads, as mentioned in the previous chapter, is also outlined. By considering these methodologies, the framework used in this research is then described, including the materials used, experiments completed, and analytical techniques utilised.

3.1. Methodological framework implemented in the thesis project

3.1.1. An overview of experimental archaeology

Experimental archaeology is described simply as "the investigation of archaeological issues using experiments" (Hurcombe 2005, 110). For example, one of the most commonly applied areas of experimental archaeology involves the experimental reproduction of past objects and technologies in order to gain a greater understanding of the social and technological choices of past societies. For instance, reproducing stone tools used in butchery in order to assess why certain tool types may have been chosen over others based on properties such as efficiency and ease of manufacture (Jones 1980). As a research methodology, experimental archaeology was initially considered separate from other scientific archaeological methods, such as dating techniques and isotope analysis. This was mainly due to the initial lack of scientific procedures, such as the correct documentation of results to enable the repeatability of an experiment, but was also due to a general academic disapproval of those who were conducting such experiments (Reynolds 1994). In the late twentieth century, however, it was generally agreed within the academic community that experimental archaeology, if properly conducted and adhering to strict scientific principles, could be classified as a scientific research technique and was therefore appropriate to use when conducting archaeological investigations (Outram 2008).

One of the main benefits of experimental archaeology is that it provides some level of authenticity by allowing archaeologists to conduct their research in a more similar environment to that of people living in the past (Outram 2008). This means that the researcher is able to not only gather important technical data but also gain hands-on experience of the technologies being researched, for example the heat and physical challenge involved when smelting iron. It should, however, be noted that the mechanical reproduction of techniques and objects from the past will always be influenced by our modern working environment and therefore cannot directly correspond to real work conditions in past societies. Additionally, this attempt to increase authenticity can cause a lack of control and therefore potentially less scientifically valuable results (Dungworth 2013). In order to avoid this issue, it is important to adhere to scientific experimental principles such as the recording of detailed observations, repeatability, and maintaining constant environmental parameters (Reynolds 1994).

One of the biggest issues of experimental archaeology relates to the skill of the researcher. Many archaeologists who conduct experimental research have little or no experience in the technologies that they are replicating (Dungworth 2013). It is therefore important to note that, although the methodology allows archaeologists to gain a much greater understanding of past technologies, the results will always have been influenced and limited by the modern experience of the researchers, which is likely to be very different to that of craftsmen in the past. Experimental research should therefore always account for the possibility that some results may be due to the limited skill and experience of the researcher rather than the technology itself. In terms of skill deficits within the present thesis, the author previously had no experience in using either hand- or bow-drills, which is noted as a potential limiting factor when interpreting the results. Some 'practise experiments' were conducted before starting the actual research project, which are described further in section 3.4.

3.1.2. An overview of microwear analysis

Microwear or use-wear analysis is "the examination of an item for macroscopic and microscopic evidence that allows us to understand how it was altered, separating damage patterns caused by manufacturing techniques and post-depositional activities from those caused by use" (Adams 2014, 129). The technique is extremely valuable as it enables archaeologists to see traces which reflect directly on the production and use of an object in the past, rather than being limited to inferring information only from macroscopic analysis, analogies with modern objects, or the site or material context (Lawn and Marshall 1979). Traces are examined under magnification using microscopy (Evans 2014). Both low and high power microscopy are commonly used: a stereomicroscope (10-100x magnification) and an incident light or metallographic microscope (50-1000x magnification) respectively. Due to their lower magnification, stereomicroscopes allow the examination and identification of traces such as striations, fractures, and rounding. These traces are usually too large to see beneath the higher magnification of the metallographic microscope, although the latter does allow the examination of more subtle traces such as polish. The use of microscopy therefore enables a more detailed examination of all aspects of the object being analysed (Van Gijn 2014c). Recent microwear studies have utilised even higher magnification in addition to optical microscopy, for example scanning electron microscopy (SEM), which can have a magnification of up to 30,000x. This technique is used in order to provide a complementary examination, for example much finer detailed imagery of traces or an elemental analysis of any microscopic residue remains (Borel *et al* 2014).

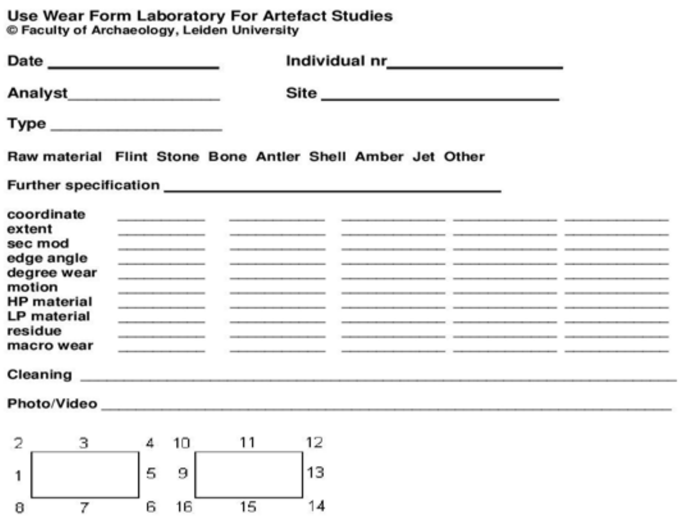
The accuracy of microwear analysis in providing valid results has been a subject of much debate, and is considered to be one of the main limiting factors of this analytical technique (cf. Newcomer *et al* 1986; Moss 1987; Odell and Odell-Vereecken 1980; Bamforth *et al* 1990; González-Urquijo and Ibáñez-Estévez 2003). This is due to several stages of the technical procedure. Firstly, the correct identification of microwear traces is highly dependent on the level of competency of the individual analyst. Secondly, post-depositional effects such as the cleaning or mishandling of artefacts both during and after their excavation could produce additional traces which can then confuse the data by affecting traces and thus observations (Grace 1990). Similarly, there is the possibility that different activities may create similar wear traces, which then makes it impossible to identify the correct activity in the archaeological record. A third issue is that of subjectivity, as the actual data produced is largely a result of individual interpretation (Van Gijn 2014c). This means that the results of a study, including identification of the microwear traces, are restricted by the competency and experience and hypotheses of the individual analyst. It is therefore important to provide as objective an identification of traces as possible. This is achieved by recording and describing all identified traces in a consistent and detailed manner, and providing macroscopic and microscopic photographic documentation. This then enables researchers to either use this data as a reference for their own materials, or reassess any past conclusions (Van Gijn 2014c).

Microwear analysis is very strongly related to experimental archaeology, to the extent that it could be considered reliant on the use of experimentation. For example, so-called ‘blind tests’ are often used in microwear analysis. During a blind test, an analyst receives an experimentally produced object and must suggest how it was made and/or used based on the microwear traces they observe (Odell and Odell-Vereecken 1980). As the pieces were made using known materials, it is then possible to confirm whether the analyst's identification of traces and subsequent interpretations are correct. Through these blind tests, it is possible to see the limitations of microwear analysis, discussed above, and so improve the methodology for use in further research. A similar utilisation of experimental archaeology involves the production of reference collections, where experimental pieces are used as an analogue for research into the same materials or objects. For example, by manufacturing and using several types of bone tools it is possible to obtain a microscopic reference collection of all production and use-wear traces created (Buc 2011).

3.1.3. Application of methodologies within the thesis research project

In order to address the issues and limitations of the two techniques mentioned above, the methodology of this research adhered to strong scientific principles. The experimental program used within the current thesis project involved the experimental production and consequent microwear analysis of a collection of cut and perforated amber nodules. The traces identified during the microwear analysis were then compared against those on three archaeological collections of prehistoric amber beads. A more detailed description of the archaeological collections used is provided in Chapter 5.

The archaeological experiments concerning bead production were completed at the Laboratory for Artefact Studies at Leiden University in a controlled environment working on an indoor clean tabletop with no dynamic environmental influences. Additionally, apart from the different drill-bit materials, all other tools and materials involved in the experiments remained constant. It should be noted that this rigidity of parameters might be seen as too limiting, as it ignores the fact that craftsmen in the past may have had a higher level of flexibility in their daily activities and were unlikely to be working in a constantly controlled environment (Dungworth 2013). However, in order to avoid any inconsistencies and to allow replicability of the experiments, it is necessary to have such guidelines in place. A level of authenticity was however provided through human, as opposed to mechanical, manipulation of the tools used. The microwear analysis also involved detailed recording of all observed traces on the Ornament Use-wear forms, provided by the Leiden University Laboratory for Artefact Studies (fig. 5). Photos were also taken of all traces on both a macroscopic and microscopic level, using a Nikon D1500 digital camera, either alone or attached to a Nikon SMZ800 stereomicroscope. For each image, a multifocal stack was acquired using Helicon Focus software. In this way, it is hoped that issues concerning subjectivity and validity have been avoided as much as possible. Unless otherwise stated, all photos included in the current thesis project were taken by the author.


Use Wear Form Laboratory For Artefact Studies
© Faculty of Archaeology, Leiden University

Date ________ Individual nr ________

Analyst ________ Site ________

Type ________

Raw material Flint Stone Bone Antler Shell Amber Jet Other

Further specification ________

coordinate
extent
sec mod
edge angle
degree wear
motion
HP material
LP material
residue
macro wear

Cleaning ________

Photo/Video ________

2 3 4 10 11 12
1 5 9 13
8 7 6 16 15 14

Figure 5. Example of an Ornament Use-wear form at the Leiden University Laboratory for Artefact Studies.

There do however remain several limitations which need to be taken into account during interpretation of the results. As the author had no previous experience with using either a hand-drill or a bow-drill, it is assumed that the time taken to complete each experiment and the effectiveness of the drilling materials was not exactly comparable to the productions of a potentially ‘expert’ prehistoric craftsperson. Thus, any lack of correlation between the experimental and archaeological collections could be due to the differences between the author and the prehistoric craftsperson, rather than a difference in the materials used. In other words, just because a characteristic material trace is absent in an archaeological perforation, this does not necessarily imply that that material was not used in prehistory. Instead, it may simply reflect the lack of skill of the author in comparison to a prehistoric craftsperson. However this does not invalidate the research, as it will still be possible to compare microwear traces on the experimental beads created by the author using tools made from different materials. As an additional safeguard to ensure the presence of valid results, the author conducted a blind test. This was done by examining experimentally produced amber beads that had been created as part of previous experimental projects conducted by other researchers at the Leiden Laboratory for Artefact Studies. Through using a list of characteristic traces based on the experiments from the current thesis study (provided in the next chapter), the potential tool materials used on each bead were inferred based on the microwear traces observed. The results from this blind test are provided in section 4.3.

3.2. The experimental reproduction of beads

3.2.1. Experimental reproduction of the *chaîne opératoire*

While examining previous studies concerning the experimental reproduction of beads, it was possible to see a pattern in the experimental manufacturing process (cf. Wright *et al* 2008; Groman-Yaroslaviski and Bar-Yosef Mayer 2015). The only variation within the experimental studies of bead production regards the point at which the perforation is drilled. It is suggested here that five main stages of production can be studied when looking at the experimental reproduction of beads:

1. Rough shaping of the raw nodule through grinding, flaking, or sawing.
2. Grinding to form an approximate final shape of the bead.
3. Perforation through drilling.
4. Rough polishing / final shaping.
5. Fine polishing.

As mentioned previously, the main aim of this thesis is to determine the tool materials used for the different steps of the production process, but with a particular focus on the potential use of metal tools. The methodology of the current research therefore did not involve a complete reproduction of beads as was achieved in the aforementioned studies. Instead, only certain stages of the production process were investigated. For example, it has been suggested that stone tools continued to be used for specific stages of production, for example grinding and rasping, well into the Iron Age, when metal files were introduced (Derry and Williams 1960). The grinding stage of the bead making process was therefore excluded from the methodology of this project, as it is assumed that metal grinding tools, for example metal files, would not have been used throughout the Bronze Age. The polishing process was also excluded for a similar reason, as metal has never been used when polishing materials. The cutting and perforating stages were, however, included in the study, as it is assumed that they represent the only stages of the bead production sequence in which metal tools could have been used, from the Late Neolithic / Early Bronze Age onwards (Thomas 2011).

3.2.2. Initial cutting / sawing stage of the bead production process

Unfinished amber nodules, for example from the site of Zeewijk (Van Gijn 2014a), have microwear traces which strongly suggest that they were sawn using flint blades. Additionally, previous researchers at the Laboratory for Artefact Studies at Leiden University have completed several experiments with the aim of splitting amber nodules using flint tools. The resulting observations from these experiments were noted on specialised Experiment Forms at the laboratory, which document the size and shape of the experimental nodule, the time taken to complete the experiment, and any additional information such as the effectiveness of the tool. Unfortunately none of the amber nodules cut using flint blades remain at the Laboratory and were able to be studied by the author. It was however possible to use the information from the Experiment Forms to gain an understanding of the technological effectiveness of flint blades as a tool for cutting amber.

Previous research has also suggested that nodules made from stone, for example jade nodules, were initially cut to shape using a string sawing technique (cf. Sax *et al* 2004). Archaeological evidence from the site of Aartswoud (Piena and Drenth 2001, 437), as well as experiments conducted at Leiden University (Verschoof 2010) have shown that this method also functions when applied to amber nodules. The nodules created by Verschoof (2010) using string sawing techniques were still available at the Leiden University Laboratory for Artefact Studies and were therefore re-examined in the current research. This examination includes a discussion on the effectiveness of the tools, as observed by Verschoof on the laboratory's Experiment Forms, and an analysis of the microwear traces evident on the sawn nodules.

In order to provide a metallurgical comparison to flint cutting and string sawing in terms of both time and effectiveness, and a comparison for microwear traces on the surface of the beads, additional experiments were conducted for this thesis using a copper saw and a bronze knife. It is presumed, following the various grinding and polishing stages that occur after the initial cutting of the nodule, that any relevant traces from such a stage would have been removed on finished beads. It is however also relevant to conduct such experiments in order to note whether such metal cutting tools are useable and how efficient they are in comparison to, for example, string sawing and cutting with a flint blade. It is also important to note that the microwear traces from the cutting stages of the production process could be compared to those potentially remaining on any unfinished beads within archaeological collections.

3.2.3. Perforation stage of the bead production process

There have already been several experimental studies examining the differences between traces left by different drill-bit materials when perforating beads. Many archaeologists agree that it is possible to see what material was used for the drill-bit based on the shape of the perforation and the traces within it (Gwinnet and Gorelick 1981). By examining the traces left through experimental drilling on amber nodules, which are described in further detail in section 3.3.1 and 4.2.1, and comparing these to perforations in the archaeological collection, it was perhaps possible to determine what material was used as a drill-bit in the latter. In addition to drill-bit material, another potential variable which could cause differences in the creation of production traces relates to the method of drilling. Since early prehistory, drilling has been accomplished using hand-drills and cord-powered drills, such as bow-drills and pump-drills (Childe 1955). It has been suggested that perforations made using a hand-drill will be more irregular than those created using a bow-drill (Piena and Drenth 2001, 440). In order to determine the validity of this statement, the drilling experiments were conducted using both hand-drills (fig. 6) and a cord-powered drill, in this case a bow-drill (fig. 7).

Figure 6. Hand drill

Figure 7. Bow drill

Previous research conducted at the Leiden Laboratory for Artefact Studies has compared different drill-bit materials when perforating amber beads (Verschoof 2010; Verschoof and Van de Vaart 2010; Guzzo Falci 2015). These have included flint and antler borers and hot copper wire, the latter of which was pushed through the amber rather than swivelled in a drilling motion. This technique will be discussed further below. In the current research project, the experiments using flint, antler, and copper were repeated, although the copper was used as a cold drill-bit, and some additional experiments were conducted using previously unused materials such as malachite and bronze. This repetition of previous experiments allowed the parameters of the present study to remain consistent, as all experiments were completed by the same researcher in the same environment, thus avoiding any anomalies in the results caused by differences between experimenters. Previous experiments have shown that the heating of copper wire (Verschoof and Van de Vaart 2010; Drenth *et al* 2011) and bronze pins (Verkooijen 2008) proved effective when perforating amber. In the current study, however, both copper and bronze drill-bits and handheld borers were used without being heated. This was in order to allow comparability between the traces left by other non-heated materials, for example flint, and to maintain a level of consistency throughout the experimental program. The potential effects of using hot versus cold materials on the production of microwear traces and the possibility of investigating these differences in further expansions of the current research are discussed in further detail in section 6.2.

In order to provide a wider range of data within the study, it was decided that an additional material should be used which would not normally be expected to be included in such a study. A copper ore, specifically malachite, was chosen to be used in its raw form as a drilling tool with which to perforate amber. This may seem an inappropriate use of the material, as the most well-known physical property of malachite besides its vibrant green colour is that it is an ore which, when smelted, forms metallic copper (Radivojevic *et al* 2010). Additionally, there is no recorded archaeological evidence of malachite having been used as a tool in its raw form, although this could be due to its eventual reuse in order to smelt copper. There is also no previous experimental research on this subject. It is argued here, however, that this is precisely the reason why such a study should take place. On discovering the remains of malachite at a site, any excavator may automatically assume that it had been involved in the act of smelting copper. This assumption is based on modern scientific classifications, through which we can understand the physical properties of malachite such as elemental composition, however we should not assume that prehistoric societies used the same classifications (Hurcombe 2007). Hypothetically, malachite may have been used to produce stone tools in the same manner as any other hard stone, for example flint. This research therefore explored the possibility of using this material as a drilling tool, rather than assuming its function as a copper ore. This idea is described in further detail in section 6.2.1. It should be noted that this inclusion was simply in order to see whether a malachite drill-bit is effective, rather than assuming that it was definitely used in the past. If it is possible to use malachite as a drilling material, the production traces that it leaves on the amber can be analysed and compared with the archaeological collection in the same manner as with the other drilling materials, described below in section 3.4.

3.3. The application of microwear analysis to the study of bead production

3.3.1. Analysis of the perforation

Evidence from previous research into the production of beads strongly suggests that it is possible to identify differences in microwear traces within the perforation depending on the material used to drill it. One such indicator is the frequency, consistency, and depth of striations on the walls of the perforation. For example, the results from a study by Gwinnett and Gorelick (1981) suggest that deep, concentric striations, described as ridges, are caused by drill-bits made from flint, whereas copper drill-bits leave very fine or no striations. Experiments completed by Van Gijn (2014) also suggested that antler, when combined with a fine slurry, left fine, regular, concentric striations. The depth and consistency of striations on the walls of the perforation were therefore examined in this study under the hypothesis that differences in traces could be identified between perforations drilled by tools made of different materials. Although the addition of abrasives and lubricants during the drilling process could also create a different depth and concentricity of striations, this parameter was not tested due to the time constraints of the current study. The possible directions of further research involving additions of abrasives and lubricants are discussed in section 6.1.2.2.

As previously mentioned, the study by Gwinnet and Gorelick (1981) suggested that the width and shape of the perforation could also be used as an indicator for the type of drill-bit materials used, for example whether it is straight, conical, or biconical. The shape of the perforation was therefore also recorded during the course of the current experiments. In regards to biconical perforations, it is widely agreed that this is caused when drilling from both sides of the bead (Thomas 2011). Initial practise experiments conducted for this thesis suggested that this method of drilling from both sides prevented the bead from cracking during production, an occurrence that was more likely if the drilling was done only from one side. This structural instability has also been described by other researchers (cf. Piena and Drenth 2001; Verkooijen 2008), and so perforations created during the experiments in the current study were drilled from both sides. This also allowed an insight into the potential level of skill involved in aligning two perforations made from opposite sides of a bead so that they meet in the middle to form one complete perforation.

It has been suggested that, when making a perforation, small indentations were initially made on the surface of the bead in order to provide a stable starting point for the drill-bit (Fabiano *et al* 2001). The presence of edge removals around the initial surface of the perforation has often been cited as evidence for this. However, due to the relatively brittle nature of amber, it is suggested here by the author that these edge removals, if not eradicated through later polishing stages of the *chaîne opératoire* or polish through use, could also indicate the material used to drill the perforation. A harder material, such as flint, could cause more chipping around the edges of the perforation than, for example, antler. The size and quantity of any edge removals present on the experimentally produced beads were therefore also recorded during the current study. The presence of further polishes and rounding could also suggest that the beads were worn (Van Gijn 2014a, 124), which would affect the visibility of any production traces both on the surface and in the perforation of the bead. Any evidence of polish or rounding should therefore also be examined and recorded.

In conclusion, the attributes that were examined within the current study were as follows: a) the depth, regularity, and type of traces within the walls of the perforation; b) the width and shape of the perforation itself; c) the presence and size of edge removals and the identification of polish or rounding.

3.3.2. Microscopic methodology

The examination of microwear traces on beads has been conducted using optical microscopy (Van Gijn 2014c). Examination of both the experimental and archaeological collections in this study were conducted using a Nikon SMZ800 stereomicroscope (fig. 8), which utilised a 1x parallel optical zoom system, an objective zoom range of 1x to 6.3x, with a 10x eyepiece magnification and a consequent magnification range of 10x to 63x. The traces identified through examination under the microscope, as well as other physical characteristics of the beads such as size, shape, colour, and transparency, were then documented using specific 'Usewear forms' available at the Laboratory for Artefact Studies at Leiden University (fig. 5 in section 3.1.3). Aspects of the perforation mentioned above, such as the presence and type of striations, the perforation shape, and the size and frequency of edge removals, were documented. Pictures of all traces were taken using a Nikon D5100 digital camera.

Figure 8. Nikon SMZ800 Stereomicroscope used during analysis

An additional analytical technique which has been used in the study of bead production is that of scanning electron microscopy (cf. Borel *et al* 2014; Ludvik *et al* 2015). This methodology enables a higher magnification to be used than in standard optical microscopy – up to 30,000x magnification – which then provides a more detailed view of all microwear traces present. However, it is often difficult to access the inner walls of bead perforations using this methodology. To overcome this issue, studies by Gwinnet and Gorelick (1981) and Ludvik *et al* (2015) utilised silicone to make a moulded impression of the drilled perforation walls, which could then be examined under the scanning electron microscope. Unfortunately, due to time constraints on the present study it was not possible to examine the amber beads using a scanning electron microscope, although future expansions on the current research could benefit from such an approach. Additionally, due to the fragile nature of the archaeological amber beads examined in this study, a silicone mould could cause damage such as breakage or excess oily residue, thus creating extra traces. Potential further research directions using high-power techniques such as Scanning Electron Microscopy is discussed in section 6.1.2.

3.4. Methodological framework implemented for the current thesis project

The methodology used in this thesis thus involved the experimental reproduction of two stages within bead production; initial shaping by cutting, and perforation by drilling. The experimentally produced pieces were then examined under an optical stereomicroscope as detailed above. Analysis of the pieces produced included a detailed description of the width and shape of the perforation, the presence and depth of striations and other traces on the perforation walls, and the presence of rounding and edge removals on the surface of the amber. Beads from the three archaeological collections and the Laboratory for Artefact Studies at Leiden University, as described in the previous chapter, were also examined in this way, thus allowing a direct comparison between the experimental and archaeological collections. Microscopic photos of both the experimental and the archaeological pieces as well as illustrated forms detailing all observed microwear traces were documented as described above. A total of fifteen experiments were planned, as detailed below:

1-3. (*Cutting*): Cutting using a bronze knife
4-6. (*Cutting*): Cutting using a copper saw
7. (*Perforation*): Hand-drill using a flint borer
8. (*Perforation*): Bow-drill using a flint borer
9. (*Perforation*): Hand-drill using an antler borer
10. (*Perforation*): Bow-drill using an antler borer
11. (*Perforation*): Bow-drill using a copper ore (malachite) borer
12. (*Perforation*): Hand-drill using a copper wire borer
13. (*Perforation*): Bow-drill using a copper wire borer
14. (*Perforation*): Hand-drill using a bronze borer
15. (*Perforation*): Bow-drill using a bronze borer

While most of the drilling materials were created into both handheld borers and drill-bits to be used with a bow drill, the malachite was only formed into a drill-bit due to insufficient quantity of material. Additionally, due to time constraints, the string sawing experiments mentioned above (Verschoof 2010) were not repeated, as there are already detailed descriptions and drawings of the nodules created during Verschoof's experiments, which are still available at Leiden University. Six additional experiments, three using the bronze knife (fig. 9), and three using a copper saw (fig. 10) were conducted in order to provide a comparison. The reason why two different materials and tool types were used for the cutting experiments relates to the time and resource restrictions of the present study. The bronze knife was readily available for use, as it had been created as part of a previous study at Leiden University Laboratory for Artefact Studies. The original proposal therefore intended to use only this knife. However, the cutting edge was very smooth and after completing experiments it was suggested that the study might benefit from an additional comparison with a serrated tool such as a saw. Unfortunately, time constraints prevented the creation of a new tool through casting, and so instead a small serrated blade was made by hammering flat a piece of 5mm diameter copper wire and then filing serrations into one side of the flattened section. Copper was used instead of bronze in this case, as it was more easily workable. This use of two different tool materials and types did not provide invalid results. As was mentioned above, the aim of the cutting experiments was not necessarily to provide an experimental collection that could then be compared with an archaeological collection. It was more of an experimental study that focused on the ability of a range of different tools to cut an amber nodule, and provided a comparison of effectiveness with other amber cutting methods.

Figure 9. Bronze knife for cutting experiment

Figure 10. Copper saw for cutting experiment

Exploratory experiments were conducted prior to the start of the study in order to allow the author to familiarise herself with the drilling techniques. During the course of these initial experiments, however, several issues emerged with the experimental drill-bits. The initial idea for the experiments was to have one straight piece of wood as the shaft, to which separate drill-bits could be attached (fig. 11). It was, however, soon realised that the detachable drill-bits were too unstable, and subsequently could not be used to drill the amber. Instead, the drill-bits were therefore attached directly into five separate, straight, wooden shafts (fig. 12) using epoxy glue to ensure that they remained in place.

Figure 11. Initial (antler) detachable drill-bit fastened into wooden shaft

Figure 12. Example of a drill shaft, here with flint drill-bit

Because the main focus of the present study is on the material of the drill-bit rather than the technology of the drilling apparatus, it was decided that modern glue could be used in this situation. Experiments in further expansions of the current research could however attempt to attach the drill-bits using archaeologically accurate adhesives. Short practise experiments of 15 minutes using the new drill shafts showed that this new design was stable. One exception was the 2mm thick copper wire drill-bit. Initially cut to be 2.5cm long, it proved too unstable to completely perforate the amber, as the wire would bend as soon as pressure was applied to the point. Thicker and more stable copper wire (4mm and 5mm thick) was therefore used instead. Initial experiments with the flint and malachite borers also suggested that a thinner and sharper drill-bit would be more efficient and would provide a closer replication of the perforations on beads in the archaeological collection.

The final selection of tools used in the perforation experiments was as follows: two previously knapped flint flakes were further sharpened to create a wider drill-bit (fig. 13) and thinner drill-bit (fig. 14), and a previously knapped handheld flint borer (fig. 15) was also used. Due to the lack of flint knapping experience of the author, previously made flint tools available at the Laboratory for Artefact Studies were utilised in the experiments. The antler drill-bit (fig. 16) and handheld borer (fig. 17) were formed by grinding the raw material to a point using a sandstone grinding stone. The wider and thinner malachite drill-bits (fig. 18 and 19 respectively) were formed using a combination of knapping to reach a nodule of appropriate size, followed by grinding on the grinding stone to create a pointed tip. All metal tools (fig. 20-23) were made from pre-made wire, which was then ground to a point using the grinding stone, with the additional use of a metal file for the bronze drill-bit and handheld borer. One bronze drill-bit and one handheld borer were made using wire with a diameter of 4mm, however the copper tools included a drill-bit and handheld borer made from 4mm diameter wire, and those made from 5mm diameter wire. When possible, the perforating tip of all tools were formed into a four-sided point, however this was more difficult to achieve with the flint tools and so, after many failed attempts, it was decided that their points would remain irregular.

Figure 13. Wider flint drill-bit

Figure 14. Thinner flint drill-bit

Figure 15. Handheld flint borer

Figure 16. Antler drill-bit

Figure 17. Handheld antler borer, overview (left) and close-up

Figure 18. Wider malachite drill-bit

Figure 19. Thinner malachite drill-bit

Figure 20. Handheld bronze borer

Figure 21. Copper drill-bit

Figure 22. Handheld copper borer

Figure 23. Bronze drill-bit

As mentioned above, both hand-drills and a cord-powered bow-drill were used for each material in order to determine the influence that this technological process has on the production traces. When using the bow drill in the exploratory experiments, leather was initially used to protect the hand at the top end of the shaft. However it became clear that this caused too much friction, and so a shell was used instead in direct contact with the shaft (fig. 24). This method proved to be a lot more effective both in terms of ease of drilling and speed of perforation.

Figure 24. The use of shell and leather to protect the hand at the top of the drilling shaft

Initially, the amber to be perforated was held between the feet, as has been ethnographically documented (Childe 1955). However, this presented the issue of being unable to see where the perforation was being made. While an experienced driller may encounter no problem in this respect, it was decided that, as the author had no previous experience in drilling, a tabletop vice would be used to hold the amber during the experiments (fig. 25). As mentioned previously in regards to the use of epoxy glue, due to the focus of the research specifically on the material of the drill-bits, it was decided that a modern vice could be used to facilitate inexperienced experimentation. There is also some archaeological evidence from finds at Bronze Age Troy which suggests that beads could indeed have been mounted on some sort of frame or vice during perforation (Ludvik *et al* 2015).

Figure 25. Table-top vice used to hold amber during perforation experiments

3.5. Conclusion

This research utilises experimental archaeology complemented by microwear analysis in order to compare the microwear traces produced from different materials when cutting and drilling amber beads. The experimental collection from previous research conducted at Leiden University was compared against six new cutting experiments using a bronze knife and a copper saw to cut through an amber nodule. Nine drilling experiments were also planned, using both hand- and bow-drilling techniques with borers made from flint, antler, malachite, copper wire, and bronze, and two additional experiments were then added using thinner flint and malachite drill-bits. Attributes such as the width and shape of perforation, the presence and depth of striations/grooves on the perforation walls, and the presence of polish and edge removals on the surface of the amber were recorded. The microwear traces identified on the experimental collection were then compared with those on the archaeological collections, the results of which are presented in Chapter 5.

Chapter 4: Analysis of the experimental collections

The following chapter presents the results from the experimental phase of the thesis project. This includes observations on tool effectiveness when attempting to split amber nodules in the cutting experiments using metal, flint, and string saws, as well as comparisons between microwear traces created when cutting with metal versus traces created during previous string sawing experiments by Verschoof (2010). Additionally, information from the drilling experiments is presented regarding both general issues during experimentation as well as the identification of characteristic production traces for different tool materials and how these were used in a blind test.

4.1. Analysis of the cutting experiment

Six cutting experiments were completed; three using a bronze knife and three using a copper saw. During these experiments, the author attempted to split amber nodules into two approximately equal halves. The effectiveness of the tools when splitting the nodules was recorded, and is discussed in further detail below, and the microwear traces created were compared with those on nodules from Verschoof's experiments (2010), which used string sawing technology.

4.1.1. Effectiveness of the cutting tools

The term 'effective' is used here to describe several aspects of the cutting experiments. First, the time taken to successfully split the nodules is considered. It is true that this notion of effectiveness, which values the speed with which an activity is completed, is based on a modern perception of time management. We cannot assume that this perception was also held by prehistoric society, who may not have considered time an important aspect and could instead have held completely different values regarding the completion of tasks (Costin 2005). It is however necessary to include an easily recordable quantitative parameter of the experiments in order to compare between the actions of different cutting materials. A second, qualitative, aspect of the cutting experiments to be considered is the level of control available to the person attempting to split the nodule. For example, whether the author was able to cut effectively along the line intended or whether the cutting tool slipped out of control along its own path. This is an important aspect of the experiments to consider because it demonstrated how it was possible to create one unusable half if the cutting line was off-centre, which was then a waste of amber material.

Although both the copper saw and bronze knife did succeed in carving grooves into the amber with the intention of splitting the nodules, the success of the experiments is considered to be low. The details of each experiment are shown in table 1, alongside information from the string sawing experiments completed by Verschoof (2010) as well as additional experiments from other researchers using flint knives, as mentioned in the previous chapter.

Table 1. Summary of cutting experiments from Leiden University's Laboratory for Artefact Analysis

Piece	Cut using	Area cut	Time	Comments	Experimenter
3161	Bronze knife	10 x 20 mm	22 mins	Split along a different fracture line to that intended.	M. Sebire
3512	Bronze knife	7 x 13 mm	44 mins	Nodule was dropped accidentally and split along the intended fracture line.	M. Sebire
3514	Bronze knife	10 x 15 mm	14 mins	Split along a different fracture line to that intended.	M. Sebire
3515	Copper saw	8 x 15 mm	23 mins	Split by hand after sawing approximately halfway through the material.	M. Sebire
3516	Copper saw	10 x 22 mm	16 mins	Side of nodule split off after 10 mins. Remaining nodule was split by hand.	M. Sebire
3517	Copper saw	13 x 20 mm	60 mins	Experiment abandoned due to lack of progress in splitting the nodule.	M. Sebire
2072	Nettle string	10 x 25 mm	10 mins	Completed split into two sawn nodules	W. Verschoof
2073	Flax string	6 x 15 mm	10 mins	Completed split into two sawn nodules	W. Verschoof
2075	Lime string	10 x 13 mm	5 mins	Completed split into two sawn nodules	W. Verschoof
1921	Flint knife	Unknown	60 mins	Completed split into two sawn nodules	W. Verschoof
1526	Flint knife	3 mm thick	76 mins	A section split off after 56 minutes, otherwise split into two cut nodules.	C. Niek
1262	Flint knife	5 mm thick	30 mins	Adding water helped to cut. Amber broke constantly during experiment.	K. Wentink
1265	Flint knife	5 mm thick	60 mins	Adding water helped to cut. Amber broke constantly during experiment.	K. Wentink
1616	Flint knife	Unknown	35 mins	Split by hand after sawing for 35 mins, however unknown sawing depth.	Unknown (Lejre 2008)

When using the bronze knife, it was difficult for the author to control the direction and depth of the grooves being cut. This could suggest an ineffectiveness of the knife to accurately cut the amber nodules, although this inability could also be related to the author's inexperience. Two of the nodules split along a different fracture line to the one intended (fig. 26). The third nodule split because it was accidentally dropped during the experiment, which is therefore considered incomplete. Because all the nodules that were cut using the bronze knife split before sawing was completed, it is also uncertain how efficient the tool is in terms of time required to split the nodules in a controlled manner. It is of course possible that splitting by hand could have been done in the past once a deep enough cut had been made in the amber material, as suggested by Sax *et al* (2004) and also by the unknown experimenter who split nodule 1616 as shown in table 1.

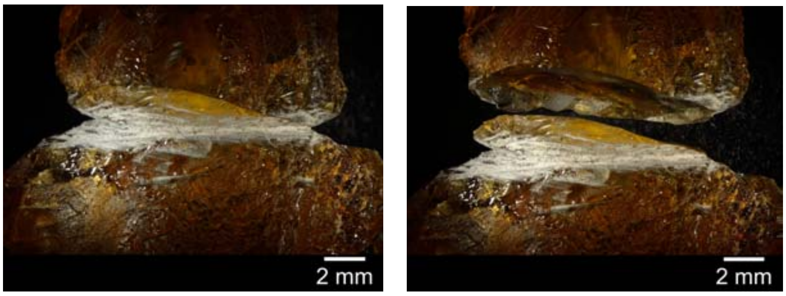


Figure 26. Magnified view of the fracture point of amber nodule 3161 (cut with a bronze knife)

When using the copper saw it was considerably easier to control both the direction and depth of the grooves being cut. This therefore also suggests that the presumed ineffectiveness of the bronze knife was not due to the researcher's inexperience, but was the result of the inaccuracy of the tool itself. As can be seen in table 1, the average time taken to successfully split the nodules was similar when using both the copper saw and the bronze knife. However, for the copper saw this time represents the number of minutes taken to saw a deep groove into the nodule, which was then split by hand to create two halves. In contrast, the times for the three nodules cut using the bronze knife represent the number of minutes taken before the nodules split in an uncontrolled manner along a different fracture line (fig. 26). This therefore suggests that the copper saw was more effective at splitting the nodules in a controlled manner.

The only issue that could be encountered when interpreting the effectiveness between the two metal tools is the variation in strength between the two types of metal used. Although a serrated edge may indeed prove more effective at cutting an amber nodule than a smooth edge, as was suggested in the results, copper is a softer material than its alloy bronze, and so even a serrated copper blade might not be able to cut any more effectively than any kind of bronze blade. It would therefore be beneficial for future studies to include a bronze saw, with a serrated edge, in order to provide a final comparison between the two tool types. It is however possible to suggest that, based on the results from the experiments and the point mentioned above, a serrated edge is more effective at cutting through an amber nodule than a smooth one. This suggestion is based on the fact that, although copper is a softer material than bronze, the copper saw was as effective as the bronze knife in terms of time taken to split the nodule, and was considerably more effective in terms of the accuracy of the split. It is therefore hypothesised that a saw made from a harder material such as bronze would prove even more effective at splitting amber nodules.

The string sawing methods were more effective than both the bronze knife and the copper saw, both in terms of time taken to split the nodules and the accuracy of the split, as can be seen in table 1. Using a flint knife, however, took considerably longer than experiments using any of the other tools, even with the addition of water in those experiments by Wentink, which apparently made the cutting process easier. This therefore implies that flint is considerably less effective at cutting amber nodules than tools made from metal, and especially less effective than string saws. It should be noted that this result could be due to the variation between experimenters, although even within experiments completed by the same researcher it is possible to see variation in terms of time taken to split the amber nodules. In order to resolve this issue, a much larger data set is required in order to prevent the inclusion of anomalies within the experimental results. The full implications of these results will be discussed in further detail in section 6.1.1.

4.1.2. Microwear analysis of the cutting experiments

As mentioned in the previous chapter, it is assumed that any traces left by cutting amber nodules were erased by later production stages such as grinding and polishing. The main aim of the cutting experiments was not therefore to compare them with archaeological collections, but rather to provide a comparison with the experimental technique of string sawing and to investigate the efficiency of metal cutting and sawing tools. It could however be possible to pursue this topic further through comparison with raw nodules or unfinished beads from the archaeological record. A brief overview of the microwear traces left after cutting an amber nodule with different materials is shown in table 2 in order to provide a second level of comparison with the string-sawing methods.

Because the nodules cut with metal tools were partly split by hand, there is an immediate distinction between these nodules and those cut in previous experiments by Verschoof (2010) in that the very centre of the split area contains no production traces. When looking only at those areas containing traces, however, it is still possible to see some differences between marks made by the different tool materials, as can be seen in table 2.

Table 2. Comparison of microwear traces on nodules cut using different tools

Cutting tool used	**Description of microwear traces**
Bronze knife	*Deep and straight striations, with some apparent fractures. Irregular splitting along an alternative fracture line to that intended.*
Copper saw	*Fine and shallow striations, with some curving of the lines.*
Nettle string	*Irregular, overlapping groups of striations at varying depths.*
Flax string	*No visible striations, but thick bands of shallow depth.*
Lime string	*Regular groups of fine striations with evidence of rounding between groups.*

While the bronze knife created deep striations (fig, 27), those left by the copper saw were significantly shallower (fig. 28), which could be due to the respective hardness of the two materials. Fine striations were also created by the lime string, however the application of a more flexible cutting material such as string can be differentiated from the solid line of a metal knife by the presence of rounding between the groups of striations in the nodule cut with the lime string (fig. 29). This rounding is however not present on both the nodule cut with flax string (fig. 30) nor that cut with nettle string (fig. 31).

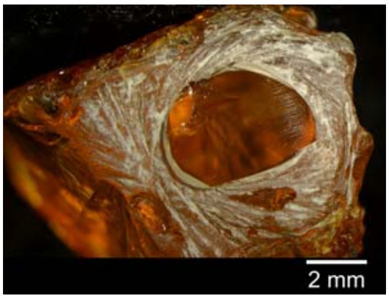


Figure 27. Traces from bronze knife.

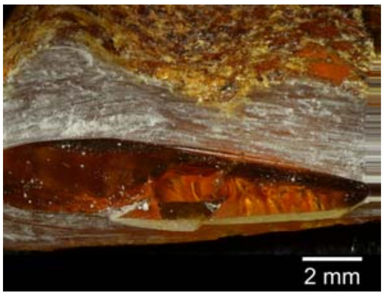


Figure 28. Traces from copper saw

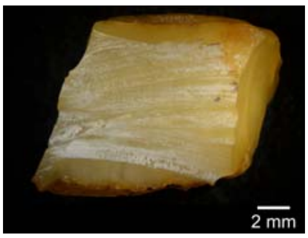


Figure 29. Traces from lime string

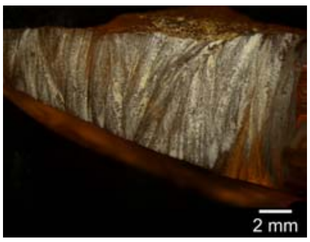


Figure 30. Traces from nettle string

Figure 31. Traces from flax string

As mentioned in the previous chapter, the amber nodules cut by previous researchers at the Laboratory for Artefact Studies using flint knives were unfortunately unavailable for direct analysis in terms of microwear trace comparison. An image of experiment 1921, conducted by Verschoof using a flint knife, was provided (fig. 32), from which it is possible to see some similarities between the cutting traces on this nodule and those cut using the bronze knife. It is also evident that the nodule was first sawn and then split along a different fracture line, again in a similar way to that of the bronze knife. This could suggest a similarity in technical effectiveness, again perhaps due to the straight edge of the flint blade and bronze knife in comparison to the serrated edge of the copper saw. More amber nodules cut using flint knives must be analysed, however, before a more certain conclusion can be made on this point.

Figure 32. Split amber nodules and flint knife from experiment 1921, taken by Wouter Verschoof

A full interpretation of the string sawing methods is available in the thesis by Verschoof (2010). Their presence within the current research project was as a method of comparison against metal cutting tools. From the microwear analysis, it is possible to see a distinct difference between those traces created by metal cutting tools versus those created during string sawing. In addition to evidence of being split by hand, those nodules cut with metal tools display more individual striations, as opposed to the groups and bands evident on the nodules cut using string sawing techniques.

4.2. Analysis of the drilling experiments

All drill-bits and borers were successful in completely perforating the amber nodules and created biconical perforations due to the method of drilling the nodule from both sides. There were only two cases where the amber nodule split during drilling; once using the wide flint drill-bit and once using the antler drill-bit. This was mainly due to the extremely close proximity of these two perforations to the edge of the nodules, thus causing structural instability, as opposed to any issues with the drilling method or tool material. In order to allow for any anomalies in the results that could be caused by this, two additional amber nodules were perforated; one again using the antler drill-bit, and one using a thinner flint drill-bit. Both perforations were successful and did not cause the amber nodules to split. Although the wider malachite drill-bit was successful in completely perforating an amber nodule without splitting it, a thinner malachite drill-bit was also used to allow a wider range of experimentation. In addition to creating a smaller and more precise perforation with steeper sloping walls, drilling using the thinner drill-bit took only 10 minutes in contrast to the 63 minutes required to perforate a nodule with the wider malachite drill-bit, thus suggesting a higher level of effectiveness.

4.2.1. Characterisation of production traces

Before providing a list of the traces considered characteristic for each tool material, some definitions of the descriptive terms used are provided in table 3.

Table 3. Definitions of the terms used to describe the production traces on all collections

Term	**Definition**
Striations	Concentric scratches running along the wall of the perforation parallel to the surface of the bead.
- Regular	*Striations or bands which lie parallel to each other at regular intervals throughout the perforation walls (fig. 33).*
- Irregular	*Striations or bands which do not lie parallel to each other but overlap at varying angles and / or intervals (fig. 34).*
Bands	A group of striations which run parallel to each other within the 'band' (fig. 35).
Ridges	Raised, linear regions of the perforation walls, usually caused by deeper bands of striations separated by narrower, finer striations / no striations or bands (fig. 36).
Scoring	Irregular traces running down the perforation walls (perpendicular to the surface of the amber) (fig. 37)
Edge Removals	Chipping around the entrance of the perforation (fig. 38)
Residue (amber)	Material accumulated on the walls of the perforation during drilling
- Loose	*Immovable but loosely attached to perforation walls (fig. 39)*
- Layered	*Condensed into translucent layer on the surface of perforation walls (fig. 40)*
- Consolidated	*Condensed into a thick lump attached to the perforation walls (fig. 41)*

Several of these terms have been used in several other previous studies (cf. Van Gijn 2014a). In order to allow differentiation between a wider range of traces, however, these terms have been altered slightly to create the more specific list provided in table 3. For example, the results from the current research show that there is a distinct difference between fine striations, bands of striations, regular versus irregular striations, and striations interspersed with ridges. Because of this, the single definition of concentric traces created through drilling, which has been previously been described as ‘striations’ or ‘rills’ (cf. Van Gijn 2014a), has been separated into ‘striations’, ‘bands’, and ‘ridges’, thus allowing a more precise list of traces considered characteristic for each tool material. All experimental pieces were cleaned in an ultrasonic tank prior to microwear analysis.

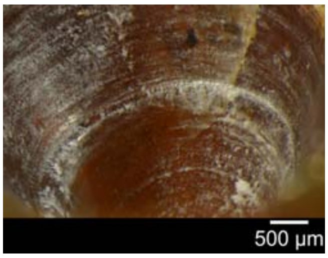


Figure 33. Example of regular striations.

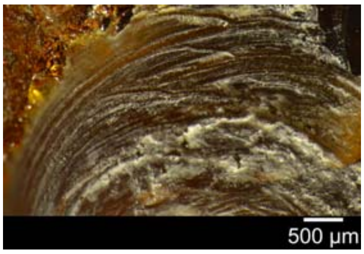


Figure 34. Example of irregular striations.

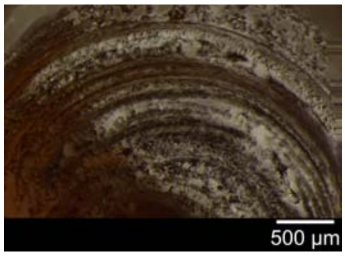


Figure 35. Example of bands.

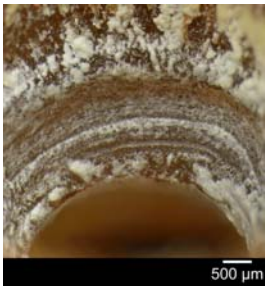


Figure 36. Example of ridges.

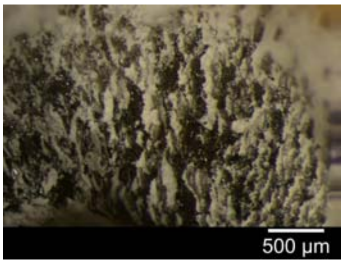


Figure 37. Example of scoring.

Figure 38. Example of edge removals.

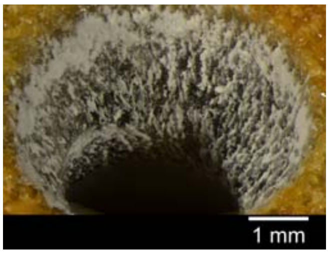


Figure 39. Example of loose residue.

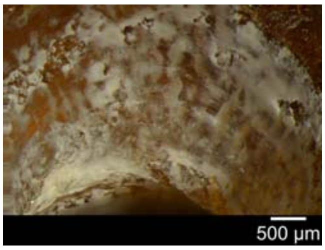


Figure 40. Example of layered residue.

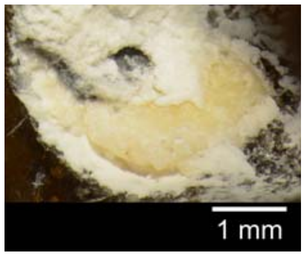


Figure 41. Example of consolidated residue.

There were some clear differences in the microwear traces caused during perforation of the amber nodules depending on which material was used for the drill-bit or handheld borer. When flint was used, the perforating action produced irregular bands and striations, often with prominent ridges between (fig. 42). In contrast, all other materials had less pronounced ridges, if any, and more regularity in both bands and striations when present. In particular, copper and bronze drill-bits produced regular and much finer bands of striations (fig. 43). Also significant when using the metal drill-bits, although particularly evident in perforations drilled with copper, was the presence of a slight 'sheen' or polish on the walls of the perforation, with very little residue of any kind remaining (fig. 44).

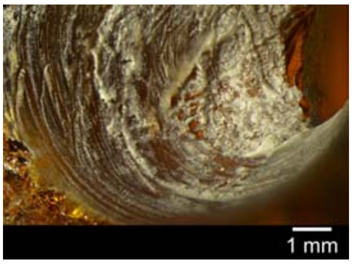


Figure 42. Irregular bands of striations left by flint drill-bit

Figure 43. Regular and fine bands of striations, left by a copper drill-bit

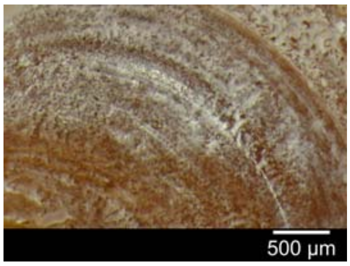


Figure 44. 'Sheen' or polish present on perforation walls after drilling with metal, here with copper.

When considering only the microwear traces, it is nearly impossible to distinguish between those created by copper drill-bits and those caused by bronze drill-bits, however both are easily distinguishable from those left by flint, antler, and malachite tools. The traces created by antler are very different to those caused by flint or the metal tools, as they consist mainly or entirely of scoring, usually partially covered in loose residue, rather than striations (fig. 45). When striations are present, they form very fine bands and often overlay sections of layered residue (fig. 46), which is also more extensive than in perforations made using other materials. Perforations made using malachite tools display indistinguishable traces to those created when using antler. The only difference between the two is the faint green colour of the layered residue on the walls of perforations created by malachite drill-bits (fig. 47).

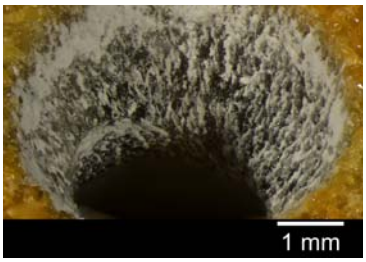


Figure 45. Scoring partially covered with loose residue.

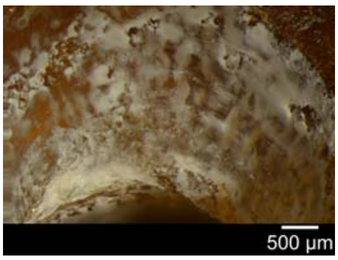


Figure 46. Layered residue overlaid with fine bands of striations.

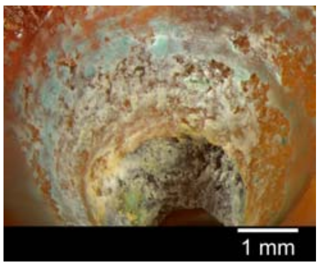


Figure 47. Green-coloured residue left by a malachite drill-bit.

A final aspect to consider when examining the microwear traces caused by drilling is the presence and type of edge removals. There were some very small differences between the tools used. For example one could say that in most cases those edge removals produced when using a copper drill-bit were usually smaller than those produced when using a flint drill-bit. However, the differences were not great enough to be used as distinguishing characteristics of the different tool materials. Additionally, no consistent differences were noted between any traces on those perforations made using a hand drill and those using a bow drill. Previous archaeological analyses (cf. Piena and Drenth 2001) and experimental studies (cf. Groman-Yaroslavski and Bar-Yosef Mayer 2015) have suggested that the presence of edge removals provides evidence that the nodules were first chipped to form an indent, in order to prevent the drill-bits slipping across the surface of the nodules during perforation. This chipping was not done in the current research project, as the drill-bits were placed straight onto the surface of the nodules to immediately start drilling. Despite this, edge removals are still present, presumably caused by the natural chipping of the amber material under the pressure of the drilling action. Does this therefore imply that other studies where edge removals are present should also consider that initial chipping of the nodule surface might not have occurred? It is also important to consider that that experimental study by Groman-Yarolslavski and Bar-Yosef Mayer (2015) concerned beads made from carnelian, which is a much harder material than amber. The pressure applied while drilling may therefore not cause the creation of edge removals on such hard materials, and they could instead have only been caused by intentional chipping of the nodule surface prior to perforation. Further research into this aspect of the drilling process is required in order to gain a greater understanding of the stages involved with bead making. A complete categorisation of the different microwear traces for each of the different tool materials is presented in table 4.

Table 4. List of microwear traces characteristic of the different tool materials used.

Tool Material	**Characteristic Microwear Traces**
Flint	Prominent ridges present between irregular bands of striations, with a small amount and size of edge removals. Small amounts of residue remaining, if any.
Copper	Very faint and mostly regular striations present in regular bands, with an overlaying 'sheen' or polish. Extremely small size and amount of edge removals, and very little residue remaining on perforation walls, if any.
Bronze	Faint but very regular striations in faint regular bands, with few edge removals.
Antler	Scoring present, often with loose residue remaining in place. Occasionally present are very faint bands of regular striations, often overlaying layered residue. Small amount and size of edge removals.
Malachite	Scoring present, as well as layered residue with faint irregular striations and occasional green colouring. (Apart from colour, indistinguishable from antler)

4.2.2. Variation in amber material

Some further aspects of the experiment are provided in table 5 below. This includes the time taken to drill each individual nodule, which varied considerably depending on the tool used, as well as the nodules thickness, which then equates to the total length of the perforation, and also the amber type of the nodule. Due to the natural properties of amber, there is some variation within the nodules in terms of colour and physical consistency. The different colours of amber, including yellow (fig. 48), orange (fig. 49), and dark orange (fig. 50), had no effect on the consistency of microwear traces, although it could be said that some colours allowed an easier identification of traces than others. For example, the very small amounts of pale-coloured loose residue that naturally get caught in the striations enable these traces to be more easily identifiable against a darker amber background, and are consequently also more difficult to identify on paler yellow amber nodules.

Table 5. Summary of the drilling experiments, regarding completed perforated nodules.

Bead	**Tool material used**	**Nodule thickness**	**Drill time**	**Amber colour / texture**
3153	Wide flint drill-bit	10 mm	35 mins	dark orange, translucent
3167	Thin flint drill-bit	9 mm	4 mins	dark orange, solid
3165	Handheld flint borer	10 mm	16.5 mins	dark orange, translucent
3155	Antler drill bit	10 mm	55 mins	dark orange, translucent
3160	Antler drill bit	5 mm	6.5 mins	dark yellow, grainy
3163	Handheld antler borer	9 mm	75 mins	dark yellow, grainy
3174	Handheld antler borer	6 mm	35 mins	yellow, partly translucent
3159	Wide malachite drill-bit	9 mm	63 mins	orange, translucent
3169	Thin malachite drill-bit	10 mm	10 mins	dark orange, translucent
3171	4mm handheld copper borer	6 mm	35 mins	orange, translucent
3173	5mm handheld copper borer	6 mm	32 mins	dark orange partly grainy
3176	Copper drill-bit (5mm)	10 mm	49 mins	orange, translucent
3178	Copper drill-bit (4mm)	9 mm	5 mins	dark orange,p.translucent
3180	Bronze drill-bit	10 mm	4.5 mins	dark orange, translucent
3182	Handheld bronze borer	10 mm	14.5 mins	dark orange, translucent

Figure 48. Example of yellow amber.

Figure 49. Example of orange amber.

Figure 50. Example of dark orange amber.

Figure 51. Example of grainy amber.

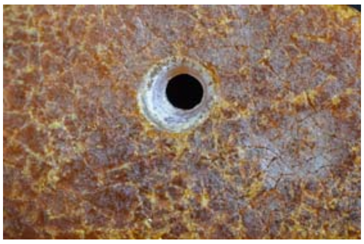


Figure 52. Example of solid amber.

Figure 53. Example of translucent amber.

In terms of the physical consistency of the amber (grainy (fig. 51), solid (fig. 52), or translucent (fig. 53)), it is possible to see some slight differences in the creation of microwear traces that could have been caused by the type of amber drilled. For example, while all nodules drilled using flint displayed the characteristic traces of irregular bands of irregular striations accompanied by ridges, the latter are much more prominent in the 'solid' amber nodule compared to the 'translucent' amber nodules. More experimental pieces have to be produced in order to determine whether this is an anomaly or whether solid and translucent amber nodules drilled with flint do display some differences in traces. In terms of the small selection created as part of the current experimental collection, any differences between the traces on different nodules are subtle enough that they do not affect the microwear analysis.

A stronger distinction can be seen between translucent and 'grainy' nodules, for example in those nodules drilled using antler. As described above, the traces created when using antler drill-bits consist mainly of scoring, and if striations are present they are very fine and overlay layered residue. When considering the type of amber nodules drilled, it can then be seen that those perforations which exhibit striations overlaying layered residue occur only in translucent nodules, although this could be coincidence based on the limited data set. Scoring is also present within translucent nodules, however they are the only traces present in grainy nodules. If we then examine the traces within other grainy nodules, for example bead number

3173 drilled using copper, it is possible to see extremely faint traces that could be classified as scoring. These are overlaid with fine, regular striations, which were then considered to be the dominant trace present. Even considering this, could it therefore be that the ‘grainy’ nature of this particular type of amber encourages the creation of scoring during perforation? When examining the archaeological beads from Kolhorn (see section 5.1), it was possible to identify apparently conflicting combinations of traces, for example the perforation of bead KH 1984 224.5/24.5 contained both irregular bands of striations and ridges (which would suggest the use of flint or a similar material), and also bands of scoring (which would suggest antler or a similar material). Considering the observations from the experimental collection, could the presence of scoring in this archaeological perforation therefore be caused by the grainy physical structure of the bead? In order to establish the validity of this hypothesis, future research should provide a more detailed classification of the different types of amber nodules available than the very small sample size from the current research project. This research should involve not only the detailed classification of experimental amber beads and nodules but also those found in archaeological contexts, as well as some experimental research into how the physical properties of amber change over time.

In summary, the potential effects that different amber types have on the microwear traces created during crafting activities, such as bead making, requires further research. The experimental collection created during the course of the current research project is small, as it was limited by time and resource availability, and so only by creating a larger and more varied experimental collection can we gain a greater understanding of the influences discussed above. For example, only by perforating each amber type with each tool material (i.e. using flint to drill grainy, solid, and translucent amber) can we truly compare any variation within the characteristic microwear traces created.

4.3. Results from the blind test

In order to test the validity of the observations of those traces deemed to be characteristic of a certain tool material, taken from table 4, a blind test was set-up using amber nodules previously perforated or cut during experiments by other researchers at Leiden University. Ten beads were subjected to a microscopic examination under the stereomicroscope and the relevant observations are provided in table 6.

As can be seen from the results of the blind tests, the microwear traces defined as being characteristic of the different tool materials proved nearly 100% successful when attempting to identify which material had been used to drill a perforation. The only inconsistency in predicted versus actual materials used was encountered when trying to differentiate between antler and materials of similar hardness such as bone. Characteristic differences in microwear traces created by bone versus antler tools may exist, however as only antler was used in the experimental section of this thesis, it was not possible for the author to make such a differentiation. Additionally, as only metals were used in the cutting experiments for this thesis, the author was not able to confidently identify which material produced the traces left on the (sixth) cut amber nodule. In all other cases, however, the characteristic traces could be used to identify which tools were used to perforate the amber nodules. Irregular bands of striations signify the use of a flint drill-bit, while the presence of scoring and a large amount of loose, layered, or consolidated residue suggests the use of antler or a material or similar hardness, such as bone.

Table 6. Observations made during the blind test using previous (unknown) experimental pieces

Bead	Nodule details	Striations present?	Scoring present?	Predicted	Actual
1	Partially perforated on both sides	Yes. Fine bands of regular striations	Yes, overlaid with large amounts of loose residue	Antler (or similar material, e.g. bone)	Antler
2	Partially perforated. Very flat bottom and straight sides	Yes. Thin bands overlaying black, layered residue	Some, and only at entrance to the perforation	Copper rod (based on perforation shape, rather than traces)	Heated copper rod
3	Completely perforated	Yes. Irregular bands of irregular striations (+ ridges)	No	Flint	Flint
4	Completely perforated. (Rounded area suggests wear)	Yes. Irregular bands of strong striations	No	Flint	Flint
5	Completely perforated / finished	Yes. Irregular bands of irregular striations	No	Flint	Flint
6	Unfinished cut	More regular cut marks than with a copper knife, but less rounded than with cord		Unknown	Mussel shell
7	Button-style perforation	Yes, but extremely fine and overlaying layered residue	Yes. Majority hidden beneath loose residue	Antler (or similar material, e.g. bone)	Bone
8	Partially perforated twice on one side	No. Too much loose and consolidated residue to accurately determine	Potential scoring, due to the way the loose residue lies	Antler (or similar material, e.g. bone), however unclear	Antler
9	Button-style perforation	No. Too much loose residue	Potential scoring, due to the way the loose residue lies	Antler (or similar material, e.g. bone), however unclear	Antler
10	Partially perforated twice on one side	Yes. Some very fine sections of bands.	Yes. Some areas, but no regularity	Antler (or similar material, e.g. bone)	Bone

One might argue that the presence and type of residue should not be considered when attempting to identify the tool material used, as it is assumed that any residue produced during perforation would have disappeared by the time the beads are excavated. During the examination of the archaeological collection from Kolhorn (Province of North Holland), however, it was possible to identify loose and consolidated residue. Although it should of course be noted that residue is not always present and so cannot be relied upon when characterising the microwear traces in archaeological amber beads, examples from Kolhorn suggest that it is possible for such residue to remain. It is therefore important to record the presence and type of residue in the experimental collection produced in the current thesis project, as such information could be used in comparisons with archaeological collections such as Kolhorn where residue is also present. This example will be discussed further in section 5.1.

4.4. Conclusion

The cutting experiments were conducted in order to compare the effectiveness of a bronze knife and copper saw with string sawing techniques from previously conducted research using nettle, flax, and lime string. The results suggest that, while the chosen metal tools were successful in splitting the amber nodules, their effectiveness was low in comparison to string sawing techniques both in terms of time required and completeness of the cut. Although it is presumed that any traces from the cutting stage of the production process of amber beads in the archaeological collection would be erased by later stages such as grinding and polishing, it is possible to determine differences in microwear traces between the different tool materials used. These results could therefore be applied to a comparative analysis of cut nodules or unfinished beads within the archaeological record.

The experimental drilling of amber beads presented mixed results. First, it is possible to differentiate between the traces left by different materials, and therefore potentially deduce which tool material was used during the production of archaeological amber beads. Three groups of trace types could be formed based on a microwear analysis of the experimental collection: traces associated with flint drill-bits, traces associated with antler and malachite drill bits, and those attributed to bronze or copper drill-bits. It is however impossible for the author to confidently differentiate between traces left by antler versus malachite, and traces left by copper versus bronze. Despite this uncertainty between traces from similar materials, it was still possible to assemble a list of traces that are characteristic of the tool materials used. A blind test was then conducted, which used these characteristic traces in order to identify the material used on previously experimentally produced amber beads at the Leiden Laboratory for Artefact Studies. The blind test proved successful, although there was some uncertainty in distinguishing traces between similar materials, for example antler and bone. Despite this uncertainty, however, the blind test showed that the list of characteristic traces created through analysis of the experimental collection could be applied to beads whose production process is unknown, such as those from archaeological contexts.

Chapter 5: Analysis of the archaeological collections

The second stage of research relating to the perforation experiments was the examination of three archaeological collections from a Neolithic settlement site in Kolhorn, a Bronze Age grave in Emmerdennen, and group of Bronze Age tumuli in Hijken Hooghalen. The experimentally created list of traces characteristic for the different tool materials was used in order to attempt to identify which tool materials could have been used to drill the archaeological perforations.

5.1. Analysis of beads from the Kolhorn settlement

The majority of the beads from the second archaeological collection – a Late Neolithic settlement site in Kolhorn in North Holland (Drenth and Kars 1990) – were sufficiently well preserved to allow the observation and identification of clear microwear traces. A total of 23 beads were chosen for detailed analysis, based on the quality of the traces present, and the results are documented in table 7, using the same parameters as in the blind test. It should be noted that the predicted tool materials are based on the knowledge gained from the experimental collection, and so for example a predicted material of 'flint' and 'antler' should be understood as 'flint or similar material' and 'antler or similar material'. As can be seen in table 7, the ability to accurately match experimental and archaeological microwear traces was not always possible. This was partly due to the occasional combination of different traces, for example the presence of both scoring and bands on certain beads, which would then prevent the identification of only those traces characteristic of one tool material. These mixed traces could be due to the use of multiple tool materials during bead production. Further experimental data is required in order to address this issue, as the time restrictions of the current thesis allowed only the production of a small experimental data set. This experimental collection can then only provide a limited amount of traces compared to those present in archaeological beads that were produced over the course of several thousand years. Despite this limitation, however, it was still possible to make comparisons between traces in the experimental and archaeological pieces using the list of characteristics created in the experimental collection. It was particularly possible to differentiate between a combination of striations and ridges, which then suggest the use of flint, and scoring, which could suggest antler or a similar material such as bone.

Table 7. Observations on the Kolhorn collection using characteristic traces from table 4.

Bead	Perforation details	Striations present?	Scoring present?	Predicted:
KH 50016	Rounded section (worn?). Misaligned or possibly incompletely finished	No clear striations, but many irregular bands	No	Flint
KH 90.007	Rounding present on both sides of the perforation (worn? Also suggested by polish on the surface, maybe caused by cord)	Yes. Regular bands with small ridges on one side, and bands of striations on the other	No	Flint
KH 90.008	Broken bead with a misaligned perforation	Yes. Bands of irregular striations	No	Flint
Unlabelled	Slightly misaligned and very rounded centre of the perforation. Combined with rounded edges: worn?	Yes. Regular bands of striations and ridges, with some loose residue	No	Flint
KH 1982 134.5/30.5	Slightly misaligned. Very rounded at the centre and edges: implies wear	No	Yes. Also some consolidated residue present	Antler
KH 1982 139.5/30.5	Broken bead with a misaligned and potentially incomplete perforation	No	Yes. Regular bands of scoring with some ridges	Antler
KH 1984 50.5/38.5	Broken perforation. Very rounded at one end: worn?	No	Yes. Also a lot of loose residue	Antler
KH 1984 224.5/24.5	Broken half of a perforation of a long bead. Some slight misalignment, and very rounded in the centre	Yes. Regular bands of striations, and ridges of very irregular depths	Yes. Some thin bands of scoring	Unclear, likely flint / flint & antler
KH 1985 227.5/35.5	Misaligned and apparently incomplete perforation	No visible traces, but black residue present at the bottom of the perforation		Unclear
KH 1981 159.5/18.5	Complete bead with flattened surfaces and quite rounded edges (worn?)	Yes, very few. However irregular bands present	No	Flint
KH 1985 224.5/34.5	Complete bead with flattened surfaces and some edge removals. No rounding	Yes. Irregular bands of irregular striations and ridges	No	Flint
KH 47.5/24.5	Complete biconical perforation with some rounding on one side: worn?	Some bands but very few striations	Yes, a lot with some loose residue present	Antler
KH 1985 224.5/39.5	Broken bead with a small misalignment and slight rounding (one worn for short period of time?)	Yes. Irregular bands of irregular striations, also with some black residue	No	Flint
KH 1983 221.5/47.5	Complete bead with flattened surfaces and many edge removals on one side	Yes, but not in apparent bands. (Coarse grinding inside perforation?)	No	Unclear
KH82 163.5/26.5	Possible elongation of two misaligned perforations, with rounded edges (worn?	Some striations present, but worn perforation walls	No	Insufficient
KH 1986 145.5/37.5	Completed bead with flattened surfaces and a biconical perforation	Yes. Some irregular bands of ridges and some striations	No	Flint
KH 146/45A	Broken perforation, very rounded on one side	Yes. Irregular bands of irregular striations and ridges	No	Flint
KH 1985 216.5/25.5	Biconical-shaped, with very worn centre and edges. (Traces in middle of wall)	Yes. Irregular bands of irregular striations	No	Flint
KH 1980 162-44	Flattened and ground blank with no perforation	Grinding marks on the surfaces suggest that blanks were first ground into shape before perforation		
KH 1986 151.5/28.5	Broken perforation in a long bead, slight misalignment	No	Some potential scoring, very fine	Antler? (unclear)
KH 1979 211/37	Wide bead with a long broken perforation, slight misalignment	Yes. Regular bands of striations, but covered with a lot of loose residue	Yes. Some bands with potential scoring, also layered by residue	Unclear due to residue
KH 1985 223.5/30.5	Broken perforation (glued together)	Slightly irregular bands with loose residue but no striations	No	Potentially flint but unclear
KH 1984 223.5/28.5	Complete longer perforation with some rounding on edges	Unclear, as covered with black residue	Unclear, as covered with black residue	Could be hot material

Additionally, the presence and type of residue that was noted in the perforation experiments, for example after using the antler drill-bit and borer, could also be matched with residue within the perforations of the beads from Kolhorn. It cannot be assumed, however, that this is always the case and that other archaeological collections can be compared in such a way. For example, no residue apart from dust could be identified on the beads from Emmerdennen or Hijken Hooghalen, both of which will be discussed further below. A broader study using a larger sample size of archaeological collections is therefore required in order to determine the influence of the presence of residue on the identification of characteristic production traces for different materials. The durability of residue is also something that should be investigated further: although cleaned three times in an ultrasonic tank, the experimental pieces continued to retain residue. Similarly, many of the Kolhorn beads have also retained residue despite evidence of rounding of the perforation and a heavily polished surface that indicate that they were regularly worn; a theory in bead analysis suggested by Van Gijn (2006; 2014). For example the broken perforation of the unlabelled bead from Kolhorn demonstrates clear rounding visible in the centre and on the edges of the perforation (fig.54). This then leads to the question of how much wear can be applied to a perforation before any residue present begins to disappear. A previous study conducted by Brasser (2015) investigated the effects of wear on beads made from jet by wrapping them in various materials such as pig skin, leather, and cloth, and tumbling them in a machine. The results suggested that it could be possible to distinguish between an intentional polish, perhaps to erase any production traces, and a use-wear related shine. This research was however limited by the boundaries of a Master's thesis and so an extensive investigation into this study area is still required.

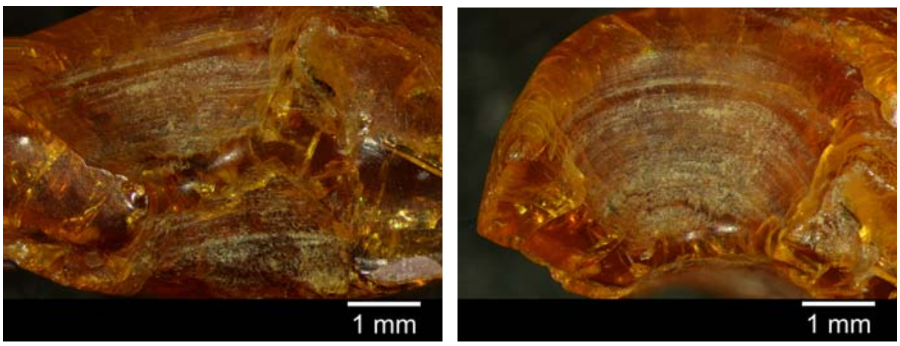


Figure 54. Rounded centre and edges of a broken perforation on a bead from Kolhorn.

As with this bead, the rounding in several of the archaeological pieces is a prominent feature of their perforations, and so was included in table 7 alongside the consequent deduction that this therefore suggests that the beads in question were worn. This inference is made purely on the basis of previous studies in microwear analysis (cf. Van Gijn 2014a). The experimentally produced beads for the current research can be compared against possible archaeological production traces, but were not worn and so cannot be used as a comparison to determine use-related wear traces.

The results strongly suggest that the experimental programme used within the current research project provided a good indication of the type of tool material used in past amber bead technologies. A visual example of the similarity between the traces on the experimental versus archaeological collections can be seen below (fig. 55 and 56).

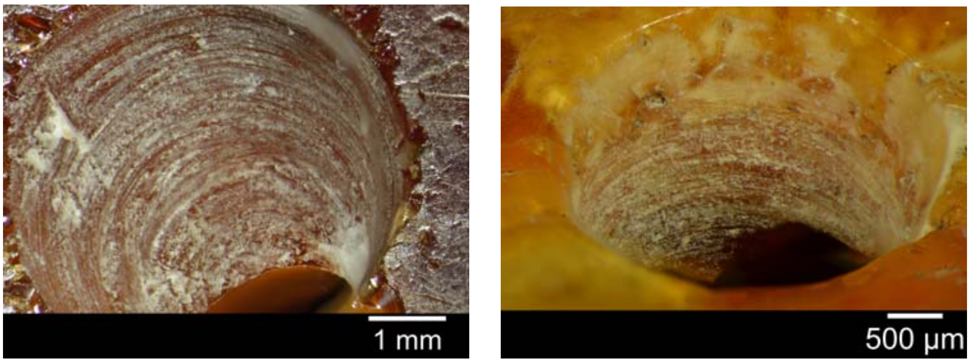


Figure 55. An experimental bead drilled using flint (left) compared with a bead from Kolhorn (right).

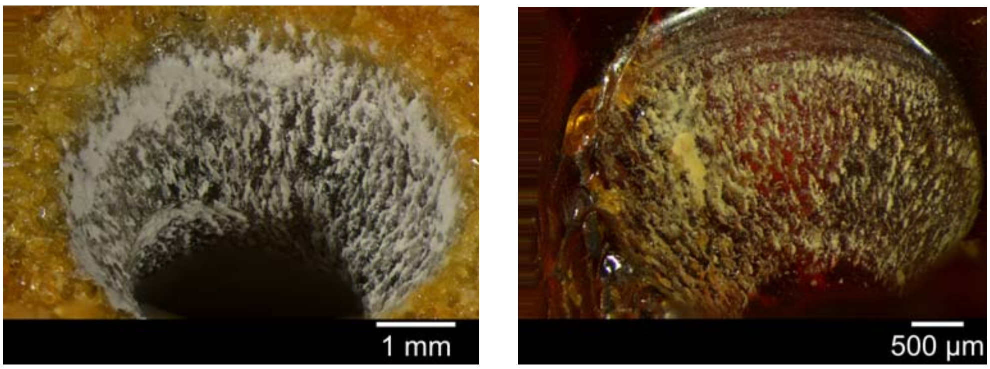


Figure 56. An experimental bead drilled using antler (left) compared with a bead from Kolhorn (right).

As mentioned before, however, these predictions should not be considered conclusive and are subject to the limitations of microwear analysis, which were discussed in the previous chapter. A higher degree of reliability and certainty could be achieved with a broader study including a larger experimental collection, access to more archaeological collections, encompassing a wider range of raw materials, and the potential addition of lubricants and abrasives.

5.2. Analysis of beads from the Emmerdennen coffin burial

A selection of beads from a Middle Bronze Age coffin burial within a tumulus at Emmerdennen in the province of Drenthe (Butler 1990) was also examined in order to identify any traces present that could be compared with those in the experimental collection. Unfortunately it soon became apparent that the beads were all extremely weathered and badly preserved. Few traces could be identified, and even then it was unclear whether the fine scratches observed (fig. 57) were created during production or through depositional and post-depositional actions. The author believes that the lack of traces on the perforation walls were caused by a lack of preservation rather than eradication through wear, as there was no evidence of rounding at the edge of the perforations, which would suggest that the beads had been worn (Van Gijn 2014a). At a microscopic level it was also possible to see a lot of dust and dirt on the beads, which could not be cleaned due to conservation concerns and so prevented the identification of any clear traces (fig. 58). It was therefore considered impossible to compare the experimental and archaeological collections, as the characteristic manufacturing traces identified on the experimentally produced beads were not observed on the archaeological beads. An alternative reason for the absence of traces is that they were intentionally removed. This suggestion is supported by the idea that the perforations are all extremely straight, as opposed to the conical and biconical perforations caused through drilling either from one or both sides. Van Gijn (2006, 199) suggests that the perforations of prehistoric beads could have been further shaped and polished using an abrasive material to remove all traces, for example *Equisetum hyemale*, commonly referred to as 'rough horsetail'. Experimental research could be conducted to provide further insight into this hypothesis by investigating how the use of such an abrasive affects the shape of the perforation and any traces present.

Figure 57. An example of faint surface scratches on a bead from Emmerdennen.

Figure 58. An example of the dust and dirt present on a bead from Emmerdennen.

One aspect of the production process from the experiments that could be identified on the archaeological collection from Emmerdennen was the accidental misalignment which occasionally occurred when drilling the amber nodules from both sides. Two examples of this can be observed below. In figure 59 the slightly elongated, ovular shape of the perforation entrance suggests that, in order to even out the walls of the perforation, an initial misalignment was corrected by drilling an additional section of the perforation. In figure 60, the additional hole in the wall of the perforation, potentially caused through a misalignment, is clearly visible.

Figure 59. Extended, ovular perforation on a bead from Emmerdennen.

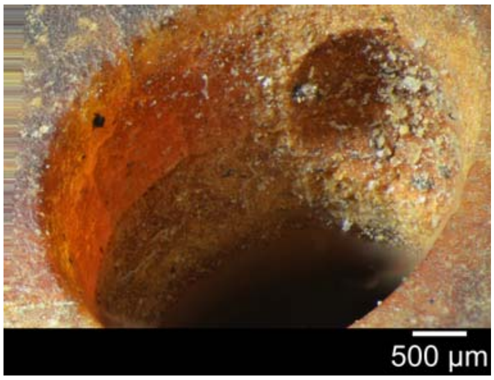


Figure 60. Additional hole in the perforation wall on a bead from Emmerdennen.

5.3. Analysis of beads from the Hijken Hooghalen tumuli

The beads from the Bronze Age tumuli in Hijken Hooghalen (Van der Veen and Lanting (1989) were unfortunately similar to those from Emmerdennen in that they were quite poorly preserved. The archaeological collection consisted of three groups of beads from three different tumuli. A distinct difference could be seen between the eight beads from tumuli 6 and 10, which were all perforated but unshaped, and the remaining sixteen beads from tumulus 9, which were fully formed. This group of sixteen beads, although much smaller than those from Emmerdennen, were similar in that they were disc-shaped and all had straight perforations with no evidence of rounding. There was also evidence of misalignment in four of the beads through the presence of holes in the perforation walls and ovular extensions of the perforations (fig. 61). There were however some differences between the two collections, as the sixteen beads from Hijken Hooghalen displayed distinct polish and flattening on the surfaces of the beads (fig. 62).

Figure 61: Example of an extended, ovular perforation which could suggest misalignment, on a bead from Hijken Hooghalen.

Figure 62: Example of the flattened and polished surface of the beads from tumulus 9 at Hijken Hooghalen.

This combination of use-wear polish and flattening could suggest that the beads were rubbing against each other, perhaps on some kind of cord (fig. 63). This could also explain the straightness of the perforations and lack of traces on the perforation walls, and could also provide an alternative interpretation of the contemporary beads from Emmerdennen. Although they do not demonstrate the same distinct polish as the sixteen beads from Hijken Hooghalen, the beads from Emmerdennen are very similar in shape and form and it is therefore possible that they too could have been worn on a necklace. If they were worn on a necklace, then the lack of well-preserved production traces in both collections could be due to their erasure during use. The fact that the Kolhorn beads also display evidence of wear and yet still retain extremely well preserved production traces, however, makes this hypothesis less likely. As mentioned above, a potential reason for the lack of traces could be due to intentional removal through the use of abrasives and polish, or else the poor preservation of the beads.

Figure 63. Diagram of the potential necklace consisting of the sixteen beads from tumulus 9.

As with the beads from Emmerdennen, the sixteen beads from tumulus 10 therefore did not provide any evidence that could then be used to suggest what tool material was used to drill the perforations. The second group of beads from tumuli 6 and 10, however, were more useful in this respect despite also being extremely weathered. Three of these beads (1953/VII20c, 1953/VII28a, and 1953/VII28b) had biconical perforations, thus suggesting that beads in the Bronze Age were still being drilled from both sides, also implying that flint drill-bits were still being used at this point. Does this therefore mean that the straight perforations in the rest of the beads was caused by a different drill-bit material, or had they also been drilled biconically and were then intentionally straightened as mentioned above? Three of the beads even displayed what could be interpreted as irregular bands and ridges (fig. 64), thus suggesting the use of flint.

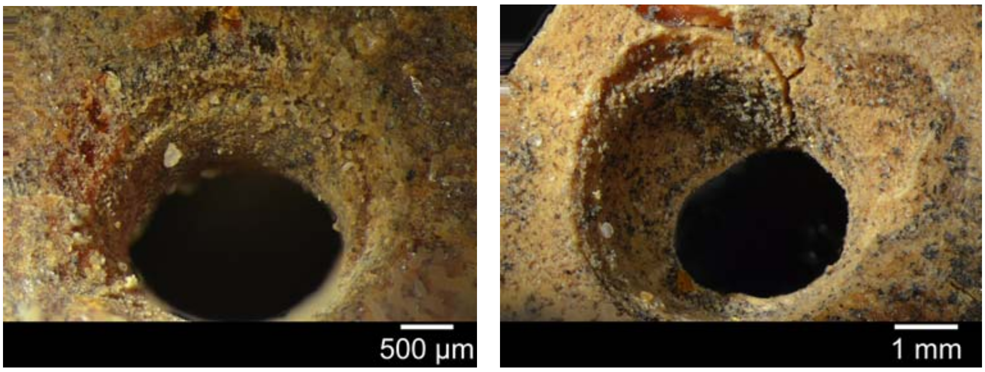


Figure 64. Irregular bands and ridges evident in three of the beads from the Hijken Hooghalen tumuli.

This could also explain why these perforations were biconical. As previously mentioned in the methodology chapter of this thesis, it is extremely hard to make flint into a specifically shaped point that is then strong enough to be used for a practical activity, as opposed to unused decoration. If flint is used to drill from both sides, it is therefore more likely that the irregular shape of the drill-bit will create a biconical perforation, as opposed to a straight perforation. To answer the question above, it therefore could be suggested that at least two different drill-bits were used to drill the beads from Hijken Hooghalen. The use of flint created the biconical perforations displaying evidence of irregular ridges, but the straight perforations could have been created by a different material entirely. This idea then leads to a further investigation of those beads from Hijken Hooghalen demonstrating evidence of misalignment, for example bead 1953/VII20a (fig. 65). By examining the shape of the hole in the wall caused by misalignment, it is possible to determine the shape of the drill-bit used and thus potentially ascertain the tool material. The most extreme misalignment present in bead 1953/VII20a included a slightly rounded shape at the bottom of the misaligned section. This therefore suggests that the drill-bit used was also slightly rounded at the tip. Based on the previous paragraph, it therefore seems unlikely that flint was used in the creation of these perforations. Instead, a material was used that could be formed into a slightly rounded point or else could become rounded through use when drilling. Within the current research project, all drill-bits were made into a four-sided point, however it was a lot easier to shape the antler and metal drill-bits to the desired shape. If a rounded tip was desired, it therefore seems more likely that either of these materials, or similar materials such as bone, could have been used as a drill-bit.

Figure 65. Evidence of extreme misalignment present on bead 1953/VII20a.

This suggestion remains valid even when considering the additional microwear traces created by these materials on the perforation walls. Both the copper and bronze drill-bits created very fine striations, and those perforations drilled using antler displayed scoring alongside the presence of overlaying residue. If the beads had been worn as a necklace for a long period of time, it is possible that all of these finer traces could have been worn away, thus leaving only the straight perforations and shaped misalignments visible in the Emmerdennen and Hijken Hooghalen collections. As already mentioned, the evidence from the wear and traces present in the Kolhorn collection could invalidate this suggestion, however it is impossible to know how long both collections were potentially worn and thus how much their use would affect the preservation of production traces.

5.4. Further evidence from the archaeological analysis

Additional information that can be gathered from an analysis of the shape of the perforations is an approximate estimate of the shape and size of the drill-bits used, as mentioned briefly above. Considering the three sites analysed within this thesis, it could be assumed that the straight perforations observed on the beads from Emmerdenne and Hijken Hooghalen could not have been created using flint drill-bits due to the latter's conical shape, which would therefore have created a naturally biconical perforation (Piena and Drenth 2001). As mentioned above, a more workable material such as solid drills made from antler or bone could have been used instead, thus explaining the rounded bottom of misalignments observed in the Hijken Hooghalen collection. Other archaeologists have different opinions as to how straight perforations could have been made in the past. For example, Drenth *et al* (2011) suggest that heated metal rods could have been used to create the straight perforations evident in beads from the Bell Beaker site of Hanzelijn. Additionally, Piena and Drenth (2001) describe how a small column of amber remaining with a perforation at the Late Neolithic site of Aartswoud provides strong evidence for the use of hollow drill-bits, for example made from bird bone. A hollow drill-bit does have some superiority over solid drill-bits in terms of effectiveness, as it prevents an excess build-up of amber residue, which could then lead to breakage of the nodule under pressure (Piena and Drenth 2001, 439). Further experimental research is required in order to determine which materials, either hollow or solid, could contribute to the shape of perforations within archaeological amber bead collections.

All of the drill-bits and handheld borers used to create the experimental perforations were sharpened to form a four-sided point, apart from the flint tools as it was too difficult to accurately knap the flint to such a point. No archaeological evidence from early prehistory has been discovered which could provide a reference for this study in terms of exactly how the point of a non-flint drill bit should be constructed. Borers discovered at archaeological sites that are sufficiently well preserved to allow an examination of their point are usually made from flint or other hard stones, which exhibit a conical point but with varying specifics of exact tip shape (cf. Piena and Drenth 2001, 439; Bains *et al* 2013, 347) (fig. 66).

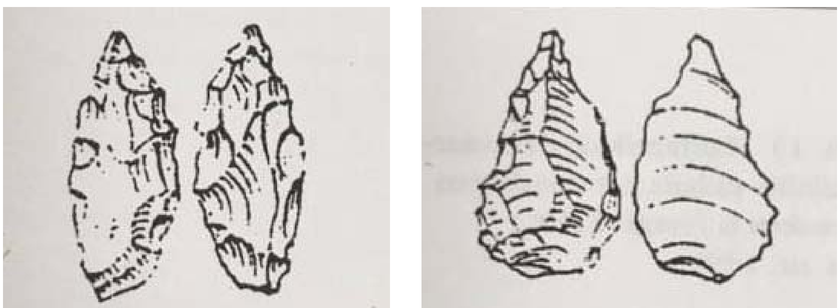


Figure 66. Examples of flint borers from the site of Aartswoud (taken from Piena and Drenth 2001, 439)

A four-sided point was therefore chosen as it was relatively easy to form in all of the materials used, apart from flint, and appeared to be an effective shape when piercing or drilling any material. It should be noted, however, that this does not therefore assume that all drill-bits in the past would have been formed to such a point, and indeed it would be interesting to investigate further whether different shapes and styles of point have any effect on the production traces created within the perforation. In terms of the diameter size of the entrance to the perforation, the experimental and archaeological collections are very similar in range, with an average of 3mm. This suggests that the main thickness of the drill-bit shaft used in the experiments is also similar to what might have been used in prehistory. The centres of the perforations, however, vary both within the archaeological collections and between them and the experimental collections. This could be due to the pointed shape of the drill-bits, which consequently causes the centre of the perforation to have a smaller diameter than the entrance due to its biconical shape. Additionally, as mentioned in Chapter 3, the initial experiments using wider flint and malachite drill-bits suggested that a thinner drill-bit might be more efficient at creating a perforation. This idea is supported by the results in the previous chapter, which shows that using thinner drill-bits in both materials allowed the consequent perforations to be completed in a much shorter time. The wider flint drill-bit took 35 minutes to complete a perforation in contrast to the 4 minutes taken when using the thinner flint drill-bit, and the wider malachite drill-bit took 63 minutes to complete whereas the thinner malachite drill-bit took only 10 minutes. When considering both this increased effectiveness (in terms of time) when using thinner drill-bits and the similarities between the perforation sizes in both the experimental and archaeological collection, it can therefore be suggested that, although the shape of the drill-bit point used in prehistory is still uncertain, the main thickness of the drill-bit is similar to that created and used within the current research.

5.4. Conclusion

The three archaeological collections provided varying results. The beads from Kolhorn included well preserved traces which provided good comparative results when identifying the use of flint and antler drill-bits. While this archaeological collection therefore provided very positive results for the applicability of the thesis experiments, no clear production traces could be identified on the perforation walls on the beads from Emmerdennen. It was assumed that this lack of traces was due to the bad preservation of the amber material, as no rounding could be identified that would suggest excessive wear of the beads to the extent that traces would be erased through use. Examination of the beads from Hijken Hooghalen demonstrating a flattened surface surrounding the perforations, however, suggested that the beads could indeed have been worn strung together on a necklace. As the beads from Hijken Hooghalen also contained either few or no production traces besides evidence of misalignment, it could therefore be assumed that being worn on a necklace had therefore worn away all production traces. This assumption is made less certain, however, by the fact that the beads from Kolhorn exhibit both evidence of rounding, thus suggesting wear, and the presence of well preserved and identifiable production traces. More research is therefore required regarding the impact of wear and weathering on the preservation on production traces.

Chapter 6: Discussion of the results

The following chapter presents a discussion of the results from both the cutting and the perforation experiments, the issues and limitations of the current research project, and how the project fits into the broader context of similar research studies. The main aim of this thesis was to determine whether the use of metal in the past could be seen through the identification of specific production traces caused by metal tools. In order to achieve this aim, two types of experiment were conducted investigating the cutting and drilling stages of amber bead production, the results of which are presented below.

6.1. Discussion of the experimental and microwear analysis results

6.1.1. Discussion of the cutting experiments

An experimental collection of cut amber nodules was created using cutting tools made from copper and bronze. These nodules were then compared with those created using string 'saws' made from nettle, flax, and lime, which had been used by a previous researcher at Leiden University (Verschoof 2010). Comparisons were made regarding the technological effectiveness of flint knives and string saws versus metal tools, and the production traces left by the latter two tool types. They were not directly compared with any archaeological collections. It was presumed that any traces left from this stage in the production process would have been erased by later stages such as grinding and polishing, as suggested by Sax *et al* (2004) and demonstrated by the completed bead production experiments by Verschoof (2010). There has been evidence from some Late Neolithic sites in Holland of the sawing of amber nodules. For example, Van Gijn (2014a) described how flakes from Zeewijk demonstrated traces of having been sawn by flint, and production waste discovered at Aartswoud showed evidence of string sawing (fig. 67) (Piena and Drenth 2001). Finding evidence of the cutting stage of bead production on a completed bead, however, is unlikely due to the eradication of previous traces through later stages such as grinding and polishing. Additionally, no traces from the cutting stage were observed in any of the three archaeological collections analysed, and so no direct comparison in cutting traces was able to be made between the experimental and archaeological collections within this thesis project.

Figure 67. Traces from string sawing on an amber nodule from the Late Neolithic site of Aartswoud (taken from Piena and Drenth 2001, 437)

A comparative analysis between different cutting materials focusing specifically on the production of beads has so far been absent within archaeological research. Comparative microwear research has instead focused mainly on cut marks created through butchering practices (cf. Walker and Long 1977; Greenfield 1999), or else on decorative carved cuts and grooves on stone ornaments (cf. Lothrop 1955; Sax *et al* 2004). The possibility of comparing the results from the studies mentioned above with those from the current research project is unfortunately quite limited. Although the differences in raw materials could provide an interesting second level of comparison – for example in order to see any consistency in trace differentiation between those traces left by cutting amber versus bone versus stone – the nature of the cut marks is completely different. In the current research, amber nodules are sawn into different sections, whereas the previous studies mentioned above considered only cuts and grooves in the surface of their respective materials. For example, an analysis of butchering marks left on bones showed that metal tools leave steep, smooth, v-shaped profiles (Walker and Long 1977; Greenfield 1999). When cutting amber nodules, however, such a profile would not be evident, as the v-shape would have split on splitting the nodule. The results from the current research project do suggest that misaligned splitting of the nodule could cause a v-shaped profile to remain, however it is highly unlikely that this would remain as evidence in the archaeological record if the nodule was then finished into a bead, as opposed to a bone which has only been used in butchery practices.

A similar problem is encountered when considering those studies investigating the differences in microwear traces left by different tool types and materials in stone ornament decoration, for example those made from jade (cf. Lothrop 1955; Sax *et al* 2004). The results from these studies showed that sawing with a straight-edged tool, such as a metal saw or knife or a flint blade, produced straight cuts with parallel longitudinal grooves, whereas string sawing created cuts with a rounded bottom edge and convex or concave surfaces. The main differentiating factor is therefore the curved nature of those traces left by string sawing. This aspect is, however, not evident in those amber nodules produced by Verschoof (2010), as those cuts created for example by Sax *et al* (2004) were only for decoration in the surface of the jade material, whereas Verschoof (2010) sawed the nodules completely through into two pieces and therefore the bottom of the cut no longer exists.

From the microwear analysis of cutting traces conducted within this thesis project, distinct differences could be seen between string sawn nodules and nodules cut using metal or flint blades. This was mainly due to the fact that string saws left traces throughout the whole of the split region, whereas both the metal and flint cutting experiments only left a band of traces before the nodule either split accidentally or was split by hand, thus leaving a smooth surface in the centre of the split region, surrounded by striations. The ability to differentiate between traces left by flint versus metal blades, however, was limited partly by the similarity between traces left by the flint blade and the bronze knife, but mainly by a lack of comparative material. Future expansions on this research should address this issue by incorporating a wider range of experimental material. Additionally, further archaeological material should be sought. Although it is rare to find amber production waste in burial contexts, plenty has been discovered at settlement sites (cf. Piena and Drenth 2001; Garcia Diaz 2013; Van Gijn 2014a), and there have also been several discoveries of amber flakes and nodules which retain evidence of cutting traces, as described above (Piena and Drenth 2001; Van Gijn 2014a). As the cutting stage is one of the first within the process of bead production, it is possibly only through waste materials such as discarded flakes and nodules that archaeologists will be able to fully investigate the associated cutting microwear traces.

6.1.2. Discussion of the drilling experiments

Another aspect of the current research project involved the perforation of amber nodules using drill-bits made from flint, antler, malachite, copper, and bronze. These perforated nodules were then compared with beads from three archaeological collections in order to see whether the traces created on the experimental pieces could be matched with those traces present in the archaeological beads. From this, the author was able to suggest which tool material could have been used to create the perforations encountered in archaeological assemblages.

6.1.2.1. Experimental collection of drilled nodules

As can be seen from the results of the current research project, there were some clear distinctions that could be made between traces drilled using different tool materials. For example, drilling using flint left irregular bands of ridges and irregular striations, whereas an antler drill-bit produced scoring. There was, however, also some overlap between characteristics. Perforations created using malachite and antler contained indistinguishable traces in the form of scoring and the presence of a large amount of residue. The only potential differentiation between the traces left by the two tool materials was the presence of a small amount of green residue caused by the natural colour of the malachite. The main point that should be taken from this particular result (i.e. the similarity of traces), however, is not that we must therefore attempt to identify the use of malachite by the presence of green residue within a perforation, but that we cannot assume that all perforations containing scoring traces were created using antler. The reason why malachite was used as a drill-bit in its raw mineral form was briefly described in Chapter 3, and is mainly due to the fact that malachite in this form would not normally be considered as a workable tool material due to its better-known property as a copper ore. This assumption that a material can only be used for one purpose is a potentially limiting one within archaeology. While it is true that some archaeological or ethnographic evidence is required in order to form a valid scientific or theoretical hypothesis, it is also important to consider evidence that may not be visible to the modern researcher. I believe that this is one of the best distinguishing features of archaeology in comparison to other fields of study: the immeasurable possibilities available when considering how societies lived in the past, none of which can ever be emphatically proven as ‘true’ or ‘false’ (Hodder 1995). When considering that the traces left by malachite are indistinguishable from those left by antler on the perforation of amber beads, for example, we must then question whether all previous ornaments identified as being made using antler tools really were made with antler. Perhaps there are many more materials which have been discarded during excavations under the potentially mistaken interpretation that they could not have been used as a tool in the past, or else could only have been used for a purpose unrelated to the one being investigated. Considering this, I would argue that, for example, it cannot be assumed that the discovery of malachite in its mineral form represents only its intended use to form metallic copper. Instead, researchers should always maintain a flexible and broad-minded attitude towards the possibility of different materials being used for different tasks that might otherwise be considered unusual.

Regarding the previously mentioned difficulty in differentiating between the traces created by antler and malachite, a problem also occurs when comparing the traces created when drilling using copper and bronze drill-bits. The bronze drill-bit used in the current research project was a lot more efficient in terms of time taken to drill the perforation, presumably due to the fact that bronze is a harder and therefore stronger material than pure copper. There is, however, no way to identify this superior efficiency when examining the microwear traces. Instead, the regular and fine bands of striations left by both copper and bronze appear visually to be very similar. Some further microscopic techniques are therefore required in order to identify differences between those traces left by the two materials. In the current study, only a stereomicroscope was used. In future research, a second level of investigation could be provided by examining the beads under a metallographic microscope and so using higher magnifications of 50-1000x. This type of analysis could potentially identify further characteristic traces that cannot be identified in detail using a stereomicroscope alone. For example, by providing a more detailed look at the metallic sheen on those beads drilled using copper and bronze in order to determine whether any difference between them can be observed.

Another form of differentiation is based on the assumed likelihood that microscopic particles of the tool material could remain on the surface of the perforation walls. By using a chemical analytical technique in order to determine which elements are present it could therefore be possible to identify whether an alloy of copper (for example bronze) or pure copper has been used as a drilling tool. Scanning electron microscopy (SEM) could provide such a solution. This technique has been used previously in studies of microwear analysis to provide a more detailed view of microwear traces at a higher magnification (20-30,000x), for example to compare both sawing and drilling techniques in stone bead production (Kenoyer 2005). It is however also possible to use SEM to provide chemical as well as visual information (Freestone and Middleton 1987). Unfortunately, there was a significant issue with using SEM in the current research project. The sample must be appropriately mounted in a sealed vacuum, which meant that the relatively fragile amber beads analysed in the current study could not be analysed using the SEM that was made available to Leiden University Laboratory for Artefact Studies. Gwinnet and Gorelick (1991) suggested a method of avoiding a direct analysis of beads by instead using a silicon mould, which can then make a negative cast of the perforation walls and so can be used in the SEM vacuum chamber. An even safer analytical technique in terms of avoiding bead damage has been suggested by Yang *et al* (2009), who successfully identified traces within bead perforations using computer tomography (CT) combined with 3D reconstruction. The benefits of this technique is that it creates a permanent 3D model, as opposed to only 2D images, which can then be analysed in place of the original artefacts. Unfortunately, it is still expensive and so cannot be used as a common investigative methodology (Yang *et al* 2009).

As an additional note, it is also a matter of some debate as to whether bronze was even used in early drilling activities. Gwinnet and Gorelick (1998) suggest that it was not used, based both on their idea that tin was still relatively rare and expensive in the Early Bronze Age, and that experiments conducted by the authors showed no advantage in terms of drilling efficiency of bronze over copper. This is in direct contrast to the results of those experiments conducted in the current research project. However, this may be due to the difference in drilled materials, as Gwinnet and Gorelick (1998) were investigating the production process of stone beads. It is likely that there is some difference in drilling techniques when objects of different hardness are compared; for example Groman-Yaroslavski and Bar-Yosef Mayer (2015) suggested that a hand drill does not have enough penetration power or vertical speed to initiate a hole, again in contrast to the results from the current research project. The study by Groman-Yaroslavski and Bar-Yosef Mayer (2015), however, was involved with the production process of carnelian beads. It is therefore assumed here that these conflicting results are due to the different materials of the objects under investigation, as opposed to any irregularity in the experimental framework. Corroboration of this assumption is however required through future research.

6.1.2.2. Archaeological collection of beads

As mentioned in the previous chapter, the archaeological collections investigated through this research project provided mixed results. Many of the archaeological beads, particularly those from the Kolhorn settlement and a few from the Hijken Hooghalen tumuli, displayed clear traces which could then be compared with the experimental collection. The beads from the Emmerdennen grave and most of those from the Hijken Hooghalen tumuli, however, displayed little or no evidence of production traces. Whether this is due to poor preservation, intentional erasure using a rough polishing material, as suggested in the previous chapter, or wear through use, remains unclear. The problems associated with trace erasure have already been discussed in some detail within this thesis, both in terms of sawing traces being removed through later stages of bead production, and use-wear potentially eradicating all production traces within bead perforations. Another part of the biography of an object that could affect the identification of production traces is the effect of post-depositional influences, which could either create new microwear traces or else eradicate existing traces (Odell and Odell-Vereecken 1980). These influences could occur at several stages, from the original deposition of the object into the ground, where it can then be subjected to taphonomic processes such as water damage or disturbance by animals, to any unintended modifications caused during its eventual excavation. Even following excavation, any traces remaining on an object can still be affected by conservation efforts, especially if we consider the early archaeologists of the twentieth century who only valued artefacts as display objects to become part of their collection (Lucas 2001). The likelihood of any kind of traces, including the different types of residue mentioned previously, surviving all of these post-depositional processes seems slim due to post-depositional contamination, and yet, as can be seen in the beads from Kolhorn, it is possible. So, to what extent do different post-depositional processes influence the preservation of production traces on amber? As with the effect of use-wear on the presence of microwear traces, this question can only be answered with more experimental research. Similar studies have already been completed investigating the impact of environmental processes on bones (Olsen and Shipman 1988) and lithic artefacts (Burroni *et al* 2002), but not specifically focusing on amber. Although many archaeologists believe that it is impossible to accurately re-create the exact post-depositional processes to which an object has been subjected (cf. Grace 1980), further experimental research will allow a greater understanding of how an amber object could have been altered since its creation.

As well as further investigations into the causes of microwear trace erasure, further possible causes of microwear trace creation, as in the traces created through production of an archaeological object, must also be considered. A clear conclusion that can be reached from the analysis of the archaeological collections is that there are still many aspects of the microwear traces which remain unclear, for example whether or not the beads were worn on a string, as was suggested with those from Hijken Hooghalen, and if so how much this use-wear would affect the identification of production traces. A greater understanding of the processes involved with archaeological bead production therefore requires an even wider range of experimentation than has already been completed in previous studies, as it is still unclear whether the traces found on different bead materials, for example amber versus carnelian, can be compared. As was discussed in Chapter 3, the drill-bits and borers used within the current research were all used dry, unheated, and without additional additives. Previous studies, however, have investigated all of these alternative properties and additives. Verschoof and Van de Vaart (2010) and Verkooijen (2008) used heated metal borers, archaeological evidence of which has also been discovered at the Dutch site of Hanzelijn (Drenth *et al* 2011, 221). Using heated metal borers is one hypothesised method by which a straight perforation can be made, as opposed to the conical or biconical perforations created using flint or stone borers. Piena and Drenth (2001) suggest that, while often flint borers needed to be used from both sides of an amber nodule in order to prevent it from breaking, the use of metal drilling tools would have allowed the craftsman to drill only from one side. This could also have prevented the issue of misalignment, and so the use of a metal tool could have been considered an improvement over the more irregular flint drilling material.

Gwinnet and Gorelick (1987) also examined the differences in traces when using lubricants and abrasives alongside the original drill-bit. This study suggested that subtle differences could indeed be seen in the production traces created when additives are introduced. The addition of abrasives such as sand are said to "enhance all aspects of drilling efficiency" (Groman-Yaroslavski and Bar-Yosef Mayer 2015, 77), which therefore suggests that prehistoric societies may also have understood the benefits of using these additives. The extent to which traces created through the use of additives allow or hinder a differentiation between different tool materials such as those used in the current thesis requires further investigation and could therefore be incorporated into future research on this topic. Lothrop (1955) also suggested that cutting and sawing could have been accomplished using an abrasive. Additionally, the use of heated materials – not just copper and bronze but also potentially flint and antler – could contribute an interesting addition to the current study. As well as identifying how the different heated materials affect the amber nodule and examining any alterations and differentiations in traces, an analysis of the method of perforation could also prove beneficial. For example, the experiments conducted by Verschoof and Van de Vaart (2010) utilised a pushing rather than drilling action when using a heated copper wire to perforate an amber nodule. Investigating the effects that this change in methodology has on the production traces would allow a greater understanding of the different influences that can be applied to the creation of microwear traces.

When considering the need for a wider range of experimentation, the main limiting factor in the analysis of the archaeological collection was therefore the small size of the data set provided through the experimentally produced pieces. Only 17 experimental beads could be created, due to the time and resource restrictions of the current master's thesis. This meant that only a small number of perforations were drilled using each tool material. Additionally, the tools used were limited to one drill-bit and one hand-held borer made from each material. Conducting further repetitions of the current experiments using not only a larger amount of perforations drilled but also a wider range of tools from each material would allow further insight into the range of perforated pieces expected in the archaeological record. This thesis included only those drilling experiments completed by the author, however future papers could combine these with other amber perforation experiments, for example those completed by previous researchers at the Laboratory for Artefact Studies. This wider range could then be used to make a more accurate list of traces considered characteristic of drilling, as it includes a more similar variety of tools to those potentially used in prehistory. While it was still possible to compare the traces from the experimental and archaeological beads and see some similarities which could then be interpreted to suggest tool material, a larger data set would provide more conclusive evidence to support and validate such suggestions. It would also be interesting to apply the same experimental framework on a wider range of materials in order to ascertain whether the same characteristic microwear traces from the different tools are created on different types of material. For example, if the same traces that metal creates on amber can also be seen on harder stones or softer material such as antler or even wood, then this could imply that the same distinguishing characteristics can be used universally. A study by Gwinnet and Gorelick (1981) showed that the traces in the perforation walls of soft and medium stone beads (Mohs scale 1-6) were very different to those observed on the perforation walls of hard stone beads (Mohs scale 7-10), with deep, irregular striations on the former and fine, regular striations on the latter. This study did not, however, combine this archaeological analysis with an experimental project in order to determine whether these differences were due to the varying hardness of the stone beads or the use of a range of drilling materials.

6.2. Additional issues encountered during the experiments

6.2.1. Efficiency of tool materials

The concept of 'efficiency' has been mentioned several times throughout this thesis, and as an analytical term it requires some further discussion concerning its appropriateness towards experimental archaeology. In the modern western world, a tool is usually described as efficient if it is able to complete a task as accurately and quickly as possible. This is likely due to the highly industrial nature of modern life, which particularly in the western world is focused on mass production, and so the ability to create and produce as many objects in as little time as possible is highly valued. We cannot however assume that past societies would also have had this relationship with the objects they produced (Costin 2005). Indeed, many past and current archaeological theories suggest that the perception of objects in prehistory was very different to what it is today. Rather than objects being seen as inanimate and passive products created by the (superior) active human subject, it is instead suggested that objects had their own agency and were capable of influencing humans during production, use, and even deposition (Hoskins 2006). In other words, people were influenced, and aspects of their personality and social status potentially formed, by the objects that they created, used, and eventually deposited or destroyed. This does not imply that we should not use the term 'efficient' when describing, for example, how the thinner flint drill-bit was able to perforate the amber nodule in nearly 10% of the time required when using the wider flint drill-bit. It is however important when interpreting the results not to assume that this modern idea of efficiency was also shared by prehistoric societies.

6.2.2. The concept of skill and specialisation

The concept of skill and how we can define it has been the subject of much debate within the archaeological study of objects (cf. Dobres 2006). Many archaeologists believe that the natural progression of society meant that the creation of certain objects became the task of specialised 'skilled' craftsmen: "craft specialization has come to be conceived of as a *state of being* that is achieved in the course of technological and social evolution" (Kenoyer *et al* 2011, 46). Many modern experimental archaeologists apparently agree with this idea, as the field of experimental archaeology strongly recommends using modern skilled craftsmen when conducting research to ensure valid results (Dungworth 2013). But how appropriate is it to apply this concept of skill to prehistoric technologies and craftsmen? As has already been mentioned within this thesis, the author had no previous experience with drilling using either a hand- or bow-drill. It was therefore expected that some mistakes might occur, such as the perforation misalignments evident in several of the experimental pieces. In correlation with the ideas described above, it should therefore be assumed that this evidence of a lack of 'skill' would not be seen on the archaeological collections, as according to the points made above it is believed that they would have been made by specialised craftsmen. But is this indeed the case? Some pieces from the archaeological collections also display evidence of misalignment in both the Neolithic and Bronze Age beads, as has also been described in other studies (cf. Van Gijn 2014a). This suggests that either the particular archaeological collections analysed as part of the current study were anomalies, which seems unlikely, or else amber beads in prehistory were also made by non-specialists who were not necessarily specialised in bead production but simply created them to the best of their ability. Van Gijn (2014) suggests that the apparent lack of a standardised production sequence evident in bead collections from archaeological sites, particularly Late Neolithic settlements such as Kolhorn, is evidence that those beads were made on site by a range of people.

In light of this conclusion, how are experimental archaeologists then to proceed with experimental research? It is true that experience is an important factor when conducting experimental investigations, as individuals who have practiced something for a long time are usually better at it and so will provide more valid results. This is however only relevant if we assume that craftsmen in the past were also specialised and skilled experts. If not, then it could be argued that using a highly skilled individual for a specific craft in modern archaeological experiments, for example employing a professional bead-maker to drill the amber beads, could warp the results in the other direction. Several experimental studies have therefore used a range of people with varied skills and ability (cf. Harlacker 2006) in order to avoid this influence. Due to the highly intangible nature of the majority of archaeological evidence, it is unlikely that we will ever know exactly what level of 'skill' craftsmen had in prehistory and how specialised individuals were in specific crafting activities. For example, whether there were specialists in amber working, or bead working, or specifically amber bead working. The evidence of perforation misalignment from the current research, however, suggests that prehistoric amber beads were not only made by highly experienced craftsmen who specialised only in the production of amber beads, as a certain level of perforation quality would then be expected.

6.2.3. Issues concerning the objective identification of traces

In addition to perforating capability, the ability of the author to correctly identify microwear traces could also have some influence on the results of the study. To assess the accuracy of trace identification, a blind test was conducted using experimentally perforated amber beads created by previous researchers at Leiden University. The blind test was successful when identifying traces left by flint, antler (or similar materials), and heated copper tools. However, the researcher's ability to determine whether traces had been caused by cold metal tools was not tested.

As well as identifying the traces evident on their own collections, microwear analysists also often encounter the issue of having to interpret the observations of other researchers. This was particularly evident in the current thesis project. In addition to directly analysing the three experimental collections from Kolhorn, Emmerdennen, and Hijken Hooghalen, the author attempted to investigate previously analysed collections of amber beads through reviewing experimental studies and archaeological reports by other researchers. Although it was possible to gain some insight into the results of these studies in this way, and in many cases images of the beads in question were provided, there was insufficient relevant detailed information that would contribute to the present discussion. Even if photographic evidence was provided from previous investigation into bead production technologies, it was not always focused on the exact area required, in this case the perforation. This is often a problem in microwear analysis, where individual analysts specialise in particular types of microwear traces and so, even if the technology being studied is the same, the area being investigated may still vary between researchers (Van Gijn 2014c, 167). This is something that requires improvement, not only in regards to further expansions of this thesis project, but also in the field of microwear analysis in general.

A possible expansion of the current research project relating to trace identification, and also a potentially useful addition to the field of microwear analysis in general, is the use of a computational image analysis. That is, a computer programme that is able to analyse microscopic images of the beads. Using these images, the programme can identify the presence of residue and both differentiate between traces such as striations and scoring as well as calculate their level of regularity. Such a method would allow a more objective approach to the identification of microwear traces, and would therefore be a highly beneficial addition to the field of microwear analysis. The methodology and results of preliminary tests using such a program are briefly described below.

Images taken using the stereomicroscope were selected according to the orientation of the perforation within the image and the level of detail visible. Two measurements were then made using custom written analysis scripts created by Michael Siebrecht in the open-source program ‘Matlab’. The first measurement taken calculated the ratio of residue present within the perforation based on the differentiation between the paler residue from the rest of the amber material. The consequent measured ratio of residue to solid amber is then displayed as a fractional measurement from 0 to 1. This first stage of measurement is still very preliminary and requires some improvement. The second measurement taken relates to the identification of traces based on their angle of orientation, such as striations which run horizontally along the perforation walls versus scoring which runs vertically down the perforation wall. These traces are identified based on a method known as the ‘image gradient’, where horizontal and vertical so-called ‘edges’ within a greyscale image are detected and counted. This quantification is then displayed in a histogram (fig. 68 and 69), from which it is possible to determine whether the chosen image displays more vertical edges (which then implies scoring), or horizontal edges (which then implies the presence of striations).

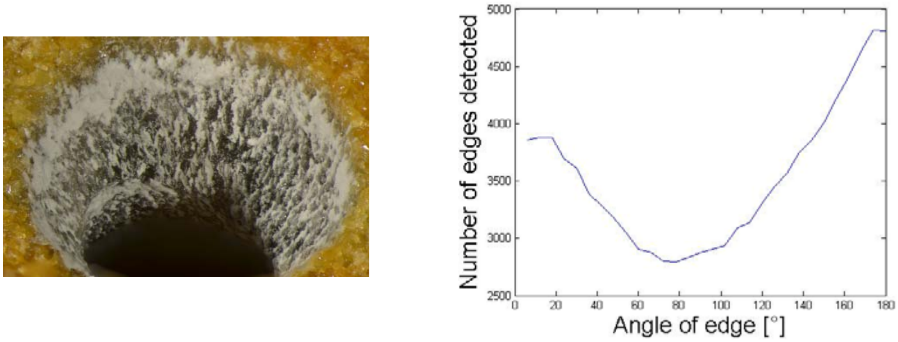


Figure 68. Example of the shape of histogram caused by the presence of scoring, here in an experimental perforation drilled using antler.

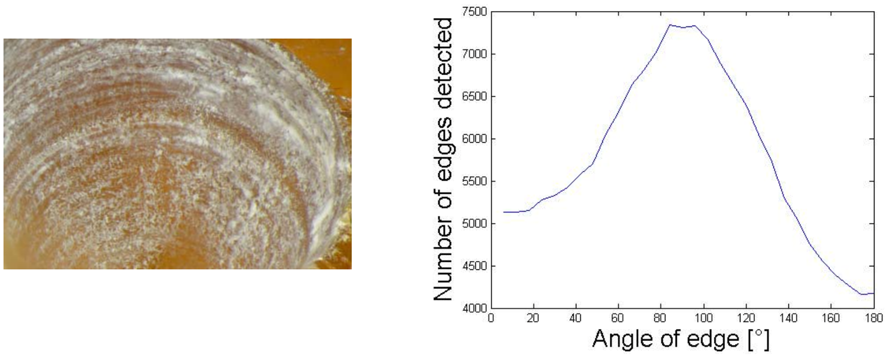


Figure 69. Example of the shape of histogram caused by the presence of striations, here in an experimental perforation drilled using bronze.

As can be seen in the figures above, the presence of more vertical edges (scoring) creates a valley-shaped curve, whereas the presence of more horizontal edges creates a hill-shaped curve. In order to present this information in a simpler form, the ratio between the two peaks of the histogram is calculated. This result could also be used to determine how regular the traces are; for example, differentiating between a wider range in horizontal edge orientation, thus implying irregular striations that could suggest the use of flint, and a smaller range, thus implying regular striations that could suggest the use of copper or bronze. A final scatter plot can then be constructed which combines the residue ratio quantification (as can be seen on the y-axis) and the ratio of the direction of traces for each bead (fig. 70).

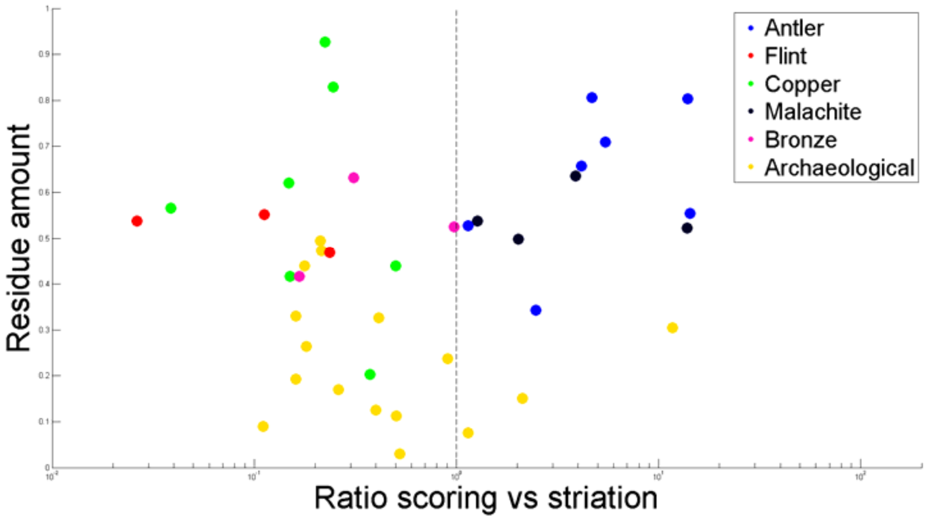


Figure 70. Quantified ratios of residue presence versus trace orientation within the walls of the perforations of both experimental and archaeological amber beads.

As mentioned above, this methodology is still in its early stages and therefore requires improvement, and an optimal analysis can only be achieved with a larger data set than the small experimental collection created through the current thesis project. As can be seen in figure 70, however, some grouping is already visible within the final graph, thus potentially enabling a further level of perforating tool material identification based on the ratios of residue and 'edge' orientation within the bead images. Traces created by malachite and antler can be clearly differentiated from those drilled using flint, copper, and bronze. Although it is still impossible, using the present data set, to differentiate antler from malachite traces and flint from metal traces, a larger amount of data points could cause the clustering of more groups within the two already distinguished. With a sufficiently large sample group and some improvement to the methodology, it could therefore be possible to use such a computational algorithm as a secondary level of analysis in future microwear studies.

6.3. Conclusion

While the cut and sawn nodules were created as part of a purely experimental project, the perforation experiments proved successful in that it was possible to make comparisons between those microwear traces in the experimental and archaeological collections. The project did however reveal some issues that should be considered before any future expansions on the current research are attempted. Firstly, a larger data set is required, both in terms of experimental and archaeological pieces, in order to provide a wider range and variation of comparative traces. The same can also be applied to the tools used, and it would perhaps be beneficial to use not only a more varied collection of tool types, for example different kinds of saws and shapes of drill-bits, but also a wider range of materials and the addition of lubricants and abrasives. Archaeologists should also always consider the possibility that materials could have been used in the past for different functions to those that we might consider normal for them, for example in this research malachite was used in its raw form as a hard drill-bit, compared to its associated function in copper production.

Additional points that were discussed included the production and durability of microwear traces, for example the effect of wear through use of the beads during their lifetime and taphonomic processes during their deposition. The relevance of skill when considering not only the current research project but also experimental archaeology and microwear analysis in general was also discussed, as was the concept of efficiency in relation to crafting activities. Potential future research, not only for this thesis project but also for the field of microwear analysis in general, could utilise an automated identification of traces, for example through the use of a computational algorithm. In order for the current research project to expand, however, it is first necessary to further investigate those issues mentioned above in order to gain a greater understanding of what external factors can affect the production of microwear traces within an archaeological object.

Chapter 7: Concluding remarks

7.1. Summary of the thesis project

The aim of the current research project was to contribute to the investigation of when metal first started to be used as a functional material in prehistory. This was achieved through the investigation of amber beads using experimental archaeology complemented by microwear analysis. An experimental collection of cut and perforated amber nodules was created, using a bronze knife and a copper saw for the cutting experiments, and drill-bits made from flint, antler, copper, bronze, and malachite for the drilling experiments. All of the nodules were examined microscopically in order to create a list of microwear traces considered characteristic for each tool material.

The experimental collection of cut nodules was compared against a previous experimental collection created by Verschoof (2010), which utilised string-sawing technology, as well as the results of experiments using flint blades. This comparison consisted of two parts. The first part investigated the effectiveness of the metal cutting tools in relation to the string saws and flint blades. The results suggested that the string sawing method was considerably more effective than both the metal and flint tools in terms of time taken to split the nodules and the completeness of the sawn groove. Following a comparison of the bronze knife with the copper saw, it appeared that a serrated edge was more effective at quickly and precisely splitting an amber nodule along an intended fracture line. The second part of the cutting analysis compared the microwear traces created by the metal tools with those created by the string-saws and a single image from one of the flint cutting experiments. It was possible to see some differences between all tools during this analysis, however the application of these results to an archaeological context is perhaps limited. Previous studies have shown that the main difference between rigid metal / flint tools and flexible string tools is the presence of rounding at the bottom of the cut, however these studies investigated cuts in the surface of objects such as incomplete sawn stone nodules, bones used in butchery practices, and jade ornaments. In a completely split amber nodule, however, the bottom of the cut is no longer present. Consequently, it is harder to differentiate between rigid tools such as metal and flint knives, and flexible tools such as string saws. Additionally, it is presumed that any traces from the cutting stage of the bead production process would be erased through later stages such as grinding and polishing. The experimental collection of cut nodules was therefore not compared against any of the archaeological collections. Future studies should however conduct a wider investigation of amber production waste, particularly in settlement contexts where crafting activities may have taken place on site.

The perforated amber pieces created through the drilling experiments, however, were compared against three archaeological collections comprising of a Late Neolithic settlement from Kolhorn, a Middle Bronze Age grave from Emmerdennen, and Bronze Age tumuli from Hijken Hooghalen. The list of characteristic traces created during the analysis of the experimental pieces was validated through the completion of a blind test using amber nodules from previous experiments conducted at Leiden University. This blind test was successful, thus implying that the list of characteristic traces could be applied to amber nodules of unknown production, for example those in the archaeological collections. It was, however, only possible to compare these traces with those on the collection from Kolhorn and Hijken Hooghalen's tumuli 6 and 10, the beads from which were the only ones to retain production traces on the perforation walls. In contrast, those from Emmerdennen and the majority of those from Hijken Hooghalen had no visible production traces on the perforation walls, although they did display evidence of misalignment in several of the beads. The main issue that arose as part of the comparison with the archaeological collections was the extent to which wear impacts the preservation of traces within the perforations. The flattened surface of several of the beads from Hijken Hooghalen and Emmerdennen could imply that they were strung on a necklace, which could then account for the lack of traces within the perforation as these traces could have been erased through wear. Many of the beads from Kolhorn displayed evidence of rounding, which therefore suggests that they were also worn, however in contrast to the other two collections they exhibit clearly preserved production traces. It has been suggested that those beads from Emmerdennen and Hijken Hooghalen could have had their traces intentionally erased, for example using an abrasive material. In conclusion, it was possible to compare traces between the experimental and archaeological collections. However, future research into the effect of wear and weathering on the preservation of production traces is required in order to address this issue.

If we consider the original, broader question of this thesis – that of when metal first started to be used as a functional material in prehistory – it is clear that further research is definitely required. The traces that could be identified on the beads from Late Neolithic Kolhorn were comparable with those experimental traces created using flint and antler tools, and so it could be assumed that metal drill-bits were not utilised at this particular site. This is however only one site from the northern Netherlands, and so a wider regional range of archaeological collections from this time period should be included in any future larger-scale project. As discussed in detail in the previous chapter, those straight perforations with un-recognisable or no traces from the beads from Hijken Hooghalen and Emmerdennen leave much more to the imagination and could not be compared in detail with any of the experimental collection. Evidence from Bell Beaker sites, when metal was considered an established material (Butler and Fokkens 2005; Kuijpers 2012), has suggested the use of heated metal borers in order to create a straight perforation (Drenth *et al* 2011). There is however also evidence of straight perforations in beads from earlier Single Grave Culture sites, such as Aartswoud, which Piena and Drenth (2001) suggest may have been created by hollow bird bones. Unfortunately these pieces could not be directly analysed by the author, and so it is unknown whether those perforations hypothesised to have been created using heated metal and hollow bird bone show any similarities in terms of perforation size / shape and microwear traces, and therefore could in fact have all been created using the same material. As discussed in the previous chapter, this issue can only be resolved by re-analysing all of the material with a particular focus in mind, in this case concentrating specifically on the perforation, and consequently making direct comparisons between the different collections. Additionally, further experimental research is required in order to create a wider range of possible perforation traces which can then be compared with those identified in the archaeological collections, as described below. Despite the limitations of the small data set within the current project, however, this thesis successfully demonstrated that a broader study utilising experimental archaeology complemented by microwear analysis could contribute valuable data towards the discussion on prehistoric metallurgy.

7.2. Directions for future research

7.2.1. Extending the research potential of the current project

Throughout the course of the thesis project, several issues arose which require further investigation through future research directions. The impact of wear and weathering on the preservation of production traces, as mentioned above, is one example. Future studies should therefore include an extensive experimental research project which investigates a wide range of wear-related activities and weathering processes. A previous study by Verschoof (2010) included a small-scale version of such an experiment, where the author wore strings of amber beads on a necklace for three months in order to see the formation of use-wear traces. If this was extended to cover a longer time period and combined with an investigation into different weathering processes, it would provide invaluable information on how the preservation of production traces can be impacted by external factors.

Another example involves the use of additives and heated tools when conducting the experimental aspect of the research. For example, several studies have suggested and/or used abrasives and lubricants both in the context of cutting experiments (Lothrop 1955; Sax *et al* 2004) and perforation experiments (Gwinnet and Gorelick 1981; Van Gijn 2014a). In all cases, these additives have greatly improved the effectiveness of the cutting or drilling action being performed, and it is also likely that their use alters the appearance of any microwear traces created. As well as the inclusion of additives, past studies have also included the use of heated metal tools (Verkooijen 2008; Verschoof and Van de Vaart 2010). In addition to involving a completely different drilling method – as the heated metal is pushed rather than drilled into the amber material – there is the very strong possibility that this technique will also create very different production traces. Future directions of the current research project should therefore include the production of a wider range of experimental pieces involving the use of additives such as abrasives and lubricants, as well as the use of heated tools. This need not be limited to heated metal tools, as it would be interesting to see what effect heating flint or antler tools would have both on their effectiveness and the microwear traces they create.

In conclusion, a much wider range of experimental pieces is required in order to better replicate the variety of production methods used in prehistory. This thesis project has shown that the methodology employed is successful and can be applied to future studies, however its current applicability is limited in terms of its relatively small data set. Expansions of the project are therefore necessary. This includes examining a wider range of archaeological collections and creating a broader experimental collection, not only in terms of the tools used but also potentially an investigation into materials other than amber.

7.2.2. Applications of alternative analytical technology

Although using a stereomicroscope (10-63x magnification) has been sufficient in order to identify and characterise production traces, expansions of the current study could also benefit from using different analytical technology. For example, the use of a metallographic microscope allows a higher level of magnification (50-1000x) and so can investigate more subtle microwear traces (cf. Van Gijn 2014c). An even higher level of detail could be seen using an SEM (up to 30,000x magnification), which would then potentially enable the researcher to identify more characteristic traces for each different tool used (cf. Kenoyer 2005). This would then allow a more specific categorisation of microwear traces created by different tool materials, thus providing more precise results.

As well as using higher levels of magnifications, future studies could also use different technology in order to better identify the traces within drilled perforations. For example, Gwinnet and Gorelick (1991) made silicone impressions of drilled holes in order to better examine the microwear traces on the perforation walls. Another example is the use by Yang *et al* (2009) of a CT scanner combined with 3D reconstruction, again in order to directly examine the traces on the walls of the perforation. Finally, the potential use of a computer algorithm which conducts an automatic identification of different microwear traces could enable a more objective analysis of images, for example images of the perforation walls. These methods mainly apply to the investigation of traces left during the perforation experiments, as these traces are always on the internal structure of the perforation and are consequently more difficult to examine.

7.3. Conclusion

The present study utilised experimental archaeology complemented by microwear analysis to investigate traces created using stone, antler, and metal tools during the production of amber beads, focusing particularly on the cutting and drilling stages of bead production. The experimental phase of the project showed it was possible to differentiate between production traces created by the varying tool materials. A list of traces considered characteristic of each tool material was constructed and used in a comparison against archaeological beads from the Northern Netherlands, ranging in date from the Late Neolithic to Middle Bronze Age. Several issues arose as part of these comparisons, the majority of which were related to the small data set of the study in terms of the both the experimental and archaeological collections. These issues should be addressed in future expansions on the current study. In conclusion, the current thesis project successfully fulfilled its aim and, if the suggested expansions are implemented in future research projects, demonstrated a further possible method of documenting the spread of metallurgy in prehistory.

Abstract

A significant step in the history of society was the onset of metallurgy. It is however unclear when metal first started to be used as a standard, functional material in prehistory. Much of the earliest evidence of metal artefacts within the archaeological record was deposited in a potentially ritual context, which suggests that the origin of the use of the metal as a functional material cannot be based on the presence of metal objects within the archaeological record. The deposition of supposedly ritual objects in the past does provide evidence for the presence of metal as a material, however this does not necessarily correlate to the presence of everyday, working metal objects and tools. While stone tools could have been immediately discarded once they are broken and so their stratigraphic placement in the archaeological record can be approximately correlated with the date that they were used in the past, metal tools can be re-melted and so recycled over a much longer period of time. It could therefore be argued that he earliest stratigraphic location of metal tools in the soil does not necessarily correlate with their time of origin in prehistory. In order to address this problem, many studies have instead studied the presence of metal indirectly, by investigating the microwear traces left by different tool materials in order to determine whether certain traces can be considered characteristic of metal tool use. These studies have ranged from an examination of cut marks in butchered bones to an investigation of drilling technology during bead production. The present study used experimental archaeology complemented by microwear analysis to investigate traces left by stone, antler, and metal tools during the production of amber beads, focusing particularly on the cutting and drilling stages of bead production. From an analysis of the experimentally produced pieces, it was then possible to create a list of distinguishing features for each tool material. This list of distinguishing features was then compared to those traces identified on archaeological collections from three sites in the northern Netherlands: the Late Neolithic settlement site at Kolhorn, a coffin burial in a tumulus at Emmerdennen, and grave goods from several tumuli at Hijken Hooghalen. The results demonstrated that it is possible to identify which tool material had been used to create the archaeological pieces, and thus potentially contribute towards existing studies in microwear analysis of tool traces, and potentially also further towards detecting the onset of metal as a functional material in prehistory.

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List of figures

Unless otherwise stated, all photos were taken by the author.

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