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This innovative journal is dedicated to the presentation, discussion and interpretation of the archaeological record of southern Scandinavia in its international, regional and local context. Providing a platform for publication and debate for professionals from the museum as well as the university sectors this journal is open for empirical, methodological and theoretical contributions covering all time periods and all kinds of archaeology with relevance for the Scandinavian, Baltic, and North Atlantic regions. In addition, the journal may publish articles of wider theoretical, discursive or global reach.
The Danish Journal of Archaeology includes original research articles, news and discoveries, and discussion pieces with the intention of fostering open debate about the archaeological record of southern Scandinavia in its broadest sense and the position of archaeology as a discipline in the modern world.

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Contents

Editorial

Mette Svart Kristiansen, Rune Iversen, Thomas Grane and Lasse Sørensen

The editorial team proudly present this volume of the Danish Journal of Archaeology in a new format as a fully-online and open-access journal. DJA is still the high-quality, blind peer-reviewed and professionally laid-out journal that you will recognise from earlier volumes, but is now fully accessible and free of charge. The Danish Journal of Archaeology is rated as amongst the highest-ranking international journals on the Danish Bibliometrical Research Indicator (BFI), and is the only one of these that mainly focuses upon archaeology in or related to Southern Scandinavia.

The journal is hosted by the Royal Danish Library at the Open Access platform www.tidsskrift.dk, which offers a variety of open access journals. We are grateful for the opportunity to publish the journal in this professional setting and for the support offered by the Royal Danish Library. We are happy that the research of authors, and work of reviewers and editors is now freely accessible for colleagues worldwide, including those who do not have access to institutional funding. All this is possible thanks to generous funding from the Danish Research Council, Farumgaard Fonden and Elisabeth Munksgaard Fonden, for which we are grateful.

The history of our journal is similar to that of many others. It started as the Journal of Danish Archaeology in 1982 with printed volumes (1982-1999, 2006). After a break of some years, the journal was revitalised in 2012 as the Danish Journal of Archaeology, which indicated its new scope, and was published by Taylor & Francis as both a printed and online journal (2012-2018). With this new 2019 volume, the aims are the same, but the journal has once again adapted to new directions in publishing and is now entirely online. This is aimed at lowering costs, as well as acknowledging the importance of reducing our environmental impact when printing and shipping. If you, as a reader, prefer to feel the paper in your hands, turn the pages and read when you are offline – you can print individual articles or the entire volume. At the end of each year, all published articles are gathered together in one pdf file, with a unique volume-specific cover. We are currently working on creating better solutions for accessing previous volumes.

We present to you a volume containing seven articles covering periods ranging from the Palaeolithic to the Viking Age, which involve fresh ideas and methods in studies of a broad variety of themes. The authors are based at universities, local and national museums, and heritage institutions in England, Germany, Sweden and Denmark. Most articles are co-authored and provide an insight into research environments extending across institutional and geographical borders.

A new feature of the journal is that we are now able to present 3D illustrations. This is used in Eggers et al. The 3D feature can be activated, when the article pdf is opened in Acrobat Reader, by clicking on the 3D illustration.

Eggers et al. examine the lithic assemblage from the Late Palaeolithic site of Skovmosen, located near Lyngby on Zealand. Based upon typological and technological traits, the Skovmosen assemblage would traditionally place the habitation within the Bromme Culture. The authors discuss whether specific types and technologies, such as tanged points, can be assigned to the Bromme Culture or if they reflect a more functional interpretation relating to the hunting of larger mammals, such as elks or giant deer, in the landscape of the Allerød area. The study of the Skovmosen assemblage opens up a discussion of the challenges we face today when assigning lithic assemblages to specific cultures from the Late Palaeolithic.

Three articles focus on the Bronze Age and illustrate how research into this fascinating period has progressed significantly in recent years, not least due to dedicated and detailed analyses of bronze objects and the people who used them. Thus, new approaches and refined techniques are enabling new interpretations of old finds and the questioning of existing interpretations and typologies. Using a geometric morphometric framework, Christina Vestergaard and Christian Steven Hoggard examine whether Bronze Age tutulus shapes conform to Oscar Montelius' old classification system. Another detailed study has been carried out by Christian Horn and Tine Karck, who examine tip and edge wear on Bronze Age weaponry to demonstrate changing preferences in combat style throughout the Early Bronze Age. Samantha S. Reiter and colleagues revisit the old oak coffin find from Ølby, Zealand, with an updated scientific approach and multi-analytical investigations, including strontium and lead isotope analyses, as well as craft-technical analyses of the deceased woman's belt plate and dagger. The results provide a unique glimpse into the provenance of a Bronze Age woman, her burial goods and the raw materials used to create these goods.

Two articles focus upon the Viking Age. A contribution by Sven Kalmring presents an amulet in the shape of a throne from Hedeby. In a discussion of the remains of throne-shaped amulets and the types of chairs that are represented, he concludes that the Hedeby amulet constitutes a miniature barrel chair, a chair type that only exists as a secondary function. Moreover, the amulet is the earliest indication of the existence of barrel chairs. Laila Kitzler Ålfeldt and Lisbeth Imer use 3D scanning and multivariate statistical analyses to identify rune carvers on Bornholm. Through this innovative technique, they have contributed to the discussion of the rune stones on Bornholm and suggested allegiances to Denmark or Sweden based upon language and style. On the basis of their analyses, identifying individual traits of workmanship, the authors could conclude that the carvers were associated with sponsor families, and were most likely to have been family members themselves.

The article by Dobat et al. presents the basic functionalities and development of the DIME portal, a user-driven scheme for recording metal detector finds. The aim is to make the registration of metal detector finds accessible to the general public and future research projects. The vision behind the DIME portal is to provide a medium between the users and specific authorities, such as local museums, the National Museum of Denmark and the Agency for Culture and Palaces.

We already have a series of articles in progress for the next volume 9, 2020, and are pleased that there is continued interest in publishing in the Danish Journal of Archaeology. As we are now a fully online journal, we are not restricted to a certain number of pages in a printed volume. It is therefore only the scope of the journal (https://tidsskrift.dk/dja/about) and the quality of the articles that regulate the length of each volume. All articles published in the present volume are research articles, and we encourage potential authors to also consider our other formats, such as debate articles and brief communication. Articles will be published when they are ready, so look out for forthcoming publications in 2020.

We hope you will enjoy this volume!
The editorial team

A Technological and Typological Analysis of Lithic Material from Skovmosen I, Denmark

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ABSTRACT
During road construction work, material attributed to the Final Palaeolithic was discovered at Skovmosen I, near Kongens Lyngby on Zealand, eastern Denmark. Although it is regularly mentioned in reviews of the southern Scandinavian Final Palaeolithic, the Skovmosen I assemblage has hitherto remained poorly described. We here review the site's discovery history and its context. Aided by a three-dimensional digital recording protocol, this article details the assemblage composition and its technology. The assemblage is comprised of tanged points, scrapers and burins, alongside blades and cores as primary reduction products. Although evidently disturbed by the road construction that led to the site's discovery, the material likely reflects the remains of a small Final Palaeolithic locale, where diverse activities were carried out.

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Final palaeolithic; Late glacial; Lithic technology; Tanged points; 3D recording.

Introduction

Late Glacial finds in Denmark are, when compared to other periods, relatively rare (https://slks.dk/fileadmin/user_upload/kulturarv/publikationer/emneopdelt/arkaeologi/aud/reg-kronologi.pdf), with a small number of contexts representing, following traditional cultural assignment, the Hamburgian (c. 12500-12000 cal BC), Federmesser (c. 12000-10800 cal BC), Bromme (c. 11500-10500 cal BC) and Ahrensburgian (c. 11000-10000 cal BC) cultures. Perhaps one of the most frequently found typological and taxonomic entities throughout this period is the Bromme culture, representing the majority of entries in the *Fund & Fortidsminder* (Sites and Monuments Record), provided by the Danish Agency for Cultures and Palaces (Riede 2017a).

The status of these cultures, the transitions between and the causes underlying the attendant material culture changes observable in the archaeological record are currently much debated (Buch Pedersen 2014; Riede 2013; 2014; Riede & Pedersen 2018; Sauer & Riede 2018; Weber et al. 2011). The difficulties of disentangling these patterns and processes of culture change are, in part grounded in the scarcity of well-described sites. Of the Late Glacial entries in the Danish Sites and Monuments Record (*Fund & Fortidsminder*), the majority of find spots actually represent stray-finds of either projectile points or knapping debris; larger and well-described assemblages are rare (Riede 2017b:27-31). This register is used primarily for administrative purposes, however, and changes in registration practice over time and between the many registrants are difficult to account for. Nonetheless, the database still offers the most immediate overview of the archaeological finds from present-day Denmark.

In a recent review of the Danish Final Palaeolithic, the site of Skovmosen I on Zealand in eastern Denmark has been listed among those assemblages (Brinch Petersen 2009), yet the material has only very briefly been described previously and never before in English (Boye 2006; Hilgart 2003). We here offer an in-depth description of legacy materials associated with the Skovmosen assemblage.

In a collaboration initiated by the site's discoverer Jan Hilgart, this paper details a selection of artefacts recovered from the Final Palaeolithic locale, Skovmosen I, in eastern Denmark. We present an overview of the locale and couple this with a tech-

Figure 1. The location of Skovmosen I in northern Zealand, Denmark.

nological analysis of the assemblage, including observations made at the time of discovery and initial retrieval. Furthermore, in the promotion of accessibility (Marwick 2017), we present digital models of selected artefacts, and finally attempt to place Skovmosen I in a wider context of the Final Palaeolithic in the region.

Skovmosen

Skovmosen I (Sted & lok. nr. 020307-178) is located in the present municipality of Lyngby-Taarbæk, Zealand, in eastern Denmark, situated between Kongens Lyngby and Jægersborg north of Copenhagen (Figure 1). Following an expansion of the Helsingør motorway in 1995, one of the authors (Jan Hilgart) discovered several Final Palaeolithic flint artefacts along the edge of a tunnel valley close to the remains of the present-day bog of Skovmosen. Skovmosen, literally meaning 'the forest bog', is situated at the bottom of a small hill and on the northern shore of the bog (Figure 2). The site is situated on the eastern side of the motorway, approximately 300 meters northwest of the late 19th century historical monument of Garderhøjfortet.

As part of the motorway construction, a small drainage canal, which would lead surface water away from the road, was dug to the adjacent bog. It was at the construction site and among the spoil heaps from this drainage that the lithic artefacts were retrieved. As the site seemed heavily disturbed by the construction, permission was given, through a collaboration with Københavns Amtsmuseumsråd, to sieve the spoil heaps and retrieve any additional artefacts. This salvage operation at the site was stalwartly continued and the spoil heaps were systematically sieved through the winter of 1995/1996. In total, 240 artefacts were recovered.

Today, the area of Skovmosen falls under the jurisdiction of Kroppedal Museum and the assemblage is currently on display at Friboeshvile Manor in Lyngby. Although the site is briefly mentioned by Hilgart (2003), Boye (2006) and Brinch Petersen (2009), we here provide a first detailed account and description of the material in English, with particular focus on the blades, tools and cores.

Locational context and discovery

As no excavation was carried out due to the site's disturbed condition, no definite location or extent

Figure 2. Photograph of Skovmosen I, taken by J. Hilgart.

can be established. From observations made by Hilgart during the discovery and his subsequently made map, it can be surmised that at least one, and possibly two, concentrations are represented in the material, which were situated in peaty soil with a sandy subsoil. Both concentrations were most likely located near the shoreline of the bog/palaeolake, adjacent to the motorway. The lithic material was distributed across an area measuring approximately 240-250 m^2 in total. Observations made at the time of discovery suggest, that the drainage canal had intersected a single scatter of lithic material, representing – potentially – a coherent site. By the same token, it is important to note that one of the artefacts recovered around the spoil heaps was a Late Mesolithic transverse arrowhead. Some mixing – especially at the locales eastern end – had evidently occurred, although whether this mixing relates to multiple occupations or the very process that led to the discovery of the assemblage – or some combination of these factors – remains entirely speculative. Prehistoric occupation at the site well after the Final Palaeolithic is certainly implicated and must be taken into account when considering the assemblage.

Lithic analysis

Of the 240 artefacts recorded, we selected five for 3D documentation by means of Structure from Motion (SfM): one complete tanged point (x2), one incomplete tanged point (x1), one scraper (x29) and two cores (x48 and x51). A copy of the fully interactive models can be retrieved from our Open Science Framework (OSF) project page: https://osf.io/jeuxf/.

Although photogrammetry has been a compelling approach, not only within archaeology but others disciplines within recent years (Baier & Rando 2016; De Reu et al. 2013; Green et al. 2014; Grün et al. 2004; López et al. 2016; Westoby et al. 2012), the methodology has not gained momentum when it comes to presenting lithic assemblages. In particular with regard to archaeological lithics, drawing curiously persists as the preferred standard mode of representation, despite the evident differences in stylistic approaches (Saville 2009) and the fact that, in most other sciences, drawing is restricted to idealised representations rather than actual specimens (Lopes 2009). In contrast to drawing, SfM constructs a 3D model based on regular overlapping 2D photographs of a given artefact, capturing the object's shape and from. It does so by identifying pixel-by-pixel spatial information in each photograph needed for triangulation, and by then using corresponding points on different overlapping photographs, to render a model in a dimensionally stable Euclidean space.

We used a portable photogrammetry rig to record the artefacts, adapted from the setup reported by Porter et al. (2016). For the necessary level of detail, a 50MP Canon EOS 5DS with a 50 mm macro lens was used to obtain the overlapping photographs, following the detailed workflow presented in Appendix 1. Note that, evidently, a refinement of these latter protocols is still necessary. Even when

Category	Sub-category	Count (Σ=240)
Secondary reduction production	Tanged point (complete)	1
	Tanged point (broken)	4
	Transverse arrowhead	1
	Scraper	22
	Burin	8
	Combination tool	1
Primary reduction production	Blade (complete)	17
	Blade (broken)	2
	Blade core	5
	Flake core	7
Debitage		172

Table 1. Breakdown of artefacts from Skovmosen I.

substantial efforts are made to standardise recording procedures, the results of individual capture events vary. To facilitate offline reading, lithic illustrations therefore also accompany this article. In recording the technological attributes of the assemblage, the "Dynamical Technological Classification of Scandinavia Lithic Blade Industries", made accessible by the Nordic Blade Technology Network (Sørensen 2013) was adopted.

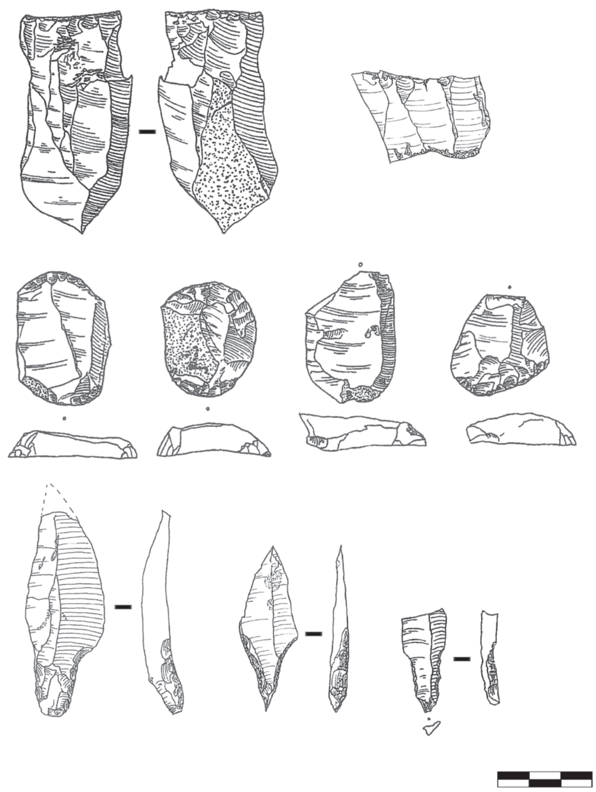

Figure 3. Top row, from left to right: cores (x48, x51). Middle row, from left to right: a selection of scrapers (x29, x28, x43, x46). Bottom row, from left to right: a selection of tanged points (x1, x2, x3). Illustrations by J. Hilgart.

Typological and technological analysis

The Skovmosen I lithic material is characteristic of an assemblage recovered through surface reconnaissance. The assemblage consists of material at all stages of production, with primary material (cores, unretouched blades and debitage) and secondary products (burins, scrapers and tanged points) present (Table 1); smaller debitage, however, is lacking. An illustration of a selection of artefacts can be seen in Figure 3.

Raw material

The lithic material is covered by red to olive coloured patina rendering an exact classification of the raw material used in the assemblage difficult. On pieces which are only partly covered by patina, the material appears to be Cretaceous (Senonian) flint.

Primary reduction products

Blades

In total, 17 complete blades were identified, as well as a further four fragments. Of the latter, two can be refitted into one complete blade (x18) and are therefore treated as such in this analysis. The blades vary

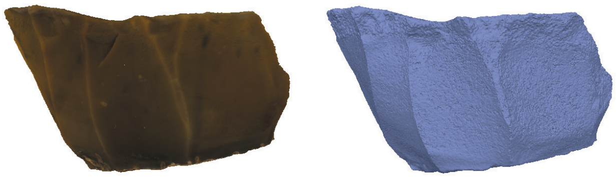

Figure 4. From left to right; textured 3D model and mesh view of x51.

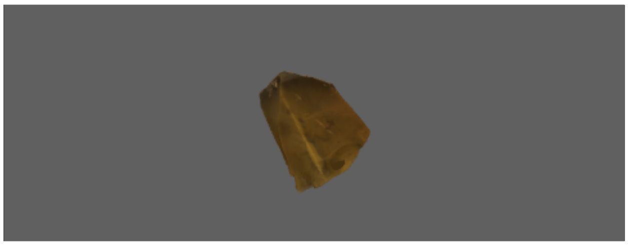

Figure 4a. 3D rendered model of x51.

from regular (n = 12) to widely-irregular (n = 6) examples, with a large number of blades showing signs of preparation of the core prior to the production of the blade (n = 12). A considerable number of blades, where observable, also indicate the use of direct hard knapping technique, with large and thick butts, and pronounced bulb formation (n = 6). Experimental analyses have shown, however, that unambiguous discrimination between direct soft and hard hammer percussion is difficult (Damlien 2015; Darmak & Apel 2008), with important implication for the validity of traditional inferences of hammer types from bulb morphology (e.g. Hartz 1987).

Cores

In total, 12 cores were identified throughout the assemblage. These relatively small pieces range in height from 22 mm to 69 mm, with an average of 41.9 mm. The majority of cores are conical in morphology (n = 10), and feature a single striking platform (n = 11). Only one core (x62) exhibits two striking platforms. A single-front or circular exploitation method is typically represented, with cortex localised and positioned on the 'back' of the core.

Five cores can be categorised as blade cores, four of which feature a relatively high core flatness, oriented towards blade and bladelet production (Figure 4). All five blade cores feature a single smooth platform and a conical morphology, and demonstrate successful blade and bladelet production, with very few examples of stepped or hinged negative distal-end scars on their circumference. One core (x48) is the exception to this rule, with multiple hinged and stepped negative distal-end scars, layered around the core's circumference (Figure 5). This example is also of greater size (15 mm longer than all other blade cores), exhibits a greater number of blade and bladelet removals, and is the only example to feature platform grinding and abrasion. Despite of the presence of many cores, no hammerstones were recovered from the site. However, deep negative scars on the majority of cores, following the above frameworks, allude to their use.

Tools

Burins

The burins (n = 8) are all dihedral burins on an edge, made on thick blades most likely produced by

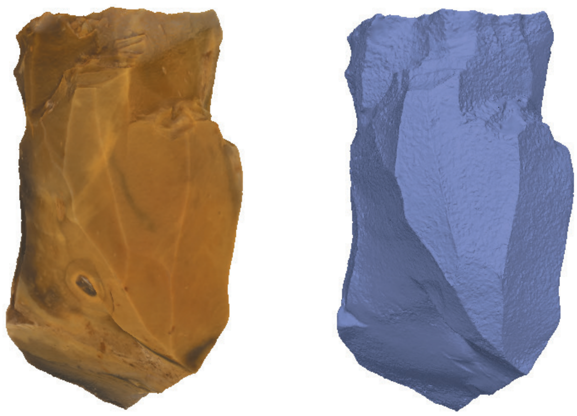

Figure 5. From left to right; textured 3D model and mesh view of x48.

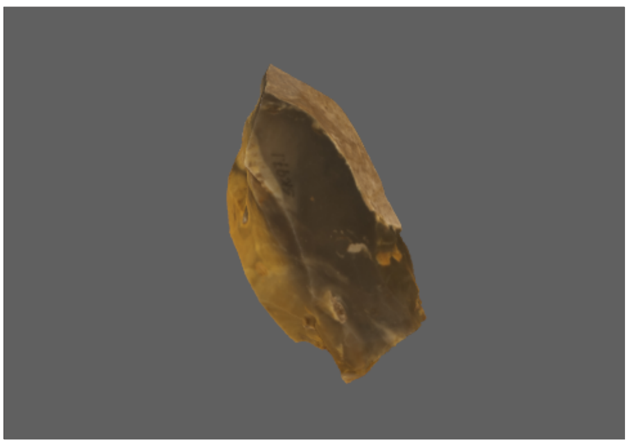

Figure 5a. 3D rendered model of x48.

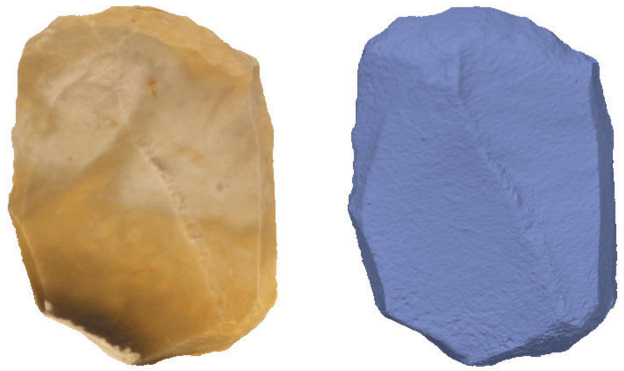

Figure 6. From left to right; textured 3D model and mesh view of x29.

Figure 6a. 3D rendered model of x29.

hard-hammer percussion. One is significant in having a retouched tang in the proximal end, and may be the resulting modification or re-tooling on a fractured tanged artefact, such as a projectile point. Another can be described as a combination tool with a

Figure 7. From left to right; textured 3D model and mesh view of x1.

Figure 7a. 3D rendered model of x1.

dihedral burin on an edge in one end and concave retouch on the other end.

Scrapers

Scrapers make up the largest part of the tool assemblage (n = 22). These primarily consist of scrapers made on flakes (n = 14) where the bulk are made into smaller and almost circular 'thumbnail' scrapers (n = 12). Scrapers on blades are represented as well (n = 8). Only one scraper preserves an intact bulb and butt indicating a direct hard percussion technique, fully in line with the evidence from primary production.

Tanged points

Finally, the assemblage contains five large tanged points, one complete and four fractured. Artefact x1 is a slightly fractured tanged point, with minor damage at the distal end (Figure 7). This is, however, a clean unpatinated break and represents a post-depositional breakage. It is therefore here regarded as a whole artefact. This example is made from a thick regular blade, with two dorsal ridges and an evenly distributed curvature. It measures 66 mm in length, 25 mm in width, 8 mm in thickness and weighs 13.2 g. The tang is located at the proximal part where the rather thick and unfaceted platform and pronounced bulb are still intact. The tanged retouch is featured on both sides of the tang and is knapped from the ventral side of the blade. The blade features converging edges towards the distal end.

Artefact x2 is a complete projectile point measuring 53 mm in length, 18 mm in width, 6 mm in thickness and weighing 3.4 g (Figure 8). Technologically similar to x1, this point is made from a regular blade, with two dorsal ridges and a tang located at the proximal end. The tang-forming retouch is applied on both sides, from the ventral side of the blade as on x1, but here removing the platform and bulb. The distal portion of the projectile has been made to converge with small scalar retouch. The weight and dimensions of these more or less complete points aligns them well with ethnographically documented dart-heads (Riede 2009).

Artefacts x3, x4 and x5 are all projectile point fragments and specifically, tang fragments. The presence of such fragments, together with primary production of blades, may provide insights into some of the activities at the site. The fracturing of these projectile points could have been the result of impact damage from hunting (Fischer et al 1984). It may also indicate re-tooling of the damaged projectile points upon return from the hunt. Similar to x2, x3 is made from a regular, rather slender, blade with two dorsal ridges and retouch on both sides at the proximal end, from the ventral side of the blade, and the bulb removed. Artefact x4 is also made from a regular, slender blade with two dorsal ridges with retouch on both sides, at the proximal end from the ventral side of the blade. Contrary to x2 and x3, the bulb and striking platform are here intact. Artefact x5 is also made from a regular, slender blade with two dorsal ridges and retouched on both sides at the proximal end from the ventral side of the blade. Both the bulb and striking platform on x5 are intact.

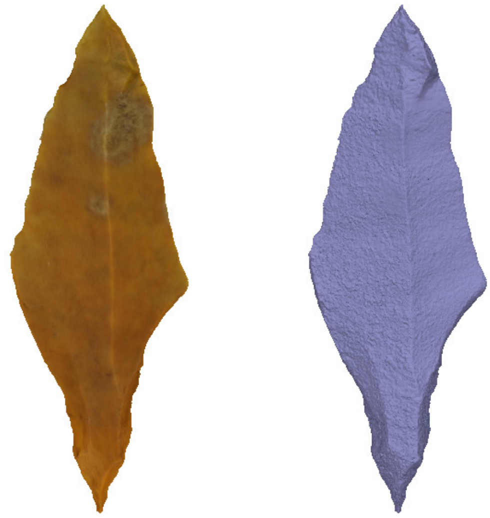

Figure 8. From left to right; textured 3D model and mesh view of x2.

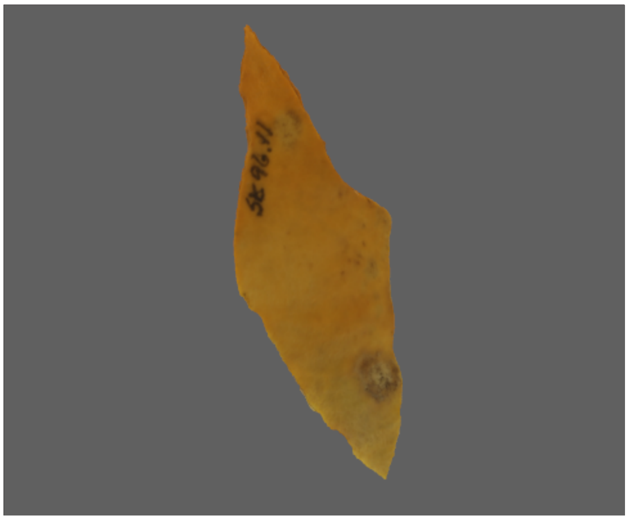

Figure 8a. 3D rendered model of x2.

Debitage

A total of 173 debitage pieces were collected, of which 57 % demonstrate signs of hard percussion technique, 15 % attest to the likely use of a softer hammer or indirect percussion and a further 28 % could not be determined. 61 % of the debitage retain some cortex, underlining that primary lithic reduction might have been taking place at the site.

The place of the Skovmosen assemblage in the Danish Final Palaeolithic

Located on slightly higher ground near a body of freshwater, the Skovmosen site shows a locational position common for the southern Scandinavian Late Glacial. In this, Skovmosen is comparable to larger sites such as Trollegave, Stoksbjerg Vest and Bro, which also are located near lakes (Johansen 2003; Pedersen 2009:120). Such a location could, following Fisher (1991), Donahue and Fisher (2015) and Petersen and Johansen (1994), indicate the status of a more permanent site as opposed to temporary hunting stations. A breakdown of the tools from Skovmosen I shows a distribution of scrapers (63 %), burins (23 %) and complete as well as broken tanged points (14 %). This spectrum of tools, together with the evidence of primary on-site lithic production would also support the notion that we are dealing with a habitation site. As the lithic technology primarily reflects direct hard percussion technique, it is difficult to assign the material to any one cultural complex or to distinguish Final Palaeolithic from later knapping products within the assemblage. Hard hammer percussion occurs in the Federmesser culture (Hartz 1987), the Bromme culture (Madsen 1983) as well as in the early Preboreal Maglemosian culture (Sørensen 2006).

Turning to the cultural historical placement of the Skovmosen I assemblage, the technological and typological traits presented above would traditionally place Skovmosen I within the Bromme culture. Ever since the discovery of a large tanged point in lacustrine deposits in the cliffs at Nørre Lyngby in Vendsyssel, north-western Denmark (Jessen & Nordmann 1915) and the later excavation of the locus classicus of Bromme in eastern Denmark (Mathiassen 1946), the Bromme culture has been enshrined as an autochthonous southern Scandinavian Final Palaeolithic culture – represented first and foremost by the presence of large tanged points. The diagnostic power of this artefact class has been questioned, however (Kobusiewicz 2009b), and a series of critical voices have expressed doubts as to the validity of the Bromme culture as an actual culture-historical phenomenon on par with similarly labelled 'cultures' elsewhere (Kobusiewicz 2009a; 2009b; Riede 2013; 2014; 2017a; Sauer & Riede 2018) thereby making even disturbed sites such as Skovmosen I important in order to elucidate such a priori cultural groups as the Bromme culture. Put simply, the issue can be reduced to the diagnostic capacity and specificity of the types and technologies associated with the Bromme culture. Large tanged points occur in the Final Palaeolithic of Europe already well before the postulated emergence of the Bromme culture (Riede et al. 2011) independently of whether one follows the available long or short chronologies (cf, Riede and Edinborough 2012; Fischer et al. 2013).

Spatially, the occurrence of large tanged points appears to correspond with the northern range expansion of the broader Final Magdalenian/Federmessergruppen complex and their occurrence in greater numbers northwards stands out as a trend rather than a discrete distribution of separate types marking separate ranges or territories (cf. Bokelmann 1978). The presence of large tanged points in Final Magdalenian/Federmessergruppen contexts prior to the suggested date range of the Bromme culture precludes the interpretation of their occurrence outside of its presumed 'core area' as cultural contact or expansion. Instead, an interpretation of these sites as more or less specialised exploitation sites – related perhaps to the hunting of large mammals such as elk and giant deer with particularly heavy armatures (Tomka 2013) in the landscapes of late Allerød eastern Denmark where these animals may have been particularly abundant (Mortensen et al. 2014) – may be more parsimonious as earlier suggested by Bokelmann (1978). These considerations lead us to be cautious with regard to a placement of the Skovmosen I assemblage into the Bromme culture, as previously suggested by Hilgart (2003), Boye (2006) and Brinch Petersen (2009). At any rate, the Skovmosen assemblage is comprised only of surface finds retrieved semi-systematically from an already heavily disturbed context. Neither lithic technology nor artefact typology can unambiguously resolve the degree of admixture or the cultural affiliation of the assemblage. All of this severely compromises our ability to arrive at robust inferences regarding site function and chronology as the mixed nature of the assemblage, also hints at some later Mesolithic interference.

Concluding remarks

The Late Glacial in southern Scandinavia has been the subject of much renewed research effort lately. Brinch Petersen (2009) has provided a useful review that, however, has plainly demonstrated that (i) true habitation sites of appreciable size are rare when compared to regions further to the south and that (ii) many of the known assemblages remain incompletely published. We have here attempted to address the latter shortcoming by presenting and discussing the small Final Palaeolithic assemblage from Skovmosen I. Despite obvious signs of admixture with later material, it is not unlikely that the assemblage can, by and large, be placed into the Final Palaeolithic. We are more cautious, however, about further assigning the material to any of the traditionally recognised Final Palaeolithic 'cultures', given recent debates about their validity and the retrieval history as well as the likely incompleteness of the Skovmosen I assemblage. Given the general rarity of Pleistocene archaeology in southern Scandinavia coupled with the fact that many Final Palaeolithic locales have discovery and retrieval histories not unlike Skovmosen I but are similarly mentioned in regional or inter-regional syntheses (e.g. Groß et al. 2016), we argue that our description makes a useful cautionary contribution to the present corpus of sites and assemblages.

Acknowledgements

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Appendix 1

A Technological and Typological Analysis of Lithic Material from Skovmosen I, Denmark.

Eggers-Kaas, T., Pedersen, J.B., Hoggard, C.S., Sauer, F.R. and Riede, F.

Supplementary information

SfM Recording strategy

These two workflows are designed to introduce the reader to the Structure from Motion (SfM) process, from the capturing of suitable images to the final creation of a 3D textured model. The **first will detail the rig components, the setup and necessary stages, and best practice**. The **second workflow will consider the image-process (post-masking application)**. This process is a modified form of the workflow detailed by:

Thi Porter, S., Roussel, M. and Soressi, M. (2016). A Simple Photogrammetry Rig for the Reliable Creation of 3D Artifact Models in the Field. Lithic Examples from the Early Upper Palaeolithic Sequence of Les Cottes (France). *Advances in Archaeological Practice* , 4 (1): 71-86.

Rig Components

The following equipment and software is used throughout this SfM process:

- **Black velvet** (for the photo backdrop)
- **Backdrop support** e.g. foam tiles or boxes
- **Turntable** e.g. a kitchen turntable (used to rotate the object)
- **Lighting** (for object illumination)
- **Kneadable rubber eraser** (artefact support)
- **Scale** (see below)
- **Camera tripod** (camera support: prices vary, choose a sturdy tripod if possible)
- **Camera** (depending on the size and nature of the object)
- **A carrying case** (to support the draping of the velvet and for portability)
- **Agisoft PhotoScan Processional Edition** (photogrammetry software)
- **Adobe Photoshop CC** (for masking of the artefact background; can also be done in PhotoScan)
- **Meshlab** (3D Mesh Editing software)
- Optional: **Laptop with camera software e.g. EOS Utility** (for remote shooting)

Rig Setup and Use

1. Open the carrying case and drape the background fabric (black velvet) over the case.
2. Set down the turntable (with the scale and colour card glued on the turntable), with the 0° mark facing forward. The scale and colour card can be found here: https://conservancy.umn.edu/bitstream/handle/11299/172480/Photogrammetric_scale_noncoded_markers_plus.pdf?sequence=28&isAllowed=y.
3. Position the camera on the tripod at approximately the same height as the turntable. Connect the

camera to the laptop and load up the **EOS Utility software** (if remote shooting).

4. Assemble the lighting; ensure light is aimed downwards towards the turntable's centre, and on both sides of the camera. Portable LED panel lamps can be used for greater portability, however they will have a limited lighting time and will require frequent charging.
5. Place the artefact rubber eraser on the centre of the turntable.

Stage 1a: Photography Instructions (Remote Shooting)

A **suitable folder structure** is first necessary as two batches of photographs will be taken. There will be **one folder** (named by the model ID) and **five subsequent sub-folders**:

- Folder (e.g. ID_2405_321)
  - o **A_Side** (the images taken for the first surface of the artefact)
  - o **B_Side** (the images taken for the second surface of the artefact)
  - o **A_Mask** (the masked images for the 1st surface - produced in Adobe Photoshop)
  - o **B_Mask** (the masked images for the 2nd surface – produced in Adobe Photoshop)
  - o **Models** (the .ply, .obj files and textures produced by the process)

In EOS Utility ensure the directory is set to the location of the A_Side sub-folder. With the camera positioned at approximately the same height as the turntable, take the first picture. In line with the Archaeological Data Service (http://guides.archaeologydataservice.ac.uk/g2gp/Photogram_Toc) the following practices were adopted:

- The camera is always set to **Manual**, with fine-tuning of the focus performed in EOS Utility.
- The **International Standards Organisation (ISO)** i.e. the sensitivity of the camera's light sensor is set as low as possible, in order to minimise the amount of noise in each image.
- **Low F-stops (apertures)** were avoided as they tend to leave object parts out of focus with a shallow depth of field (the highest possible aperture was therefore used).
- **A short shutter speed was generally required**, given the low ISO, and high aperture.
- If photographs are taken manually, use a **two-second delay** in order to avoid blurriness that can result from movement caused by pressing the shutter button on the camera button.

Following the first picture rotate the turntable **30°** so that the **30°** mark is facing the camera. Take a second image. Continue rotating the turntable and taking photographs every 30° until the turntable has been fully rotated (i.e., at the **60°**, **90°**, **120°**, **150°**, **180°**, **210°**, **240°**, **270°**, **300°**, and **330°** marks). Using the tripod, raise the camera slightly and tilt it towards the target object. For small objects, we usually raise the camera approximately **5 to 10 cm**. Rotate the turntable so that the **10°** mark is facing the camera. Take a photo. Rotate the turntable **30°** so that the **40°** mark is facing the camera. Take another photo. Continue rotating the turntable and taking photographs **every 30° until the turntable has been fully rotated** (i.e., at the **70°**, **100°**, **130°**, **160°**, **190°**, **220°**, **250°**, **280°**, **310°**, and **340°** marks). Raise the camera again and tilt it towards the target object. Rotate the turntable so that the **20°** mark is facing in the direction of the camera. Take a photo. **Rotate the turntable 30° so that the 50° mark is facing the camera**. Take another photo. Continue rotating the turntable and taking photographs every **30°** until the turntable has been fully rotated (i.e., at the **80°**, **110°**, **140°**, **170°**, **200°**, **230°**, **260°**, **290°**, **320°**, and **350°** marks). At this point you should have taken **36 photographs**. Depending on the shape of the object, it may be necessary to raise and tilt the camera once again and take **an additional round of photographs in order to sufficiently capture the top of the object**. Usually, we take fewer photographs at this camera position (e.g., four photos with the turntable at the 0°, 90°, 180°, and 270° positions.

Turn the object over, flipping it **180°**. What was previously the top of the object should now be facing downward towards the turntable's surface. Repeat the photography protocol as before, but in reverse. The directory should be now set to the 'B_Side'. In other words, begin taking photos with the camera in a very high position and work downward systematically rotating the object as before.

Stage 1b: Photography Instructions (Manual Shooting)

For manual shooting, the above process is largely the same. The only exception is that images should be subsequent stored into a folder system following the capturing of 72+ images. Ensure that the correct images are in the appropriate folders.

Stage 2: Masking Procedure

For the following image-processing workflow, and the generation of high-quality 3D models, the velvet background is 'masked' from the image. This means that Agisoft Photoscan Professional will ignore the background. This stage is essential to the Structure from Motion operation, as we are 'cheating' the camera and that the only structure it should consider is the artefact and turntable. **This can be done in Agisoft Photoscan Professional (see the next workflow), MS Paint, or automated through a batch process operation in Adobe Photoshop CC**.

The masking script for this automated process is as follows:

1. Open a photo taken with the photogrammetry rig in Adobe Photoshop.
2. Open the action window by clicking on **"Window" > "Action".**
3. Create a new action by clicking on the square paper icon (circled in red in the screenshot below). Give the new action a name, and set it as a default action. Click **"Record".**
4. Using the **"Magic Wand"** tool a spot on the black background in the upper left hand corner of the image is performed. You will want to click on a place that will consistently select the background in each photo, you are processing and not the object. Make sure the box next to **"Contiguous"** is checked (as indicated by the white arrow). You may want to experiment with the tolerance level, but a setting of 15 usually works well.
5. This selection is then inverted through the **"Select" > "Inverse"** function.
6. If you zoom in, you will likely notice a line of black pixels is still included in your selection. To mitigate this, click **"Select" > "Modify" > "Contract".** Contract the selection by 2 or 3 pixels, depending on the resolution of your photos and the size of the remaining black area you observe.
7. Now you will create an alpha channel around representing your selection. To do this, click **"Select" > "Save Selection"**. Save the selection as a new channel. Give the channel a name. Click "OK".
8. Next, save the photo by clicking "**File" > "Save As"**. Save the image as a copy and a TIFF, and be sure to include the alpha channel. Click **"Save".**
9. You can use compression in order to avoid overly large file sizes. Click **"OK"** to save the file.

To run a batch process click **"File" > "Automate" > "Batch"**. Select the script that is created, set your source folder as the folder containing the raw images, and choose the mask folder for your processed image. Make sure that **"Override Action "Save As" Commands"** is selected. Click **"OK"**. Once the batch process has run, if you open the designated destination folder for your processed images, the image thumbnails should display with a white background.

Stage 3: Importing photos (Agisoft Photoscan Professional)

- The process will involve two 'chunks' (A side and B side), so in Agisoft Professional click on **"Workspace"** and select **"Add chunk"**. Repeat twice. Chunks can be selected by double-clicking on the chunk description in the **"Workspace"** window.
- In each of these chunks import the masked-files (in .tif format) for each of these sides. The masking will have been done in Adobe Photoshop/Paint/CorelDraw. From here, the **"import masks"** should be clicked, ensuring that the mask is from the same file.
- Masks (in original or silhouette form) can be checked or altered in the **"Photo"** view. To alter a mask,

click on an image, click the **"Magic Wand"** tool on the top toolbar and the area you also wish to mask. By clicking **"ctrl"** + **"shift"** + **"A"** on the mask you integrate the new area into the mask. Other selection tools can be used to select different regions or areas. The tolerance (strength of the masking) can also be changed by clicking **"Options…"** on the **"Magic Wand"** icon.

Stage 4: Aligning photos (Agisoft Photoscan Professional)

- This stage allows the computer to calculate where the camera positions are. These should be around the entirety of the image, in three bands (the three camera orientations).
- Cameras can be aligned for each side separately or together using the **"Batch Process"** function under the **"Workflow"** tab. In this new window click on **"Add"**, choose **"Align Photos"** on the **"Job Type"** tab, and ensure that this is applied to **"All Chunks"**. A high accuracy is favourable (time vs. quality), but ensure that **"constrain features to mask"** is selected. It is always good to ensure that the project is saved after each stage so select **"Save project after each step"**, save as appropriate. Click **"Ok"** to run the process if the save function did not automatically run the process.
- Following this process, close the dialogue box and you should be able see the position of the cameras and the aligned photos (in point cloud form). To hide the trackball, in the centre of the screen, click the **"Show Trackball"** function under **"Show/Hide items"** in the **"View"** tab.
- Check that the camera positions are in the correct area and that the point cloud is not too busy.
- Note: the bounding box/region needs to encapsulate all you wish to model (including the scale). To do this use the region tools on the panel above the viewing window. Rotate, resize and position as necessary. Whatever is not in the bounding box will not be processed further.
- Stray points, close to the point cloud, may hinder the level of detail produced throughout later stages. These can be deleted through the **"Free form selection"** function, with the relevant areas highlighted and deleted (using the **"Delete"** button on the keyboard). Because these are scattered and do not cluster we can assume that these points are sources of error and not integral to the model.

Stage 5: Building a dense cloud (Agisoft Photoscan Professional)

- Using the **"Batch Process…"** function in **"Workflow"** again, remove the previous process and add **"Build Dense Cloud"** to the **"Job Type"**. This stage will add further points now we are satisfied with the camera alignment. Set the **"Quality"** to however you see appropriate, and leave **"Depth filtering"** on **"Aggressive"**. **"Reuse depth maps"** should also be selected to **"No"**. Run this process. If you click on the **"Dense cloud"** option we can then view the model in greater detail. At present, this is a not a mesh but many points (if you zoom in you can see this).

Stage 6: Chunk alignment, merging and mesh creation (Agisoft Photoscan Professional)

- This next stage involves taking the two dense clouds, aligning each perspective, and subsequently merging to produce one final model.
- The alignment stage can be done automatically, however, in some instances this may not work correctly and manual alignment may be necessary.
- For automatic alignment, merging and mesh creation:
  - o Choose **"Workflow"** on the header, and choose **"Align Chunks…"**. We keep the **"Method"** as **"Point based"**, as we are using the dense cloud, the **"Accuracy"** as we see appropriate and **"Point**

  - **Limit"** to the default number. Again, we tick the **"Constrain features to mask"** function, so we can ignore the background.
  - Upon completion, we can click **"Show Aligned Chunks"** on the icons above the viewing window, and see how the software has aligned the point clouds. Click off this when done.
  - We can now edit these point clouds to align and consider just the dense cloud and the scale we wish to keep. In one chunk, using the rectangular tool we can delete the scale and putty, as previous. Continue to clean the image, removing noise where possible. In the second chunk, we want to keep some part of the scale, so we can scale appropriately later. Therefore, remove half of the scale board and the putty. Again, tidy as appropriate. When we again click **"Show Aligned Chunks"**, we can now see the aligned artefact with one scale bar.
  - If the quality of the model is better on one part of the shape than on another chunk then the low-quality section of that particular chunk can be deleted, using the same stages as above.
  - The chunks are still two separate entities and we now need to merge the chunks. To do that we go to **"Workflow"** and **"Merge Chunks"**. Here we combine the models (ignoring the markers), and click **"Ok".** If we now click on the **"Merged Chunk"** we can now see one chunk with all references points in one model. Resize and reposition the bounding box as appropriate.
  - We can now build a mesh, using the **"Build Mesh"** function in the **"Workflow"** tab. Leave the **"Surface Type"** as **"Arbitrary"**, **"Source Data"** as the **"Dense cloud"** and increase the polygon count as necessary. Always aim high (c. 500,000), it is always easy to simplify later (you can not add further detail later!). Leave all other options as the default and click **"OK".** This step is usually quite quick.
  - At the top, above the viewing window, we now have more options and can click the **"Mesh"** icon and see the final product. Now we can add the texture (see below).
- For manual point alignment, and subsequent merging and mesh creation:
  - Using markers we can align the two models. Using the **"Batch Process"** function, select the **"Build Mesh"** and **"Build Texture"**, we want a texture so we can accurately pinpoint areas of topographical correspondence (ensure that the polygon count is high!). For the texture mapping we want the **"Blending mode"** as **"Average"**, with a **"Texture size"** of 4096 and a **"Texture count"** of 1. Colour correction does not work particularly well, so leave this unticked. These processes can also be applied to the above mesh now. When these two stages have been added click **"OK".** Each chunk will now have a mesh and a texture.
  - We now need to add corresponding markers on each chunk, ready for alignment. When you have decided on places for the markers (roughly 8-10 will work well), right-click on the areas and choose **"Create Marker".** Make sure that the markers are spaced out around the object (the further apart the better), on both sides, and that the ordering is consistent. Tip: take a screenshot of one chunk to better align the markers on another model.
  - When the points have been placed on each chunk, go to **"Align Chunks"** and, this time, change the method to **"Marker Based".** Ignore the **"Fix Scale"** function as we have not yet made a scale.
  - After clicking **"Show Aligned Chunks",** we can do the same operations as before, deleting noise in the dense cloud, the putty and scale bar on one image, and half of the scale bar and putty in another. Merge chunks as previous. We can then rebuild the mesh for this new model following the previous method.

Stage 7: Solving the "putty issue" (Agisoft Photoscan Professional)

- If we were to build a texture using the two models, the software will include photographs of the putty, and two discoloured areas will appear: one on the top of the artefact and one on the bottom of the artefact.

- To fix this issue we will mask the putty in the photographs using the previous method of masking (by using the free-form selection or the rectangular selection tools). We however have many photographs, and not all are necessary to make a texture, so, using the **"Disable cameras"** function on half of the photographs and mask the others.
- If we run the **"Build Texture"** function now the issue should be fixed.

Stage 8: Creating the scale (Agisoft Photoscan Professional)

- There are two ways a scale can be created. Both use markers, the same markers used in the manual alignment. These are placed on the model or from the photographs.
  - o From the model:
    - > Using the **"Shaded"** view of the model, place two markers (of a determinable length) on the model by right-clicking on a position and selecting **"Create Marker".** Repeat for a second point.
    - > Using the selection tools highlight both markers and select **"Create Scale Bar"**. In the **"Ground Control"** window (this may need to be selected from the **"View"** function at the top of the program) we can now see **"scale 1".**
    - > If we click on the scale, we can input the correct length underneath the **"Distance (m)"** header.
    - > To ensure that your model is the correct size we click **"Update"** at the top of the panel.
  - o From the photographs:
    - > Highlight a photograph (ideally a photograph from a pretty high angle) and add additional two markers on the scale, the program should auto-select the points for the other photographs and repeat the process as above.
  - o Note: If we do both methods, we can calculate the total error (as viewed in the left window).

Stage 9: Exporting the model (Agisoft Photoscan Professional)

- **File/Export Model** and choose whichever format you require (.obj and .ply are the most common model formats).
- In the options we can choose how we want the texture to be exporting (.jpg is fine).
- Click **"Ok"** and the model should be created. We can now open this up in MeshLab or any other program for additional tidying or modifications e.g. mesh-simplification.

A Novel Geometric Morphometric (GMM) Application to the Study of Bronze Age Tutuli

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ABSTRACT
In this paper we examine the morphological diversity of the tutuli object group from the Early Nordic Bronze Age onwards, an often over-looked artefact. With a significant presence throughout this period, and their widespread geographic and temporal distribution throughout the Nordic Bronze Age, tutuli are of great interpretive potential. Currently, only a few studies, focusing on the morphological diversity of tutuli have been published, consisting of accepted decades-old typologies. The objective of this paper is first and foremost methodological, examining two research questions grounded on the classification and periodisation of tutuli. Specifically, through an analytical and exploratory framework this article examines whether the breadth of archaeological tutuli shapes conform to the classificatory system of Montelius' typology, and whether a temporal relationship exists between specific tutuli types and shapes.

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Introduction

From the beginning of the earlier Nordic Bronze Age (NBA henceforth), ranging from c. 1700-1100 BCE (following Nørgaard 2018), an expansion in the variety of material culture, owing to the introduction of the 'new' raw material, is witnessed. Through the medium of bronze, and its distinct new structural properties, an assortment of different object types were then made possible. With such an abundance of new material culture, many (often smaller) objects are frequently over-looked in archaeological studies. One such often-overlooked example to appear, which is the focus of this article, is the tutulus.

It is now accepted within archaeological literature on the NBA that tutuli are, to some degree, overlooked (Nørgaard 2018), and only superficially considered when present within large hoards (e.g. Aner 1962; Antiq. Tids. 1849-51; Frost 2008) or in extraordinary burials (e.g. Bergerbrant 1999; Boye 1896; Clausen 1990). An exception to this rule is Kristiansen (2013), who provides a general introduction into jewellery from Scandinavia. Kristiansen (2013:758) introduces tutuli by explaining, that "*the label tutuli (singular tutulus) was designated early on to distinguish some small circular plates, which have an eye or crossbar on the underside and a more or less protruding tip on the upper side*" (Figure 1). Another exception is Nørgaard (2018: 234-236), who thoroughly analysed and discussed the processes behind the crafting of tutuli, in addition to a broad collection of other Early NBA object types. In their form, tutuli vary considerably, from small and flat-plated morphologies to cone-shaped and even hemispherical shapes (Figure 2). And given their abundance throughout the NBA, spatially throughout Denmark, Sweden and Northern Germany, and chronologically throughout the entire Early NBA, as well as their sheer quantity, with over a thousand examples recorded in Denmark and Northern Germany alone (Aner et al. 1973, 1976, 1977, 1978, 1981, 1986, 1991, 1995, 2001, 2005, 2008, 2011, 2014; Aner and Kersten 1979; Aner, Kersten and Neuman, 1984; Aner, Kersten and Koch 1990; Aner et al. 1993), there is considerable interpretive potential in their analysis. (Figure 1 and 2)

Originally, tutuli were thought to have been designed for practical purposes with initial interpreta-

Figure 1. A cone-shaped tutulus (top left) and a flat-plated tutulus (top right). The lug on the underside of the cone-shaped tutulus is a crossbar (bottom left), while the flat-plated tutulus has an eye (bottom right). Not to scale. Photographs by Christina Vestergaard.

tions highlighting their function as shield-buckles (Rafn 1856). This viewpoint, however, stemmed from an incorrect interpretation of remains from an Early NBA burial at Buddinge, Sealand (Kristiansen 2013; Rafn 1856). Excavations at Buddinge revealed a Bronze Age individual, with wooden fragments positioned on the torso, which were in turn interpreted as the remains of a shield; it was hypothesised, that the tutuli bound the edges of the 'shield' together, thus providing a functional interpretation (Rafn 1856, 362). However, later investigations established that the wood belonged to a wooden coffin rather than a shield (Kristiansen 2013, 758). Excavations between 1878-1883 at Hesselagergaards Mark on the Danish island of Bornholm also questioned this notion, when four tutuli were recovered *in situ* and attached to remains of textiles. Sehested (1884, 51) argued that the tutuli could not be interpreted as parts of a shield as no wooden remains were recovered. Accordingly, a decorative and a more style-centric interpretation was provided (Sehested 1884, 51). Yet, several other function-based interpretations followed, including the use of tutuli as clothing buttons and/or as beltware (Bergerbrant 1999, 152; Broholm 1944, 107). In one particular example, Broholm (1944, 119) argues that when tutuli, and specifically flat-plated tutuli (Figure 2: Type A), were used by men, these functioned as cape buttons, while for women they fulfilled a solely aesthetic role. Nevertheless, with a lack of debate in the last few decades, and the absence of rigorous empirical frameworks, the functional and stylistic debate on tutuli remains open.

Here, we wish to focus on the strength of tutuli classificatory schemes, that is to say how tutuli are catalogued by archaeologists, and the degree of success in these morphological-based classifications. From the later part of the 19th century onwards, typological approaches were intgral to how archaeologists understood the Bronze Age and later prehistory in general. Hildebrandt (1866) was the first to apply a typological method on archaeological material, albeit with limited engagement with the archaeological material (c.f. Gräslund 1987). While establishing a typology, Almgreen (1967) notes that Hildebrand (1866) did not consider typological connections as a proxy for chronology. Building on from this, Montelius (1872) published his first typological frame-

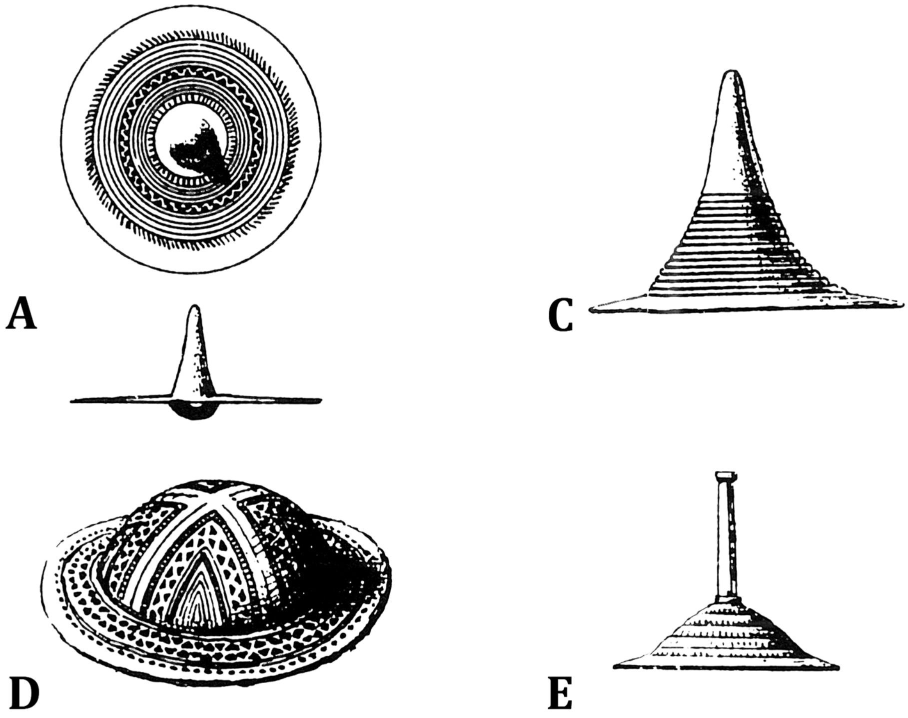

Figure 2. Montelius' four types of tutuli. Type A: a flat-plated tutulus (called belt discs by Nørgaard (2018, 234)); Type C: a cone-shaped tutulus; Type D: a hemispherical tutulus; Type E: a protruding tutulus with tip. Montelius' Types B and F (early and late belt plates respectively) are not accounted for in this article. The complete typology also accounts for belt buckles from NBA IV and NBA V (Montelius 1885, pl. 2 and 3).

work, encompassing a variety of material culture including fibulae, hanging vessels, shaft-hole axes, knifes and swords. Following this, Montelius (1875, 253) noted explicitly that the more important features of antiquities could be used to distinguish between different periods of the Bronze Age (Gräslund 1987), emphasising that Bronze Age burial customs, and changes in these customs, could underpin a chronological system within the Bronze Age. Resulting from these object typologies, Montelius (1885) established six periods (from NBA I to NBA VI). See Gräslund (1987) for further information on these subdivisions.

A number of other typologies have also been constructed, expanding from Montelius' mid-19th century classification (Baudou 1960; Kersten 1936; Laux 1971), grounded on artefact variability and their presence and/or absence; these are all of differing detail, and geographical and chronological focus. While Baudou (1960) only considered the Late NBA, Montelius (1885) paid particular attention to the Early NBA. Meanwhile, Laux (1971) and Kersten (1936) consider both the Early and Late NBA periods, but of differing geographic scope: Laux (1971) focused on the Lünenburger Heide (Lower Saxony) region of Germany, while Kersten (1936) focused broader. To further complicate the scenario, the starting points for the different typologies are quite different as Montelius (1885) considered the morphology of the tutuli, while Kersten (1936) constructed his groupings (and sub-groupings) through both the morphology and the decoration of the objects.

Given the lasting impact of Montelius (1885) on the periodisation of the Bronze Age (Bergerbrant 2007; Gräslund 1987; Hornstrup et al. 2012; Kneisel 2013; Kristiansen 2013; Vandkilde 1996; Vandkilde et al 1996), the framework's temporal scope, and the explicit focus on tutuli, this classificatory system is perhaps the best starting point, and most applicable method, for analysing the shape of larger tutulus datasets over multiple regions and periods. While so, the classificatory success is unknown; and it is unknown how idealised shapes account for the nature of variation as witnessed in the archaeological record. Furthermore, and building on from this, with an abundance of examples ranging throughout the NBA, it is unknown how tutuli shapes conform to the different periods of the NBA, if at all. This point of analysis is particularly delicate as the majority of contexts which contain tutuli have been dated relatively and lack an absolute date. We could be risking a circular argumentation when analysing the chronological distribution of types in a certain context, when such a context may have been dated only on typology. Hence, the chronological dating of the objects in question should not be considered as 'fixed' absolute chronologies – but rather as temporal periodisations.

Through this lens, the objective of this paper is first and foremost methodological, utilising a geometric morphometric (GMM henceforth) framework to answer two research questions (RQs):

1) *How robust is the Montelius (1885) classificatory system for cataloguing tutuli?*
2) *Do specific tutulus shapes conform to the temporal periodisation of the Early NBA?*

Examining RQ1 permits a greater understanding of – what can be understood as – one of the commonly adopted classifications for the Bronze Age, while RQ2 provides greater scrutiny on the tutuli as an artefact and where explicit changes in morphology can be seen throughout the Bronze Age.

Materials and Methods

To investigate these two RQs, catalogue drawings of complete tutuli cross-sections were digitised and analysed from a number of artefact catalogue publications (Aner et al. 1973, 1976, 1977, 1978, 1981, 1986, 1991, 1995, 2001, 2005, 2008, 2011, 2014; Aner and Kersten 1979; Aner, Kersten and Neumann 1984; Aner, Kersten and Koch 1990; Aner et al. 1993). Only illustrations of cross-sections were examined as this perspective is a standard perspective for illustrating tutuli and provides sufficient information to examine the Montelius (1885) classificatory scheme of periods. Furthermore, cross-section illustrations permit a complete analysis of artefact shape and all morphological information contained within the entire object. While illustrations can be viewed as both objective and subjective, demonstrating a "concourse between detail, realism, visuality and selectivity" (Lopes 2009, 14), similarly to lithic illustrations, their analytical potential should not be ignored. Of course, caution should be present when analysing illustrations as the main input of data, particularly as idealised characteristics may be over-emphasised and subtle minutiae ignored. However, it is the authors' view that these actions may relate more to decorative elements on artefacts and not the artefact's morphology. Furthermore, with a standard suite of illustrative and technical signatures adopted throughout the catalogues, and a relatively large dataset, any such issues should be muted and insignificant when analysing artefact shape change.

The chronological information of the objects follows chronological determinations as recorded in the catalogue publications. As these catalogues do not use the Montelius (1885) typological framework on the recorded tutuli, and as no one corpus of tutuli feature such a classification, one author (CV) examined each tutulus cross-section and categorised as appropriate. While 1004 examples were recorded in the catalogues, the majority of the objects were fragmented or modified through post-depositional transformation and mechanical damage; a number of examples also lacked an illustration. Therefore, 376 tutuli are used to test the two RQs. It is important here to note that the examination of a classificatory scheme, and the first RQ, is through the success of the classification as per one individual and not on pre-existing designations. This is elaborated on further in the discussion section. For a breakdown of the temporal, geographical and morphological distribution of the tutuli sample see Table 1 and Figure 3.

As we wish to avoid absolute chronological assumptions in this paper, we consider the typology as a form of temporal periodisation, where types are combined in a relative order (see also Kneisel 2013). Montelius (1885) worked with six temporal periods (from NBA I to NBA VI) based on object typologies. Later subdivisions partitioned the Early NBA into six periods. However, this system has been argued to be difficult to practice (Hornstrup et al 2012; Zimmermann 1988), and hence this paper adopts the original division based on Montelius (1885). Only two of these defined periods consider the tutuli object group: NBA II, where Montelius (1885) place type A, C and D, and NBA III, where he placed type E. However, the reality is seldom clear-cut and hence overlaps are expected. Yet, as illustrated in table 1, Montelius' (1885) expectations

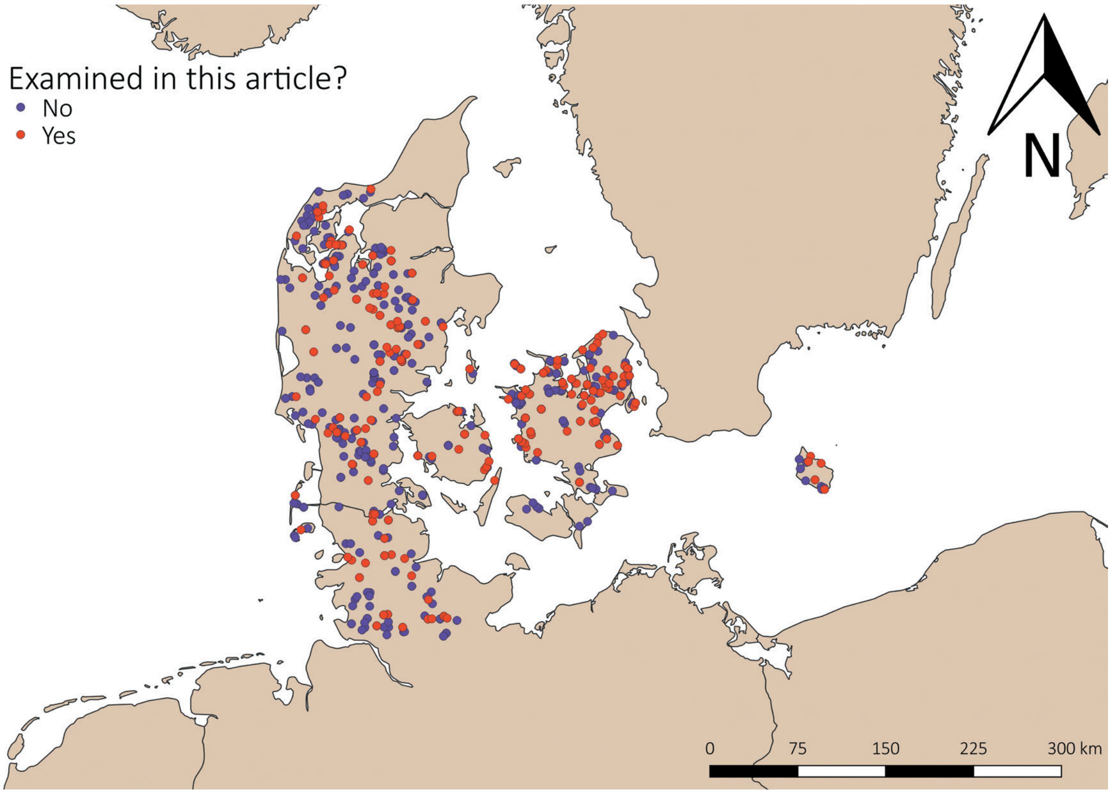

Figure 3. A map of all tutuli examined in this article (red) and all other recovered tutuli (purple).

		Type: Montelius (1885)				
		A	C	D	E	Total
Period	NBA II	136	84	51	5	276
	Transitional II/III	0	4	2	0	6
	NBA III	1	34	1	56	92
	LBA	0	1	1	0	2
	Total	137	123	55	61	376

Table 1. Rows: the dataset according to temporal periods of the NBA (as per the catalogue data); columns: the dataset according to types sensu Montelius (1885). Note: all objects have been accessed by CV and divided into the four typological groups by Montelius (1885). Sample size: 376.

are very close to the distribution of the objects in the dataset. However, it would not make sense to consider Montelius' (1885) expectations before we examine the robustness of his typology. Hence, this point will be revisited in the discussion part of this article.

Rather than attempting to record individual measurements and distances between diagnostic features (which are few in number) using traditional techniques (which are seldom straight-forward and feature a significant number of sources of measurement error), the cross-section was quantified and analysed through two-dimensional GMM. Over the last few years GMM methodologies have become routinely employed for the analysis of artefact morphology, providing a powerful statistical and exploratory framework for understanding artefact shape variance, the robustness of artefact groupings and temporal and spatial change in artefact shape (Birch and Martinón-Torres 2019; Bonhomme et al. 2017; Buchanan and Collard 2010; Freidline et al. 2012; Gilboa et al. 2004; Lycett et al. 2010; Wilczek et al. 2015). Shape is defined in this framework as the total amount of information which is invariant under

ID#	Description	Landmark category sensu Bookstein (1991)
1	Most proximal point of the tutulus tip (spike)	II
2	Midpoint of LM1 and LM3	III
3	Most distal point of the tutulus tip	II
4-5	Automatically produced equidistant landmarks (semilandmarks) between LM3 and LM6	III
6	Most-inner section of the curve between LM3 and LM9	II
7-8	Semilandmarks between LM6 and LM9	III
9	Most proximal point of the tutulus base	II
10	Midpoint of LM9 and LM11	III
11	Most distal point of the tutulus base	II
12-19	Semilandmarks between LM11 and LM20	III
20	Extremity of the tutulus cross-section	II
21-28	Semilandmarks between LM20 and LM1	III

Table 2. The landmark configuration (n=28) for the tutuli examined in this article. Note: the adopted semilandmarks represent a special 'Type 3' category through the Bookstein (1991) categorisation.

translation, rotation and isotropic rescalings (Small 1996). In this definition, and throughout this article, the analysis of shape does not include artefact size (which when combined define the form of the shape). This is noted in greater detail further in the discussion section of this article. Through GMM, landmarks (points of morphological correspondence) can be analysed, assessed through a multivariate framework and a continuous morphospace, thus allowing the reconstruction of mean and/or median shapes, in addition to cataloguing and displaying the total amount of shape diversity within a particular group of interest (Adams et al. 2004; MacLeod 1999; Navarro et al. 2004; Slice 2007; Zelditch et al. 2004). While researchers in the Bronze Age are becoming increasingly familiar with GMM approaches (e.g. Forel et al. 2009; Monna et al. 2013; Wilczek et al. 2015), there currently exists no examples of GMM analyses on tutuli, and accordingly a new workflow was necessary for this article.

The following procedure was therefore employed. Digitised images of tutuli cross-sections (scanned at 400 dpi), in TIFF format were first collated from the available catalogues (Aner et al. 1973, 1976, 1977, 1978, 1981, 1986, 1991, 1995, 2001, 2005, 2008, 2011, 2014; Aner and Kersten 1979; Aner, Kersten and Neumann 1984; Aner, Kersten and Koch 1990; Aner et al. 1993), converted into binary format, and synthesised into one thin-plate spline (.tps) file in the open-source tpsUtil v.1.69 software (Rohlf 2017a). A total of twenty-eight landmarks (2D cartesian coordinates) were then calculated for each image (i.e. each object) through tpsDig2 (Rohlf 2017b). These landmarks and semilandmarks (i.e. equidistant landmarks calculated through an algorithm) define the entirety of the object, correspond on all examples, and best represent points to anchor the range of morphological variability exemplified in the dataset. See Table 2 for definitions of each landmark and Figure 4 for a visual representation of the landmark configuration.

In order to extract the data by which shape variables are obtained from landmark data a Generalized Procrustes Analysis (Adams et al. 2004; Bookstein 1991; Gower 1975; Rohlf and Slice 1990) was performed. In this, all specimens were translated to a common origin (0,0), scaled to unit-centroid size, and through a least-squares criterion, were optimally rotated until all coordinates of corresponding point align as closely as possible. 78 iterations of this procedure were performed until maximum convergence was recorded (see R Script). Through this three-fold procedure, the resulting aligned Procrustes coordinates represent explicitly the shape of each specimen.

Using the Procrustes coordinates shape was first explored, through both period and the Montelius

(1885) classification system, by means of a Principal Components Analysis (PCA henceforth); see Jolliffe (1986) for an extensive review of PCA. The percent variation along each axis was noted through a scree plot, with relative positions in the morphospace represented for the range of variation within the dataset. The clustering for each period and classification is mapped through confidence ellipses (set to 75 %). Mean shapes for each period and classification type are also visualised. In exploring if specific tutuli shapes can be linked to different periods of the NBA, and if tutuli shapes can be successfully classified through Montelius' (1885) classificatory scheme, a discriminant analysis (Canonical Variates Analysis) of the first ten principal component scores (which represent 99 % cumulative shape variance), with leave-one-out cross-validation (jackknifing) was implemented. In following guidelines by Kovarovic et al. (2011) caution must be taken with certain groupings within the period-based analysis, as two groups ('Transitional Period II/III' and 'LBA') feature lower than the recommended group size (n = 40). While so, the classification correctness of NBA II and NBA III periods retain large dataset sizes and thus remain robust and are suitable to a discriminant analysis. No issues associated with dataset size are apparent with the Montelius classificatory-based analysis.

In complimenting this exploratory data exercise, the Procrustes coordinates were examined through a statistical framework, as to examine whether different periods of the NBA, and different types of the classification by Montelius (1885) are attributable to different shapes or trends to certain shapes. This was conducted through a Procrustes ANOVA (Goodall 1991), with the sum-of-squares calculated through 1000 permutations of the Procrustes process. Throughout this exercise an alpha level of 0.01 (significance level of 1 %) is adopted, with a null hypothesis (H0) of no difference between populations assumed.

All exploratory and analytical procedures were produced in the R Environment (R Development Core Team, 2014), using both the geomorph v.3.0.7 (Adams and Otárola-Castillo 2013) and Momocs v.1.2.9 (Bonhomme et al. 2014) packages. In promoting computational and research reproducibility, open science and data transparency (Marwick 2017) we attach with this article the .tps file, metadata (in

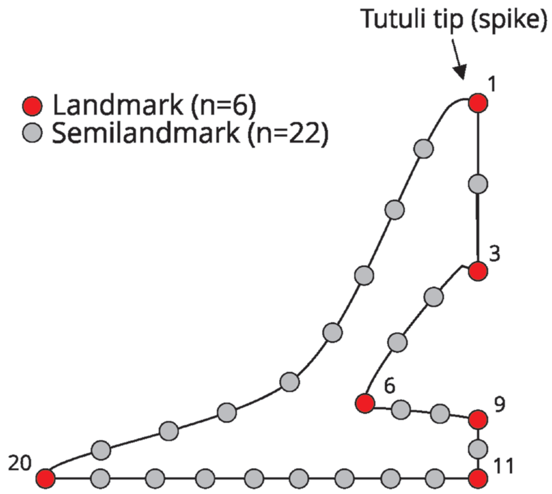

Figure 4. A visual representation of the landmark configuration used in this article.

.csv format) and R script (with extended commentary). A copy of all files can also be found on the Open Science Framework (OSF): https://osf.io/fcp43/.

Analysis

The first two principal components (main sources of shape variation for all tutuli) account for 84.3 % cumulative shape variance with the first five components accounting for 95 % cumulative shape variance, and the first ten components accounting for 99 % cumulative shape variance. This means, that 84,3 % of the shape variance of all objects analysed in this paper can be represented by two axes (or components), while the full morphological variance (or rather 99 % of the morphological variance) can be represented by ten axes. The first principal component extends from examples featuring a flat body and a slightly convex centre (more positive principal component one scores) to examples featuring a shorter and more pronounced cross-section (more negative principal component one scores). The second principal component extends from examples featuring a flat body and high central point (more positive principal component two scores) to a more domed and hemispherical tutuli appearance. When plotted through a two-dimensional tangent space (Figure 5a), clear subdivisions can be observed between the temporal NBA II and NBA III groups, with the NBA II/III transitional overlapping with both NBA II and NBA III. This is perhaps to be ex-

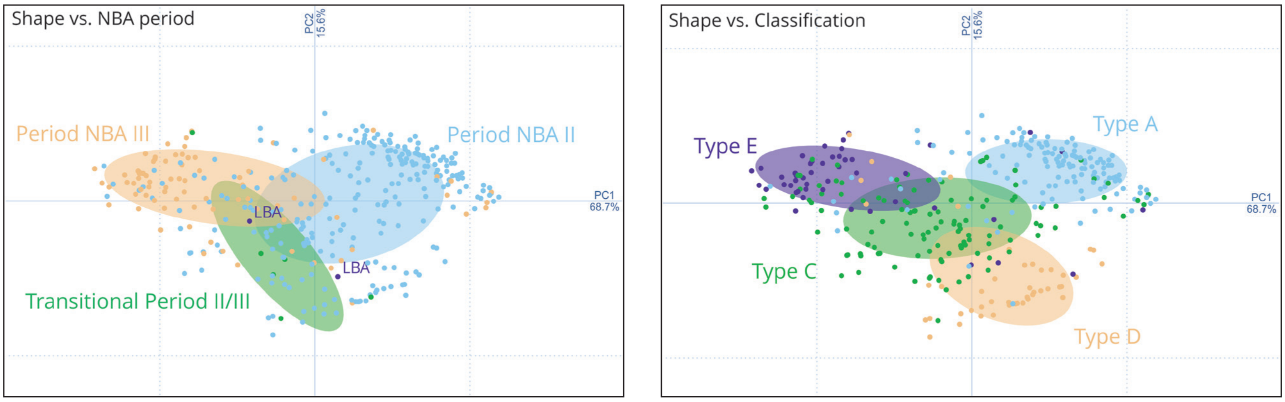

Figure 5. A principal component tangent space for the first two principal components (representing 84.3% cumulative shape variance), with morphospace positions for the axis ranges. Left: clustering according to NBA period for all tutuli examined. Right: clustering according to classification sensu Montelius (1885) for all tutuli examined. Confidence ellipses: 75%.

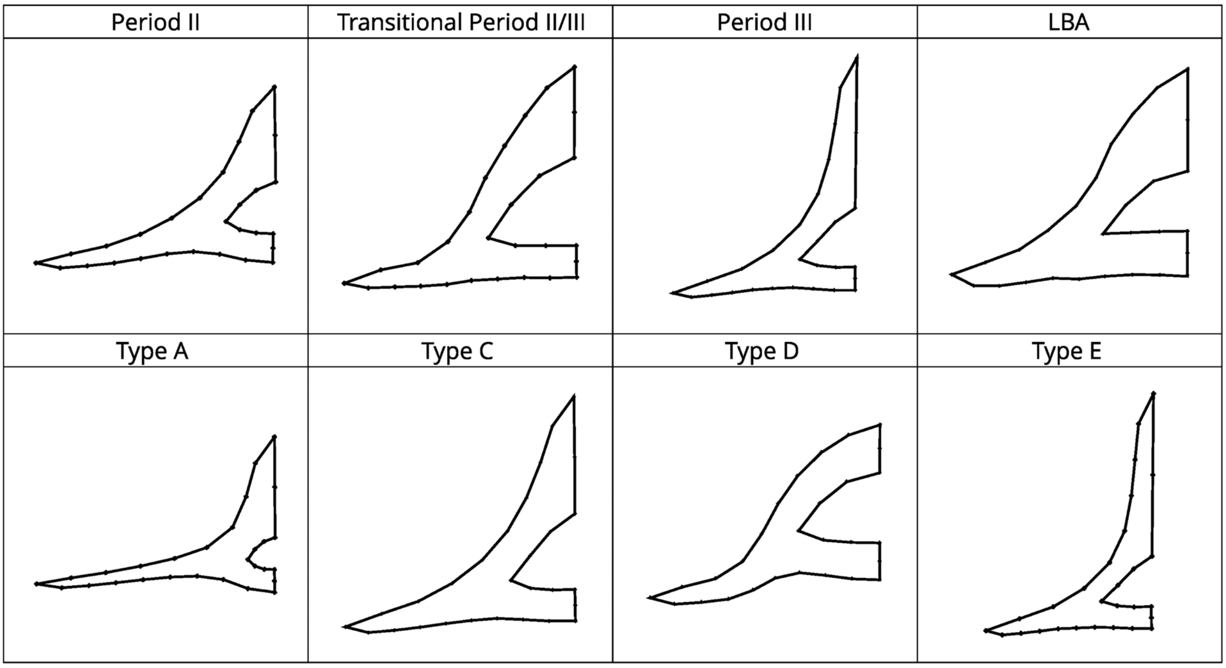

Figure 6. Mean shapes for both period (top) and Montelius' (1885) classificatory scheme (bottom).

pected considering that these tutuli originate from contexts with both NBA II and NBA III characteristics. NBA II examples feature more positive principal component one scores indicative of flatter tutuli cross-sections, while NBA III cluster towards more negative principal component one scores, indicative of more pronounced heightening in the centre of the tutulus. The two examples attributed to the Late Bronze Age feature no distinct spatial positioning. Interestingly, the four groups of Montelius' (1885) classificatory scheme do feature differing spatial clustering (Figure 5b) with minor overlap only documented between type C and all other types. In this, type A examples feature more positive principal component one scores, while type E forms feature more negative principal component one scores. The greatest differentiation between type C and type D forms lay in the second principal component, with type D examples featuring greater negative principal component two scores in comparison to all other groups. In their entirety, these two plots demonstrate the degree of success of the Montelius (1885) typology, and the observation of explicit shapes to different period. Mean shapes for each of the periods and groups can be seen in Figure 6.

The discriminant analysis further reiterates the trend and degree of dissimilarity as seen in the PCA (Figure 7). For the period-based classification of tu-

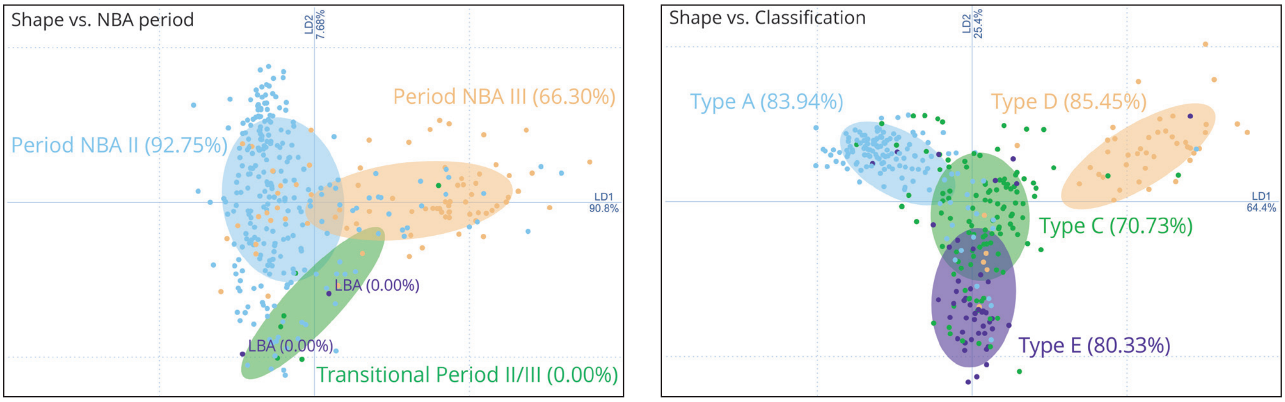

Figure 7. Discriminant analysis (Canonical Variates Analysis) for both classificatory schemes. Left: period-based classificatory scheme. Right: classificatory scheme sensu Montelius (1885). Percentages correspond to class correctness values.

tuli, differences between NBA II and NBA III can be observed, with the transitional group NBA II/III also appearing distinct (through confidence ellipses). Regarding the classificatory scheme, minor overlap is again observed for types A, C and E, with type D distinct from all three ellipses.

Through a jackknifing (leave-one-out cross-validation) procedure a high degree of classificatory success was noted with 84.3 % (317/376) examples assigned to the correct periodic group. In this a greater class correctness could be observed in the group NBA II with 92.75 % of examples correct classified, compared to 66.30 % success in NBA III. The NBA II/III transitional group and LBA examples could not be correctly classified, however, this is, as mentioned earlier, unsurprising given the low sample size. For the Montelius (1885) classificatory scheme, 79.3 % (298/376) of examples were correctly classified with over 80% class correctness for types A, D and E (83.94 %, 85.45 % and 80.33 % respectively) and a lower 70.73% class correctness for type C. Given its position within the PCA morphospace and the discriminant analysis (overlapping with type E and A) it is perhaps unsurprising that a lower-class correctness was calculated. The discriminant analyses in their entirety demonstrate that, to a high degree of correctness, random tutulus shapes can be assigned to the correct period-based and type-based classificatory schemes. For a more detailed breakdown of the discriminant analyses, please refer to the R script.

Finally, through a Procrustes ANOVA, this success in discriminating between tutuli is replicated for individual NBA temporal periods (F: 38.375, Z: 6.458, p: 0.001) and the Montelius (1885) typological scheme (F: 96.258. Z: 7.632, p: 0.001). Through these values both null hypotheses were rejected, and difference between types (groups/periods) concluded.

Discussion

Despite a lack of quantitative frameworks previously assessing the nature of these groupings, the GMM analytical and exploratory procedure demonstrated how robust both schemes are. In each of these schemes, a target shape is idealised with the true variability of shape fitting into these 'subjective' boxes. But however subjective these boxes may appear, they do stand up to scrutiny, and are useful classificatory schemes for the tutulus object group. Relatively high-class correctness scores were obtained, with differences in the exploratory visual exercise noted and statistical significance observed. And while not perfect, with roughly 20% of all examples incorrect in each classification, they are of merit to cataloguing NBA tutuli.

As mentioned in the methodology section, Montelius' (1885) typology was grounded through a temporal framework, in which type A, C and D 'belong' in the period NBA II, and type E in NBA III. As illustrated in Table 1, his expectations were met by the chronological information in the data source (i.e. the Aner and Kersten catalogues). As we established the robustness of Montelius' (1885) morphological types, we can hence discuss his expectations compared with the true variation observed in the archaeological record.

The majority of types A, C and D are placed in the group NBA II, with only a few objects placed in later – or rather in succeeding – periods. This is especially true for type A, where only one object is considered later than NBA II. Additionally, the majority of the type E objects are placed in NBA III. It does, however, seem that type C are more inclined to be distributed later than NBA II compared to types A and D. Even though only four objects are placed in the transition group NBA II/III (remember that only six objects are placed in this group) this type of tutuli may in fact be regarded as a transition type – maybe even a hybrid between type A (archetypical NBA II) and type E (archetypical NBA III). Type C does indeed share morphological characteristics with both of these types. It should however be mentioned, that type C contextually are often found with especially type A tutuli, but only seldom with type E (at least in the present dataset). Furthermore, the exploratory procedure (PCA variation and CVA scores) suggests greater variation in tutulus shape range in the early period, while later object groups exhibit tutuli of greater standardisation.

A temporal relationship between the types A, C and E is indeed suggested by Kersten (1936, 14-19, Abb. 1). However, his suggestion includes several other types such as the NBA III belt plate. It is not possible to determine a temporal relationship between these types based on the analyses presented in this article. We rather suggest that the temporal relationship between types A, C and E should not be understood as simplistic and evolutionistic as Kersten (1936, 14-19, Abb. 1) illustrates in his typology. More likely these types existed at the same time – although they may be inspired from one another – and gradually type C replaced type A, and later type E appearing more frequently than type C. This does indeed emphasise the temporal nature of the NBA periodisation.

In improving these classificatory schemes, we suggest four further avenues of research. First and foremost is the integration and pairing of examples with absolute radiocarbon dates to the above (or similar) GMM exercise. The majority of examples within this dataset are of poor chronostratigraphic setting and are based on contextual observations. For a more accurate scheme (through the assumption that specific shapes do always confirm to a specific period), and in building on from this article, the integration of robust chronological data is essential. This would furthermore change the perspective from a division-based periodisation to an actual fixed chronology. As we wish to maintain a methodological focus in this paper, this has not been pursued here. Furthermore, in examining morphological differences across Denmark, between the islands and mainland Jutland for example, an interesting avenue of research in testing these classificatory schemes further. It is generally understood that cultural differences, or according to Kersten (1936, 2) *cultural zones,* existed at this point in time; this does not only apply to the material record, but also to technical and crafting traditions (Nørgaard 2018), in addition to the pace of which new traditions were adopted (Randsborg 1968, 1972, 1987). This regional variation, which is particularly prominent in NBA III and IV (Hornstrup et al 2012, 10) is largely influenced by the number of objects originating from Zealand, totaling approximately 40 %, and one could hypothesise regional preferences in the style and use of tututli. While so, all four tutuli categories have been documented on Zealand, Funen and Jutland; further research could however test this observation further. Thirdly, for an improved classificatory scheme, further examples (with the available typological data) should be incorporated. Through the open-science approach adopted here, it is our hope that this dataset is re-analysed through other means and incorporated into other available datasets. To further test the robustness of Montelius' (1885) classificatory system, it is essential, that the experiment in recording through typology (as above) is replicated with multiple individuals, as a means of testing inter-observer error, in addition to the testing of examples where the classification has been applied. Finally, in improving these classificatory schemes a three-dimensional approach incorporating the whole artefact shape (and the factor of size) of tutuli is essential, incorporating surface data. With this available data, the analytical procedure can be more robust and more meaningful, taking into account a greater amount of data, and thus provide further insights into the meaning of NBA tutuli.

Conclusion

In its totality, this study demonstrates the strength of GMM methodologies for examining the variability in tutulus artefact shape, and its potential for better understanding the earlier NBA periods. With the methodology described above, utilising landmark and semilandmarks, tutulus cross-sections can now be catalogued to a high-resolution, and examined to better understand their underlying meaning, whether this be through the analysis and documentation of possible production centres or regionalised traditions (similarly to Wilczek et al. 2015), or through an assessment of artefact shape and their associated archaeological material. With these quantitative shape-based methodologies, there is now a potential to better understand the importance of tutuli throughout the NBA and provide an empirical framework for discussing their morphological change.

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Datadownload: https://osf.io/fcp43/

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Supplement

id	artefact_id	site	date	classification	diameter_cm
1	1141III-1	Valbygård	II	C	4.8
2	1141III-2	Valbygård	II	A	6.6
3	1148-2	Landsgrav	II	C	4.8
4	1148-5	Landsgrav	II	D	4.65
5	1148-6	Landsgrav	II	C	2.55
6	1148-7	Landsgrav	II	C	3.9
7	1160-1	Svenstrup	II	D	4.65
8	1160-10	Svenstrup	II	A	4.5
9	1160-11	Svenstrup	II	A	4.65
10	1160-12	Svenstrup	II	A	4.65
11	1160-13	Svenstrup	II	A	4.05
12	1160-15	Svenstrup	II	A	4.05
13	1160-16	Svenstrup	II	A	4.35
14	1160-17	Svenstrup	II	A	4.05
15	1160-18	Svenstrup	II	C	3.45
16	1160-19	Svenstrup	II	C	2.4
17	1160-2	Svenstrup	II	D	4.5
18	1160-20	Svenstrup	II	C	4.05
19	1160-21	Svenstrup	II	C	3.15
20	1160-22	Svenstrup	II	C	2.85
21	1160-23	Svenstrup	II	C	3.45
22	1160-3	Svenstrup	II	A	4.65
23	1160-32	Svenstrup	II	A	4.65
24	1160-33	Svenstrup	II	A	4.65
25	1160-34	Svenstrup	II	C	2.4
26	1160-4	Svenstrup	II	A	5.7
27	1160-5	Svenstrup	II	A	4.2
28	1160-6	Svenstrup	II	A	4.65
29	1160-7	Svenstrup	II	A	4.35
30	1160-9	Svenstrup	II	A	4.65
31	1163A-1	Tårnborg	II	C	3
32	1163A-2	Tårnborg	II	C	3.3
33	1170	Ormslev	III	E	9.3
34	1274B-1	Ørslev	III	E	5.1
35	1274B-10	Ørslev	III	E	NA
36	1274B-11	Ørslev	III	E	NA
37	1274B-12	Ørslev	III	E	NA
38	1274B-2	Ørslev	III	E	5.1
39	1274B-3	Ørslev	III	E	5.1
40	1274B-4	Ørslev	III	E	NA
41	1274B-5	Ørslev	III	E	NA
42	1274B-6	Ørslev	III	E	NA
43	1274B-7	Ørslev	III	E	NA
44	1274B-8	Ørslev	III	E	NA
45	1274B-9	Ørslev	III	E	NA
46	1283-1	Store-Linde	II	C	4.05
47	1283-3	Store-Linde	II	D	4.65
48	131	Ferslev	II	A	4.35
49	1373-1	Sigerslevvester	II	D	6.15
50	1373-2	Sigerslevvester	II	D	NA
51	1384	Varpelev	III	C	3.75
52	1409-2	Sydsjælland	II/III	C	3.15

53	1420	Sjælland	II	A	NA
54	1422-1	Sjælland	II	A	4.05
55	1446-1	Krasmose	III	E	5.55
56	1446-2	Krasmose	III	E	5.55
57	1446-3	Krasmose	III	E	5.55
58	1446-4	Krasmose	III	E	5.55
59	1446-5	Krasmose	III	E	5.55
60	1464C	Stammeshalle	III	E	8.85
61	1482M	Jomfrugård	II	A	3.45
62	1492A-1	Limensgård	II	D	6.75
63	1492A-2	Limensgård	II	D	NA
64	14A-3	Bakkebjerg	II	C	4.2
65	150-1	Østby	II	A	7.35
66	150-4	Østby	II	C	4.2
67	152	Østby	II	C	5.1
68	1533	Lousgård	II	D	2.7
69	1760	Voldtofte	III	C	4.5
70	1777-1	Torøhuse	II	A	4.05
71	1777-2	Torøhuse	II	A	4.5
72	1777-3	Torøhuse	II	A	4.5
73	1777-4	Torøhuse	II	A	5.1
74	1777-5	Torøhuse	II	A	4.8
75	1777-6	Torøhuse	II	A	6.15
76	180-1	Lynge	III	D	5.55
77	180-2	Lynge	III	C	5.4
78	1820-1	Hasmark	II	D	4.2
79	1820-2	Hasmark	II	D	4.2
80	185A	Sigerslevvester	III	E	4.8
81	1868-1	Vellinge Mose	II	A	7.8
82	1868-2	Vellinge Mose	II	A	5.4
83	1868-3	Vellinge Mose	II	A	5.1
84	1868-4	Vellinge Mose	II	A	4.35
85	1868-5	Vellinge Mose	II	A	4.35
86	1868-6	Vellinge Mose	II	A	6.6
87	1868-7	Vellinge Mose	II	A	4.65
88	1944	Lumbygård	II	D	4.95
89	1960A	Rågelund	III	C	5.4
90	1960B-1	Rågelund	III	E	8.1
91	1960B-2	Rågelund	III	E	7.8
92	1960B-3	Rågelund	III	E	7.8
93	2011B-3	Hesselagergård	II	D	2.4
94	2019	Refsøre	III	C	4.05
95	2022	Davrehøjsmark	II	C	4.2
96	2039-1	Fæbæk	II	C	3.75
97	2138C	Bovense	II	C	3
98	2.16E+01	Smidstrupgård	II	D	2.4
99	2.16E+00	Smidstrupgård	II	D	NA
100	217	Smidstrupgård	II	C	2.85
101	218A	Vallerød	II	D	2.85
102	2234	Haurup	II	D	3.15
103	2266B	Massbüll	II	D	5.1
104	2292-2	Süderschmedeby	II	D	3.3
105	23	Smidstrup	II	C	3.15
106	2404-1	Schleswig	II	D	4.5
107	2409E	Schuby	III	C	3.9

108	2413-1	Schuby	II	D	3.9
109	2413-2	Schuby	II	D	NA
110	2414H	Schuby	III	E	5.7
111	243I-1	Præstegårdsmark	II	A	6.3
112	243I-2	Præstegårdsmark	II	C	3.75
113	243I-3	Præstegårdsmark	II	A	NA
114	2519D	Schoolbek	III	C	4.65
115	2553A	Sehestedt	II	C	2.1
116	2646B	Hedehusum	III	E	3.15
117	266	Farum	II	C	4.8
118	2669-1	Kampen	II	A	3.15
119	2669-2	Kampen	II	A	
120	278	Søsum	II	C	4.65
121	2816	Husum	III	C	1.8
122	281C	Søsum	LBA	D	3.9
123	2831	Ostenfeld	II	C	3
124	2844	Schobüll	II	D	2.85
125	294-1	Svenstrup	II/III	C	3.6
126	294-2	Svenstrup	II/III	C	3.6
127	2956-2	Fårhus	III	E	1.8
128	2962B-2	Frøslev	II	C	2.55
129	2979A-1	Padborg	II	A	4.95
130	297F	Store Salby	III	E	7.65
131	299-1	Ølby	II	D	3.45
132	299-2	Ølby	II	D	NA
133	299-3	Ølby	II	D	NA
134	3077A	Hønkys	II	C	4.8
135	3378-1	Sundbølgård	II	C	3.3
136	3378-2	Sundbølgård	II	C	2.85
137	3378-3	Sundbølgård	II	C	2.85
138	3378-4	Sundbølgård	II	C	2.85
139	3378-6	Sundbølgård	II	C	2.85
140	3378-7	Sundbølgård	II	C	2.85
141	3443-2	Hennekesdam	II	A	3.15
142	3443-3	Hennekesdam	II	A	4.65
143	347	Smørumnedre	II	D	2.85
144	353	Smørumovre	II	D	4.8
145	3600	Vojensgård	III	E	4.35
146	3601	Vojensgård	II	C	3.45
147	361	Bringe	II	C	3.6
148	3715-1	Toftlund	II	A	NA
149	3717A-2	Toftlund	III	E	2.1
150	378C	Bagsværd	III	E	9.3
151	379-3	Buddinge	II	C	3.15
152	379-4	Buddinge	II	A	4.65
153	379-5	Buddinge	II	A	6.9
154	379-6	Buddinge	II	C	5.1
155	379-7	Buddinge	II	C	5.1
156	379-8	Buddinge	II	C	NA
157	379-9	Buddinge	II	C	NA
158	3799A	Lejrskov	II	C	3.6
159	3817B	Hafdrup	II	A	3.75
160	3856	Tange	II	E	5.1
161	3866B	Gredsted	III	C	1.8
162	3919B-2	Tobøl	II	C	2.1

163	3919B-3	Tobøl	II	C	2.1
164	3919B-4	Tobøl	II	C	1.95
165	3939C-1	Nørre-Holsted	III	C	7.35
166	3939C-2	Nørre-Holsted	III	E	1.95
167	408-2	Rødovre	II	D	3.9
168	4084A	Lunde	III	E	1.95
169	411	Store-Magleby	II	D	2.55
170	417-1	Jægerborg Hegn	II	C	2.4
171	417-2	Jægerborg Hegn	II	C	3.15
172	417-3	Jægerborg Hegn	II	C	2.4
173	417-4	Jægerborg Hegn	II	C	3.15
174	4170	Søviggårde	II	C	8.4
175	426-1	Jægerborg Hegn	II	D	3.15
176	430	Søllerød	II	D	3.45
177	431	Søllerød	II	C	2.55
178	443-1	Petersdal	II	D	1.65
179	443-2	Petersdal	II	D	1.65
180	4513	Kobberdal	III	E	7.35
181	4544	Jelling	II	C	2.4
182	4574D	Bindeballe	II	D	3.75
183	460-2	Herslev	II	C	4.65
184	460-3	Herslev	II	C	4.35
185	460-4	Herslev	II	C	4.5
186	460-5	Herslev	II	C	4.35
187	460-6	Herslev	II	C	4.35
188	460-7	Herslev	II	C	4.35
189	460-8	Herslev	II	C	4.35
190	4602	Hanneup	III	E	4.8
191	4633	Ejsing	III	E	6.75
192	4654	Stendis	III	C	4.05
193	466C-2	Hvedstrup	II	D	4.35
194	4740A-1	Muldbjerg	II	A	3.45
195	4804	Kobberup	III	C	2.85
196	4858-2	Gudum	III	E	1.65
197	491	Roskilde	II	A	6.9
198	502-1	Lille-Valby	II	A	5.4
199	502-2	Lille-Valby	II	A	3.9
200	5085-1	Lækjær	II	D	3.3
201	5214A	Aldershvile	III	A	6.75
202	5227	Silstrup	II	E	4.95
203	5231B	Vorupørvej 16	III	E	1.65
204	525-1	Snoldelev	II	C	1.8
205	53-1	Lavø	II	A	5.1
206	53-2	Lavø	II	C	4.2
207	5353-1	Fredsø	II	D	3.15
208	5353-2	Fredsø	II	D	3.15
209	5379	Ljørslev	II/III	C	3.3
210	5530A	Aldrup	II	C	3.15
211	5557	Thy	LBA	C	2.85
212	556	Ledreborg	III	C	4.05
213	5616-1	Over-Torp	III	E	1.8
214	5616-2	Over-Torp	III	E	1.8
215	5638	Hald	II	C	2.55
216	5652	Toustrup	III	E	5.4
217	5663	Fur	III	C	4.8

218	5707A	Nautrup Hede	II	A	5.85
219	5735	Vile	III	C	5.7
220	5794	Ødeskovhede	II	D	5.25
221	590A	Ejby	II	E	7.05
222	5936A-C-1	Enslev	II/III	D	4.2
223	5936A-C-2	Enslev	II/III	D	4.05
224	5952D-4	Vranum	II	A	3.3
225	6003C	Torning	III	C	4.65
226	6008	Torning	II	D	2.7
227	6060	Middelhede	III	C	5.7
228	6099	Bækkelund	III	E	4.95
229	6121-2	Pederstrup	III	E	1.95
230	6132B	Tapdrup	III	C	5.7
231	6175-10	Møldrup	II	A	3.6
232	6175-3	Møldrup	II	A	3.15
233	6175-8	Møldrup	II	A	3.9
234	6175-9	Møldrup	II	A	3.45
235	6185	Højslev Mølle	III	E	2.1
236	6201A-1	Hverrehus	II	A	4.2
237	6201A-10	Hverrehus	II	A	4.2
238	6201A-11	Hverrehus	II	A	4.2
239	6201A-12	Hverrehus	II	A	4.2
240	6201A-13	Hverrehus	II	A	4.05
241	6201A-14	Hverrehus	II	A	4.2
242	6201A-3	Hverrehus	II	A	4.95
243	6201A-4	Hverrehus	II	A	4.2
244	6201A-5	Hverrehus	II	A	4.65
245	6201A-6	Hverrehus	II	A	5.1
246	6201A-7	Hverrehus	II	A	4.95
247	6201A-9	Hverrehus	II	A	3.9
248	6201E	Hverrehus	II	A	3.9
249	6254A	Briksbjerg	III	C	4.2
250	6268-2	Lihme	II	C	3
251	6347B	Nørgård	II	A	NA
252	6403-1	Nørbæk	III	C	2.1
253	6403-2	Nørbæk	III	E	4.8
254	6404	Nørbæk	III	E	5.7
255	6452	Hårup	III	C	3.45
256	6455	Hårup	III	C	1.8
257	6460B	Linå	III	C	4.2
258	6461	Linå	III	E	7.05
259	6482-1	Silkeborg	II	C	3.15
260	6482-2	Silkeborg	II	C	3.3
261	649B	Asnæs	III	E	4.95
262	6585-3	Legårdslyst	II	D	1.95
263	6585-4	Legårdslyst	II	C	3.6
264	6648B	Hvidsminde	II	A	3.3
265	6653C-1	Nim	III	E	3.3
266	6653C-2	Nim	III	E	2.85
267	669-1	Rye	II	A	6.3
268	669-10	Rye	II	A	5.4
269	669-11	Rye	II	A	3.45
270	669-12	Rye	II	A	5.4
271	669-13	Rye	II	A	5.4
272	669-14	Rye	II	A	5.7

273	669-15	Rye	II	A	6.15
274	669-16	Rye	II	A	6.3
275	669-18	Rye	II	A	5.1
276	669-19	Rye	II	A	6.75
277	669-2	Rye	II	A	4.8
278	669-20	Rye	II	A	5.1
279	669-21	Rye	II	A	5.1
280	669-22	Rye	II	A	6.75
281	669-23	Rye	II	A	6.9
282	669-3	Rye	II	A	4.05
283	669-4	Rye	II	A	6.6
284	669-5	Rye	II	A	7.35
285	669-6	Rye	II	A	7.35
286	669-8	Rye	II	A	5.1
287	669-9	Rye	II	A	5.1
288	6700A	Lykkensspil	III	C	5.7
289	6711	Grædstrup	II	A	5.1
290	6750B	Troelstrup	III	C	5.1
291	6827	Naldal	III	C	3.45
292	6884C-2	Hundshoved	III	E	1.8
293	6928C-1	Højballegård	II	C	5.55
294	6949	Knudrisbakke	II	C	4.2
295	708-1	Kongsted	II	A	8.4
296	708-10	Kongsted	II	A	5.55
297	708-11	Kongsted	II	A	5.25
298	708-12	Kongsted	II	A	4.2
299	708-13	Kongsted	II	A	4.05
300	708-14	Kongsted	II	A	6.6
301	708-16	Kongsted	II	A	6.3
302	708-17	Kongsted	II	A	5.1
303	708-18	Kongsted	II	A	4.8
304	708-19	Kongsted	II	A	4.35
305	708-2	Kongsted	II	A	10.05
306	708-20	Kongsted	II	A	4.95
307	708-3	Kongsted	II	A	8.1
308	708-4	Kongsted	II	A	6.3
309	708-5	Kongsted	II	A	4.65
310	708-6	Kongsted	II	A	6.9
311	708-7	Kongsted	II	C	3.6
312	708-8	Kongsted	II	A	7.05
313	708-9	Kongsted	II	A	5.55
314	74-2	Ågerup	III	C	6.6
315	744	Ods	II	C	3.9
316	745	Ods	II	C	4.2
317	746	Ods	II	A	4.05
318	761B-5	Høve	II	A	4.95
319	761B-6	Høve	II	A	6.9
320	761B-7	Høve	II	A	5.25
321	761B-9	Høve	II	A	4.35
322	825-1	Annebjerg Skov	II	D	5.55
323	872	Nykøbing Sjælland	III	C	4.05
324	896B	Hønsinge	II	A	4.05
325	9363A-1	Drage	II	D	5.85
326	9363A-2	Drage	II	D	5.85

327	945D-1	Sælvig	II	C	3.6
328	9462A-2	Wrack	II	E	2.1
329	9481B-1	Puls	II	D	4.35
330	9481B-2	Puls	II	D	3.45
331	9504-1	Vaale	II	A	6.3
332	9504-2	Vaale	II	A	6.9
333	9515B-1	Warringholz	III	E	1.95
334	9515B-2	Warringholz	III	E	1.8
335	9700	Schmalstede	II	E	1.8
336	973-1	Eskebjerggård	II	A	4.95
337	973-2	Eskebjerggård	II	C	4.65
338	976-1	Eskebjerggård	II	A	4.65
339	976-12	Eskebjerggård	II	A	3.45
340	976-13	Eskebjerggård	II	A	3.15
341	976-14	Eskebjerggård	II	A	3.3
342	976-3	Eskebjerggård	II	A	4.05
343	976-4	Eskebjerggård	II	C	3.9
344	976-7	Eskebjerggård	II	A	3.9
345	976-8	Eskebjerggård	II	A	4.05
346	976-9	Eskebjerggård	II	A	3.6
347	9765	Gadeland	III	E	2.55
348	9816B-2	Bornhöved	III	C	5.25
349	9816B-3	Bornhöved	III	C	2.7
350	9841	Bornhöved	III	C	3.75
351	998-1	Kilshoved	II	A	3.3
352	998-2	Kilshoved	II	A	3.45
353	999-1	Mastrup	II	D	2.85
354	999-2	Mastrup	II	D	NA
355	9992C	Tarbek	II	C	2.7
356	1199	Sønder-Bjerg	II	C	2.55
357	3369	Tornum	III	C	4.05
358	5501A	Villerup	III	C	3.45
359	6121-1	Pederstrup	III	E	2.55
360	708-18	Kongsted	II	A	4.8
361	9911	Gross Kummerfeld	III	C	3.3
362	1000-2	Mastrup	II	C	3.45
363	1013B-1	Birkendegård	II	C	3.6
364	1013B-2	Birkendegård	II	C	3.15
365	1013B-3	Birkendegård	II	A	3.6
366	1013B-4	Birkendegård	II	A	3.6
367	1013B-5	Birkendegård	II	A	3.6
368	1013B-7	Birkendegård	II	C	2.85
369	1051B-1	Næsby	III	E	4.05
370	1051B-2	Næsby	III	E	5.25
371	1070-2	Bognæs	II	D	4.05
372	1077-1	Løserup	II	A	4.35
373	1077-2	Løserup	II	C	3.75
374	1077-3	Løserup	II	C	2.55
375	1111B-3	Ringstedmark	II	A	1.8
376	1121	Boeslunde	II	D	3.9

Weapon and tool use during the Nordic Bronze Age

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ABSTRACT
Wear analyses of 100 bladed objects including swords, spears, daggers, and knives dating to the Nordic Bronze Age was conducted focusing on Northern Germany. These analyses indicate changing patterns for tip and edge wear, the relationship of curvatures, fractures, and cracks, and for different traces of repairs. Comparing these results to published wear analyses suggests changing patterns across object forms and time. It can be hypothesized that there is a trend towards accommodating fighting style preferences with diverging object designs. This started at the end of the Late Neolithic with the change from halberds to swords/daggers and spears.

The changing patterns were interpreted as indications of shifts in the use of swords, spears, and daggers following changes in the design of these objects. Swords and spears were used in increasingly more specialised motions over time, i.e. swords in slashing/cutting and spears more often for thrusting. Daggers may have shifted away from a role as combat weapons to multipurpose tools more in line with period III knives. This was interpreted as evidence for the existence of a technological network in which changes in design and use of bladed objects inform each other. The results provide the base for future research into object design, specialization, and social significance that can test the hypotheses put forward in this paper.

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Introduction

Early Nordic Bronze Age metalwork is essential for the study of Bronze Age technology, practices, and social organization in this region. Archaeologists often investigate bronze objects within the scope of the study of economic processes using methods including contextual, trace elemental, and isotopic analysis (Earle, 2002; Earle et al., 2015; Kristiansen, 2016; Larsson, 1989; Ling et al., 2013; Ling et al., 2014). Early use-wear studies used within this framework substantiated hypotheses on the economy of metal supply and management (Kristiansen, 1979, 1984). Kristiansen saw the re-sharpening and reduction in the general shape of swords as indicative of a prolonged use-life as a consequence of supply shortages. This was an important contribution towards understanding the socio-economic dynamics of the Bronze Age in Scandinavia. However, a more detailed analysis can inform us about the use and significance of the objects themselves.

In his later work, Kristiansen included other damage, which he termed "scars" (Kristiansen, 2002). However, these "scars" have different forms, each of which could be caused through considerably different activities, actions or processes. A more detailed study of wear marks and their position can enrich our knowledge about these bladed objects. Dolfini and Crellin (2016) have argued that a stricter protocol is necessary in order to fully understand the use of weaponry. Such an approach has been used to argue the fighting styles using swords or spears during period I of the Nordic Bronze Age (1700-1500 BC) followed similar patterns. This may have facilitated the adoption of innovations in weapon technology (Horn, 2013, 2014a). Building on this prior work, our aim is to give a more detailed account of Nordic Bronze Age weaponry by extending the chronological framework and including the results of new wear analyses.

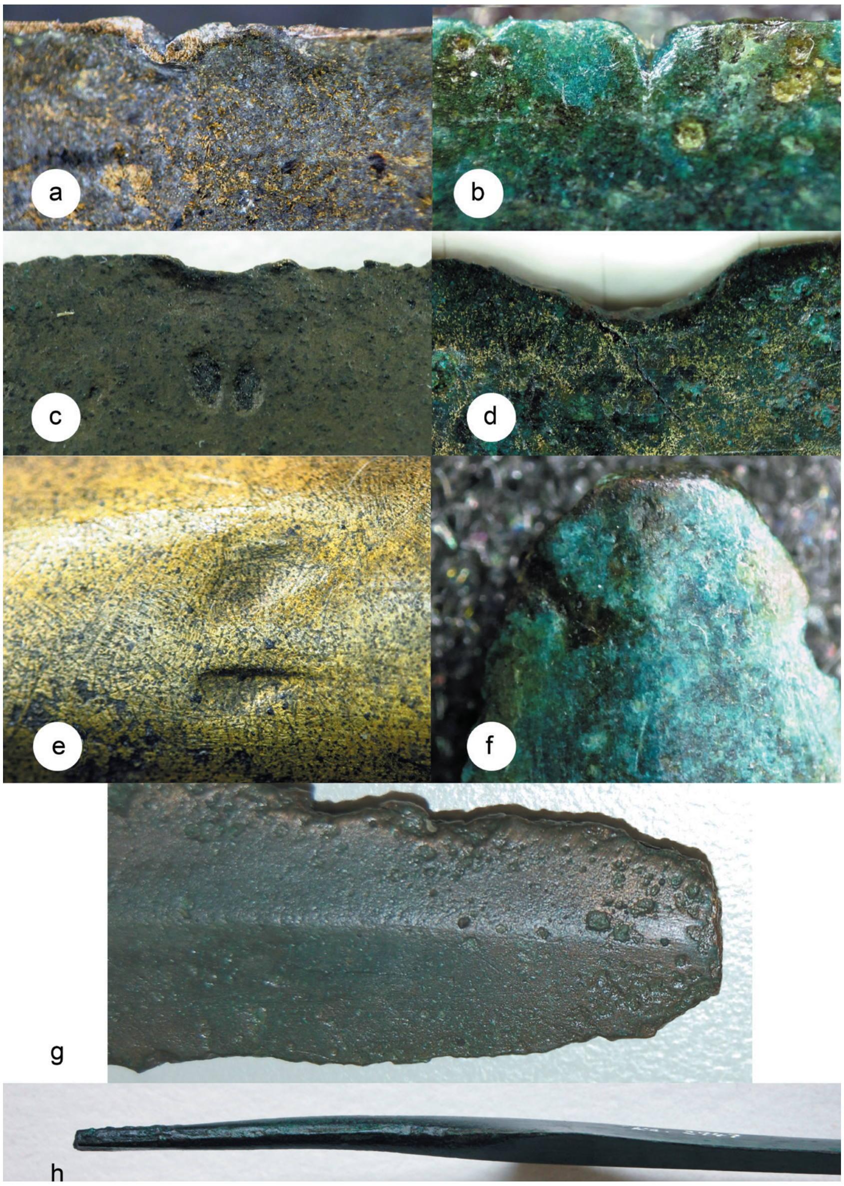

Fig. 1: a. Notch with displaced material (x150, LMSH KS923);
b. Notch with micro-fissure at the central point (x150, LMSH KS8017a);
c. Indentation with material displacement (x60, LMSH KS1204);
d. Indentation with a fissure (x60, LMSH KS7367);
e. Two blowmarks (x60, LMSH KS11145.2);
f. Pressured tip (x60, LMSH KS2948);
g. Tip broken and lost (MUFB Im1155);
h. Hilt with curved deformation (LMSH KS2947).

Method

To enable detailed observations, it was necessary to classify several wear categories, building upon earlier work (Bridgford, 1997; 2000; Dolfini, 2011; Horn, 2013; Molloy, 2008; Molloy et al., 2016; Contributions in Uckelmann and Mödlinger, 2011). The formation of damage depends upon complex processes involving material properties (for example hardness, toughness, malleability, tensile strength, etc.), surface shape of both objects, speed and strength of the impact, dimensions of the involved objects, the relational trajectories of the objects, and potential prior damage such as hair-line cracks. To be archaeologically visible the force of the impact has to surpass the material properties of the metal to leave a trace, the damage has to occur on a preserved part of the weapon – e.g. not the wooden shaft, and the wear has to be mostly unaffected by corrosion (Horn and Holstein, 2017).

Wear marks can be classified based on their morphology (Horn, 2013, 2014a) which will be outlined in the following. Other nomenclatures have been proposed (Bridgford, 2000; Gentile and van Gijn, 2019; Molloy, 2006), however, to keep comparability with earlier papers in the region we keep the definitions put forward in Horn's previous publications (Horn, 2013, 2014a, 2017). *Notches* are v-shaped intrusions (Figure 1a-b) and *indentations* have more rounded u-shapes (Figure 1c-d). Both occur along the cutting edge of bladed objects. *Blow marks* are similar in form to notches and indentations but are located on the weapon's body (Figure 1e). *Pressured tips* are recognisable by a flattening of areas on top of the tip (Figure 1f). This does not preserve a mark that is indicative of the shape of the object that the subject impacted against. *Fractures* propagate through the entire object and commonly break it into several pieces that could be lost (Figure 1g). This is an obvious problem because these lost pieces could carry damage that becomes unobservable using archaeological analyses. Cracks are a preliminary stage of fractures because they do not propagate through the entire object, and do not break it apart. Fractures and cracks can a direct outcome of blows that also cause notches, indentations, and blow marks (Figure 1b, e). *Curvatures* can occur on a scale from faint to extreme forms and on several different axes (Figure 1h). Subtle curvatures that extend across the entire object can be caused by earth pressure when the artefact is buried in the ground. Small, slightly broken or chipped material that is still attached to the main body of the object and that is directly associated to an impact has been termed *material displacement*.

Wear formation is complex, but the mechanics of deformation of metal can cause wear that forms through different actions to look very similar. That can happen when the surfaces impacting against each other have a similar morphology (Horn and Holstein, 2017). For example, pressured tips may have the same shape regardless of whether the tip hits bone, metal, or a rock on the ground. The same is true for damage caused by thrusting or throwing. Furthermore, curvatures from sudden impacts or prolonged high pressure can also be very similar. Therefore, the only remedy is a comparative approach to the different wear marks on an individual weapon, the distribution of wear patterns across a single weapon category, and the similarities and differences of wear across different weapon categories. Additionally, the morphology of the objects should be taken as an indicator of the intended use of an object. Nevertheless, it should be kept in mind that objects can be used in a variety of ways which were not anticipated when they were produced. It is, therefore, important to compare the described damage categories to damage produced by independent experiments conducted by various researchers (Anderson, 2011; Dolfini and Crellin, 2016; Gentile and van Gijn, 2019; Molloy, 2006; O'Flaherty, 2007; O'Flaherty et al., 2008).

Cracks are more susceptible to corrosion which propagates along those features leading to internal stress which could be relieved through the formation of fractures (Horn, 2013; Horn and Holstein, 2017; Hunt Ortiz, 2003; Orfanou and Rehren, 2015; Sáez and Lerma, 2015; Shreir, 2010). Corrosion can preserve traces of wear, for example striations in fine grained patina. Conversely, aggressive patina affects thinner parts more strongly, especially when weakened through damage, such as at cutting edges. That means that areas which are interesting for wear analysis can be obscured or dissolved first (c.f. Horn and Holstein, 2017). However, detailed observation of corrosion processes can provide information about damage, contexts, and the position of metalwork within such contexts (Högberg et al., 2016). The change in the material properties through the forces of an impact (for example, in density) can cause different colourings and rates of corrosion to occur around the impact. This may, for example, help in differentiating the character of indentations, especially those affected by repair or corrosion. The impact causing an indentation affects the material differently than a casting flaw leading to a different coloration of the patina. This can sometime be observed as a kind of corona around the previously damaged part (Horn, 2013; Horn and Holstein, 2017). This should ideally coincide with other indicators. For example, an indentation would, if observable, have a more or less flat bottom while a casting flaw like a sinkhole would extend convexly towards the body of the weapon. Thus, it may be possible to observe damage through the discoloration of patina.

Attention was also paid to *striations, hammer marks, material reduction*, and *asymmetries* as possible indicators of *repair*. Repair results from the curation of weapons, performed to keep them in a usable state. Therefore, while repairs are an indicator for the use of an object, they also obscure the specifics of the damage which had originally been there. However, re-damaging of repaired sections opens a window to a new dimension in which it is possible to investigate the complexity of object biographies (Molloy, 2011, 2018). It is a window into ongoing use, as is, for example, the stratigraphy of a pit that has been filled and re-cut repeatedly (Horn, 2013).

Material

Wear analysis was conducted on a sample of 100 bladed objects (Table 1). The sample contained

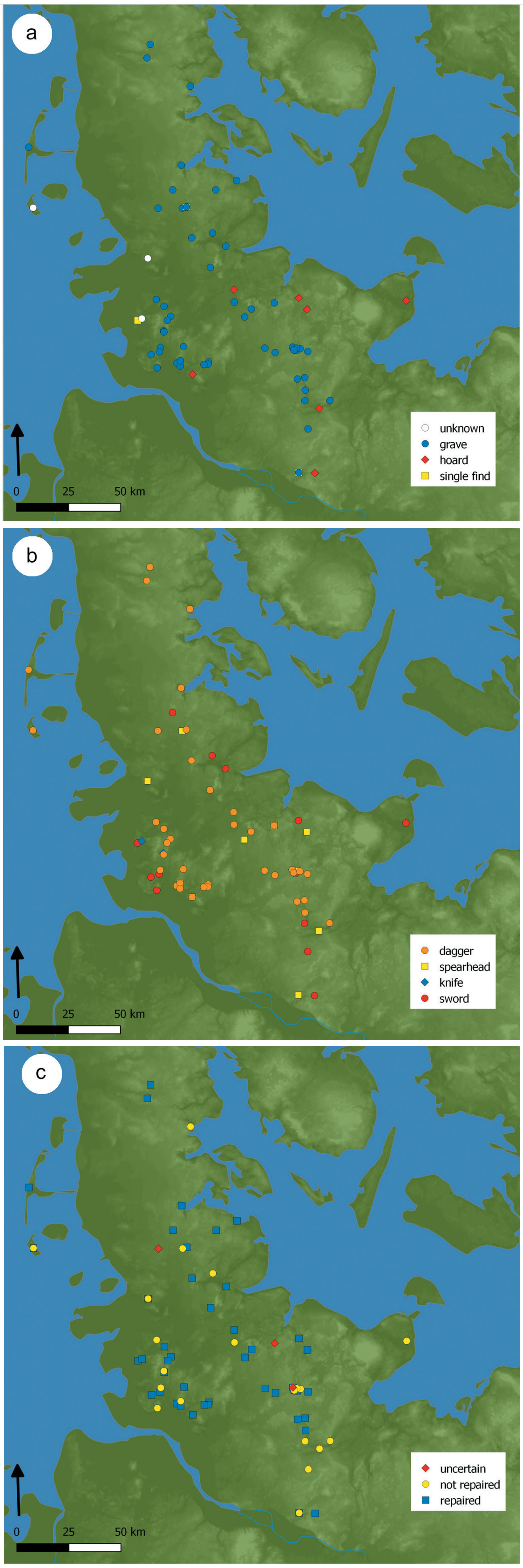

Figure 2. Distribution of analysed artefacts:
a. Context;
b. Object category;
c. Repaired vs. not repaired.

swords (23) and spearheads (18) which are traditionally seen as weapons, although spears could also have been used for hunting or fishing. The daggers analysed (49) are traditionally seen as being multifunctional objects. Additionally, ten Bronze Age knives were studied as a sample of objects commonly identified as being a 'tool'.

Of importance for this discussion, one earlier study concentrated on the wear of weaponry dating to period I of the Nordic Bronze Age (Horn, 2013, 2014a) and another focused on Late Neolithic copper-alloy halberds (Horn, 2017). The material for this study is more varied, mainly deriving from later periods to enable us to compare and to expand the relevance of the results of previous studies. However, the geographic focus is narrower as all objects analysed were discovered in the region of Schleswig-Holstein in the north of Germany (Figure 2). Of the swords, six belong to period II (1500-1300 BC), eight to period III (1300-1100 BC), five date either to period II or to period III. Six belong to the Late Bronze Age in period IV (1100-900 BC) or V (900-700 BC). Eight daggers may be dated to period I, thirty-one to period II, and seven to period III. One dagger comes from a context at the transition of period I to II and another cannot be assigned to any specific period within the Early Bronze Age. Of the spearheads, nine belong to period II, only two to period III and five to the Late Bronze Age. Two additional spears from period I were analysed. Apart from one knife dating to the Late Bronze Age, the remaining nine were discovered in period III contexts. If the material is broken up by object type and chronology, the numbers become very low which makes the interpretation tentative. Full metal hilts were present on twelve daggers and on one sword. These numbers are too small to justify further detailed discussion. Given the structure of the sample, the focus will be on the different categories of artefacts: knives, swords, daggers, and spears.

For source criticism, the different contexts of discovery for the material will be outlined (Horn and Holstein, 2017). Most finds were discovered in graves and the number of single finds is negligible (Figure 3a). Spears are almost equal in proportions from hoards and graves (Figure 3a). Swords were deposited more often in graves, however, seven were discovered in hoards (Figure 3a). Only two daggers come from hoards while forty-two are finds from

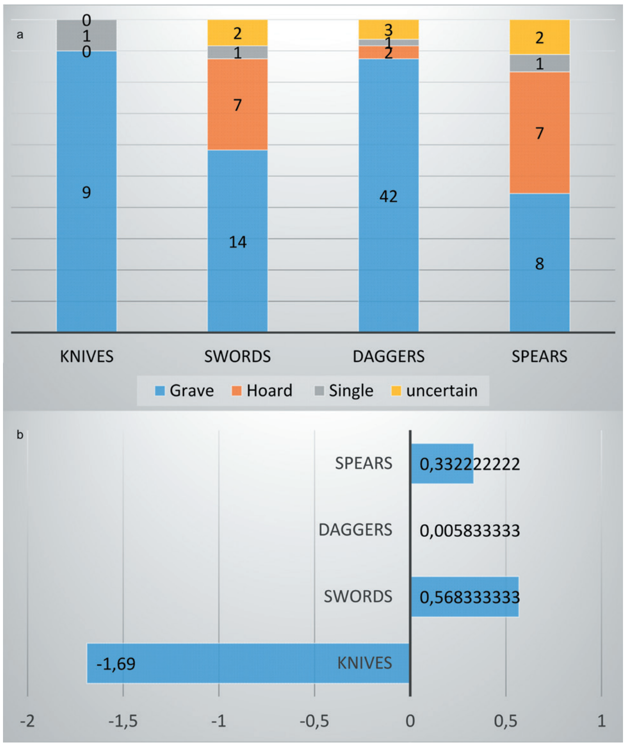

Figure 3. a. Relative quantities of the contexts of the object categories;
b. Deviation of the object categories from the damage average.

mortuary contexts better (Figure 3a). This is significant, because burial finds are more often affected by heavy, dissolving corrosion which affects the visibility of wear marks negatively (Horn and Holstein, 2017; Sáez and Lerma, 2015). Therefore, wear marks may be underrepresented in the sample.

Analysis I – Damage

It was possible to document 292 direct indicators of use and 114 potential traces of repair (Table 1). That means overall, that the average of direct evidence for wear was 2.89 per object. Swords (3.46) and spears (3.22) deviate in the positive from this average (+0.57 and +0.33) meaning they have over three indicators of use on average (Figure 3b). Conversely, knives deviate in the negative with only 1.2 wear marks on average (-1.69). Daggers represent the average well. The average for repair traces is 1.13 per object. Here the deviation per object gives a different impression. Knives, swords, and spearheads deviate in the negative with 0.8 to 0.94 repair traces on average. Only daggers diverge in the positive with an average of 1.4 traces (Figure3b).

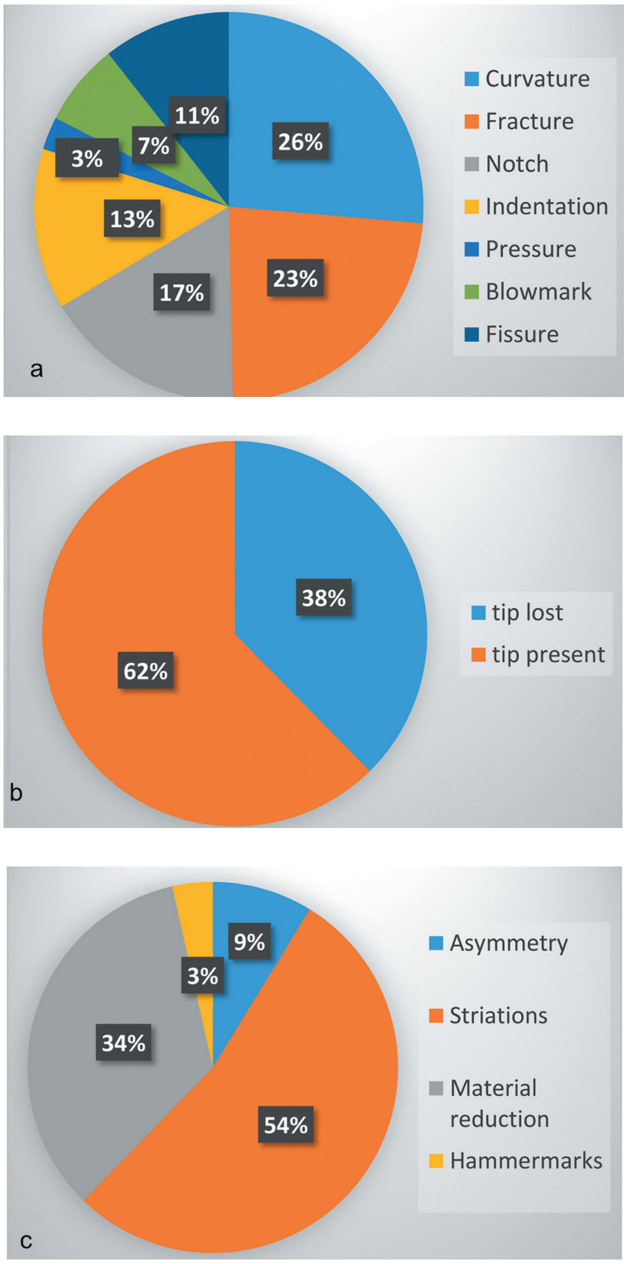

Figure 4. a. relative share of damage categories in the sample; b. Lost tips compared to preserved tips; c. relative share of repair trace categories in the sample;

Curvatures of various degrees represent most wear with 26 % (77; Figure 4a). Together with fractures (23 %, 68) curvatures account for ca. half of the observed indicators of use. Notches are the third most frequent damage with 17 % (49) followed by indentations (13 %, 39) and cracks (11 %, 31). Blow marks only account for 7 % (20) of the visible damage. Pressured tips were observed in only nine cases (3 %, 9).

It seems that pressured tips only rarely occur. However, Horn has argued that this observation may be misleading, since fractures often disturb tips, and the loss of tips makes any investigation impossi-

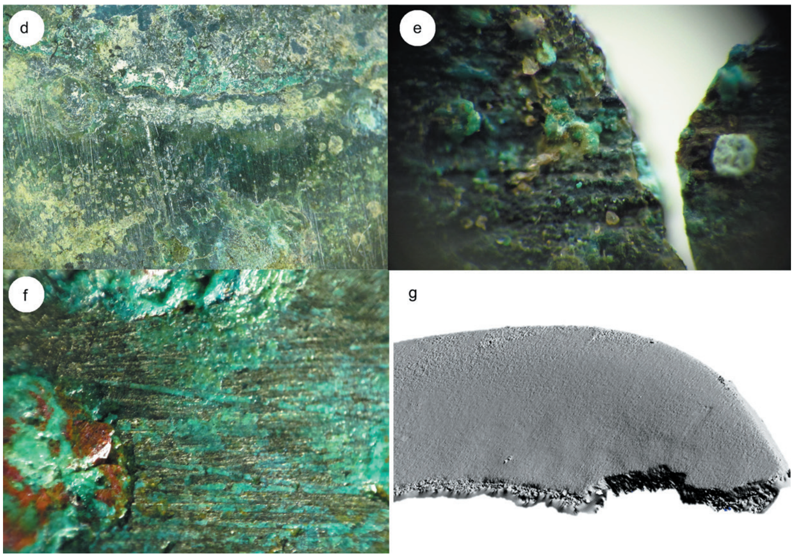

Figure 4. d. striations stopping in front of a discoloration that indicates the area covered by the hilt of a sword (x60, LMSH KS8020a);
e. grinding striations under patina, disrupted by a fracture (x300, LMSH KSB26a);
f. grinding striations partially covered by patina (x150, LMSH KSB150m);
g. hammer marks visible on a 3D model produced from x60 images (LMSH KS11440b).

ble (Figure 1h) (Horn, 2013). Tips are lost in over one third (38 %) of the analysed cases (Figure 4b). Therefore, the number of pressured tips could be much higher. While other damage indicators can occur more than once on a single object because they can be located on a different section of the cutting edge, pressure can only occur in two places. Swords and daggers with a hafting plate offer the opportunity for the occurrence of pressure not only on the tip, but also on the edge of the hafting plate. However, the force that creates pressure must be so strong that it travels through the entire object to push the hafting plate hard enough into the handle to compress the metal. Yet, forces diminish as they travel through the metal. Additionally, the hafting plate is pushed into the softer wood which serves to cushion the blow. This gives rise to forces that may be strong enough to lead to pressured tips but be too weak to travel through the object and damage the hafting plates.

Indicators of repair are often varied and overlaying striation patterns that occur on different parts of the object (Figure 4d-f). They account for over half of the traces (54 %, 61; Figure 4c). This is followed by the material reduction in thickness, width, and length on a third of the objects (34 %, 39). Asymmetries on objects that may be caused by repair processes are a specific form of material reduction. A separate category was created based on the difference in form. Asymmetries were observed on 9 % (10) of the objects. The least frequent were unambiguous hammer marks (3 %, 4). The problem here is that hammer marks are often subtle. The reasons for this could be careful and minimal cold working that does not risk damaging the blade. Alternatively, hammering could be smoothed over by grinding or polishing. Another problem might be that hammer marks, although faint, cover larger areas. This means a microscope is needed to recognise hammer marks, but the hammer marks are too large to fit in the frame making their observation difficult. The hammer marks on a knife from Bornhöved (LMSH KS 11440b) were discovered only later when a 3D model was reconstructed from photos taken with 60-times magnification allowing the observation of a larger surface at a microscopic scale (Figure 4g).

Analysis II – Objects

If the focus is shifted to the damage and repair categories on the individual object types (Figure 5a-b), it turns out that spears exhibit the most frequent instances of direct impact damage, i.e. notches, indentations, blow marks, and pressured tips. This accounts for over 50 % of the damage documented on all spears and on swords combined. A slight difference exists between rates of damage seen on swords and spears. Spears are more likely to have pressured tips and blow marks, while swords have higher instances of notches. Spears were more frequently affected by curvatures. Curvatures also outweigh cracks and fractures on swords, but when combined, the latter are more frequent.

Damage patterns of knives are different to swords and spears (Figure 5a). Curvatures, fractures, and cracks outweigh other damage. In fact, indentations, pressure on tips, and blow marks are absent.

Although notches were observed in only three cases, the relative proportions make them almost as important on knives as they are on swords.

In the overall damage distribution, daggers represent a mixed artefact category between knives on one side and spears and swords on the other (Figure 5a). Notches, indentations, blow marks, and pressured tips are present, but compared to other damage these categories occur less often than on spears and swords. Curvatures, fractures, and cracks are much more frequent which resembles the pattern found for knives. The relative distribution of these categories, however, is different.

Comparing only the relative proportions of curvatures, fractures, and cracks, it turns out that daggers are much closer to swords (Figure 5b). Fractures and cracks occur more often than curvatures, with fractures being slightly more frequent on daggers (Figure 5b). Knives and spears both have curvatures as their most frequent category of damage in this comparison (Figure 5b). Looking at the relative proportions of notches, indentations, pressure on tips and blow marks, knives are the outlier (Figure 5a). Compared to the knives, the other artefact categories are much more similar. Spears, however, deviate to a small degree, as pressured tips and indentations are more pronounced (Figure 5a).

The traces of repair processes on daggers and spears are more similar than the damage patterns. For both object categories, asymmetries occur more or less pronounced (Figure 5c). No hammer marks could be recognised on spears and only on one dagger (Figure 5c). Conversely, on knives and swords hammer marks occur in several cases. Strong asymmetries could not be observed on swords. Knives are produced asymmetrically, which prevents assessment.

Summarising the traces of use (damage and repair) on tips, swords and spears appear to be rather similar again with 62 % (15) and 61 % (11) of the tips affected by damage and/or repair (Figure 5d). Only 40 % (19) of daggers possessed tips with evidence of use (Figure 5d). This category of damage could not be observed on knives at all.

Figure 5. a. Impact damage amounts per object category; b. Plastic deformation amounts per object category; c. Repair indicators per object category; d. Contexts per object category.

Analysis III – Through time

The following analysis is very fragmented and the sample size for each category can be small. Therefore, the remarks will be kept short due to their tentative nature. Knives were excluded because all except one dated to period III of the Nordic Bronze Age. The Early Bronze Age finds are in 80 % of cases retrieved from burials, therefore, the patterns described in the following cannot be attributed to a difference in depositional patterns. The Late Bronze Age finds have primarily been discovered in hoards (58 %). It is of course possible that the patterns described in the following are a result of different deposition practices, i.e. there could be contexts in which largely unused objects were deposited. However, this seems in this case unlikely to be a general rule since wear can be observed on objects from all contexts.

Changes in the damage pattern for daggers occur from period I to period III. The most obvious is that the relative amount of curvatures increases. This is perhaps related to the decrease in fractures and fissures (Figure 6a). This goes along with an increase in edge related damage, i.e. notches and indentations with a simultaneous decrease in instances of tip damage (Figure 6b). Another interesting observation is that unambiguous material reductions

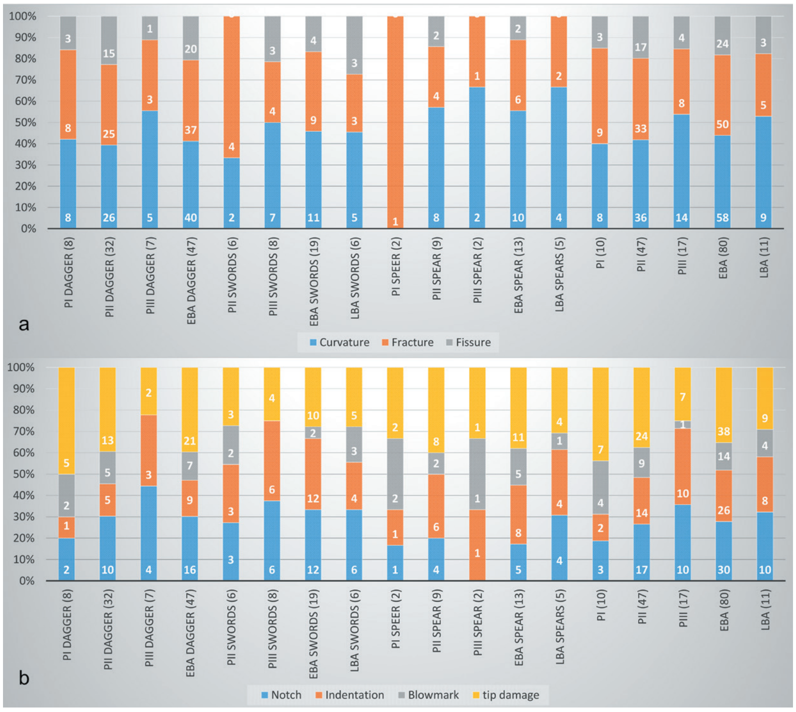

Figure 6. a. distribution of amounts of plastic deformation chronologically sorted; b. impact and tip damage chronologically sorted.

are more common on later daggers than earlier ones. Throughout the Early Bronze Age hammer marks may become more prevalent (Figure 7a). When we compare instances of damage traces and repair traces, the latter become more pronounced in their size or extent over time (Figure 7b).

Swords exhibit curvatures in period III more often than in period II. This coincides with a strong decrease in fractures (Figure 6a). Spearheads show an increase in curvatures, but only two spearheads dating to period III have been analysed. Compared to daggers, notches increase. This relative increase could be misleading because it is caused by the absence of blow marks (Figure 6b). Indentations are more frequent in period III. The relative amount of striations remains stable on swords from period II to period III. Hammer marks only occur in period III (Figure 7a). Swords and daggers display a relative increase in repair traces (Figure 7b).

Comparing Early Bronze Age swords and spears to Late Bronze Age specimens shows several differences. In terms of damage, the categories for swords remain relatively even. However, the sample from period III shows that the relative quantity of curvatures is lower again (Figure 6a). The Late Bronze Age swords have a more even distribution of notches, indentations, and blow marks (Figure 6b). Notches and indentations increase on Late Bronze Age spears (Figure 6b) and so do curvatures when plastic deformations are compared (Figure 6a), but blow marks and tip damage rates decrease (Figure 6b). On Late Bronze Age swords, traces of repair are more frequent than on their Early Bronze Age counterparts (Figure 7b). This trend is reversed on spearheads where they show a faint increase. During the Late Bronze Age, striations occur somewhat more often compared to material reductions on both weapon forms. Horn and von Holstein (2017) point out that use wear is better preserved overall on objects from hoards. The raised amounts of observable use wear during the Late Bronze Age could, therefore, be a result of the higher amount of finds from hoards.

Discussion - Comparison with published material

In the following, the data will be discussed including the published results of wear analyses on Nordic Late Neolithic and Bronze Age metalwork (Horn, 2013, 2017). For this discussion, cracks were merged with fractures as they were not separated in the older publications. The separation between swords and daggers dating to the Nordic Bronze Age is another problem. Despite few longer specimens, for example, in Torupgårde, Denmark, early blades of the Sögel-Wholde complex and the Apa-derived blades can be very short, more akin to daggers. In the older publications, these were termed swords because

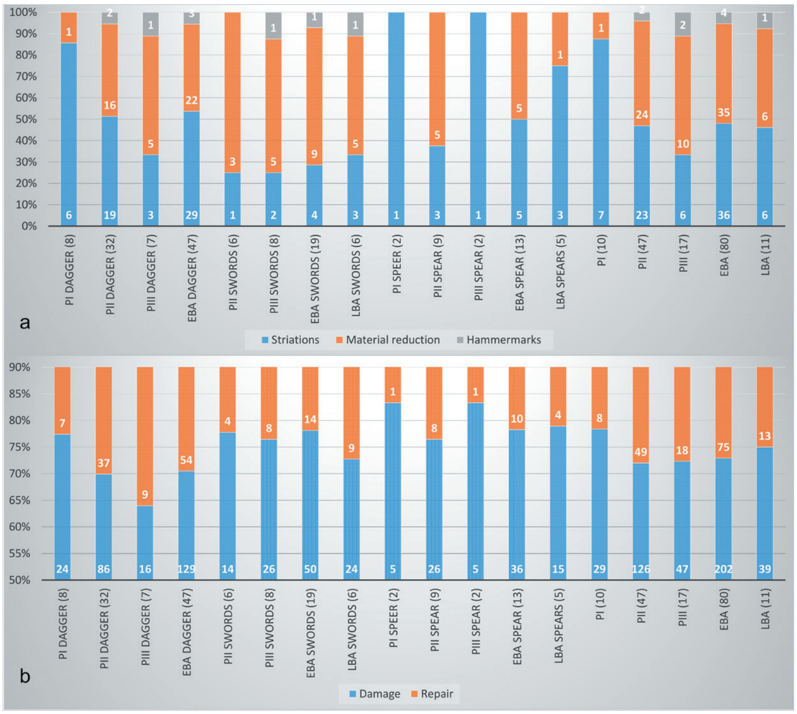

Figure 7. a. repair indicators chronologically sorted;
b. comparison of damage versus repair indicators chronologically sorted.

the sample only contained period I material. Judging by the relative size of contemporary blades they fulfilled the role of swords. To complicate matters even more swords can be shortened to dagger-length through use and repair (Horn, 2013; Kristiansen, 1984, 2002). In this work, we will include period I blades into the category daggers, but also compare them to the swords. The published sample included 156 spears and 50 daggers (swords) dating to period I or the Nordic Bronze Age and 15 halberds dating to the Late Neolithic. This material was discovered in Northern Germany, Denmark, Sweden, and Norway (Horn, 2013, 2017).

From the Late Neolithic halberds to period II daggers and swords, curvatures decrease relative to fractures, which means that later weapons fractured more frequently. Curvatures again increase in period III. However, they do not eclipse the sum of curvatures on halberds (Figure 8a). This is likely the result of higher impacting forces through the longer lever arm. This may have been counteracted by producing them with stronger mid-ribs than period I and II daggers and swords (Horn, 2014b; Liversage and Liversage, 1989; Vandkilde, 1996). This, and perhaps differences in fighting style, made fractures perhaps less likely. Therefore, the different morphology of these weapons could explain the different damage patterns. However, period III daggers do not have thicker cross-sections than period II specimens, yet curvatures increase. Therefore, the observed changes could be related to a significant change in use. Spearheads of period I and II have high levels of curvature like halberds (Figure 8a). Given the narrow cutting edges and the strong sockets reinforced by being a composite construction of bronze with a wooden shaft, high impact forces were necessary to fracture these weapons. This means that stress caused by impacts is more likely to be relieved in curvatures. Throughout the Bronze Age, spears were constructed with increasing sturdiness (Jacob-Friesen, 1967) which may explain the increase in instances of curvatures during the Late Bronze Age. Curvatures on swords and daggers decrease in frequency in the transition from period I to period II, while the patterns observed on spears remains more stable.

Notches, indentations, and blow marks below the tip section are testimony to the use of cutting or slashing actions in combat because such actions expose these sections of the blade to potential damage. Conversely, stabbing and thrusting exposes the tip because it hits resistance first. To bring the differences between cutting/slashing and stabbing/thrusting into sharper focus, notches, indentations, and blow marks below the tip and tip damage have been summarised. Each weapon may occur more than once in the statistic because a single weapon can obtain both edge and tip damage.

Dagger use may be mostly unchanged from period I to II with a slight increase in evidence for stabbing/thrusting. A significant change occurs during

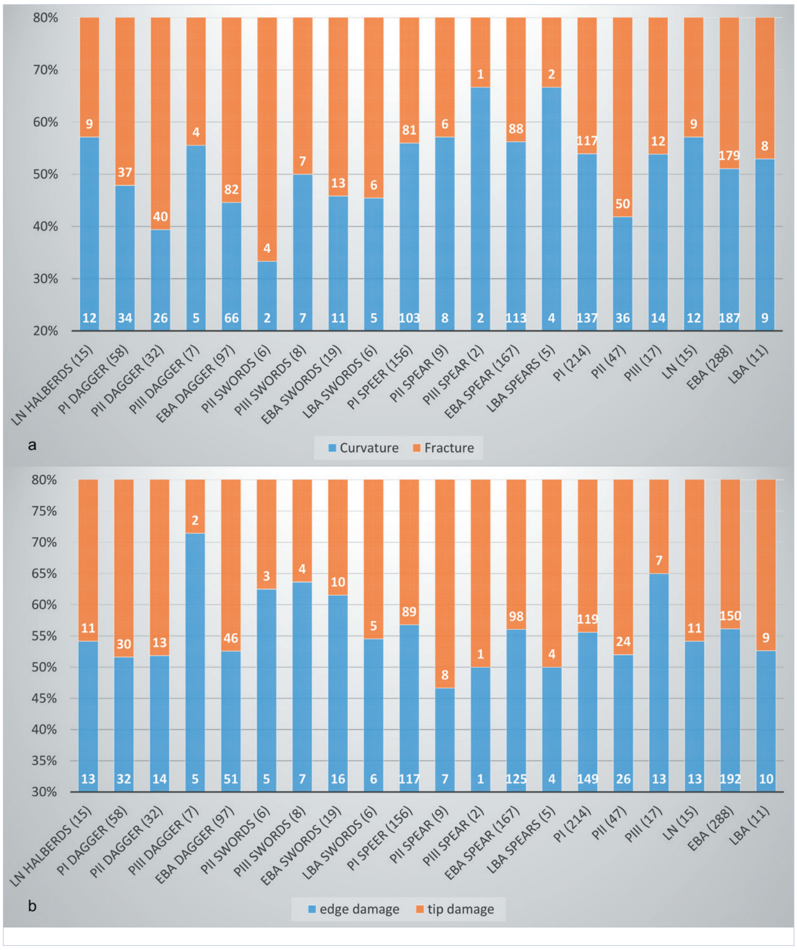

Figure 8. a. Plastic deformation comparison with published samples;
b. edge and tip damage comparison with published samples.

period III with a shift to cutting/slashing. The traces begin to resemble the damage pattern seen for knives (Figure 8b). The data for spears experiences a significant shift from period I to period II, in that rates of damage to the tip increases (Figure 8b). Late Bronze Age spears show a similar trend when compared with the Early Bronze Age specimen. The data for period I swords (here re-classified as daggers) shows a significant shift when compared to period II swords. Conversely for spearheads, documented instances of edge damage becomes more pronounced (Figure 8b). During the Late Bronze Age rates of edge and tip damage seem to be on the same level again (Figure 8b).

Interpretation

Based on a comparison of the quantities of copper objects and the degradation of swords through use, various authors have argued that period II is the phase of the most significant influx of metal into the Nordic sphere (Earle et al., 2015; Kristiansen, 1979; Ling et al., 2013; Ling et al., 2014). This is congruent with an increase in the dimensions of swords and spears (Aner and Kersten, 1973-2014; Kristiansen, 1984, 2002; Oldeberg, 1974, 1976) which confirms a better availability of copper and tin. One effect is that swords and daggers become more distinct in form. The increase in thickness especially makes the objects sturdier, so that they are less likely to fracture. Therefore, the increase in curvatures from period I to period II could be based on technological change facilitated by a better availability of raw copper and tin which may have worked in concert with other changing factors like the display of status and prestige.

Regardless of the maximum thickness and other dimensions, the cutting edges are always thin to allow for effective cutting. In the same sense, tips are often the part of the weapon that is most prone to damage because they are narrow and thin. This means that cutting edges and tips can theoretically withstand a similar amount of damage independent of the overall dimensions of the object. Therefore, the relative distribution of damage on cutting edges, including blow marks, and tips is more likely to inform us about the use of bladed objects than curvatures and fractures. This means that we can use the data on edge and tip wear presented above to interpret the functionality and the changes in use patterns for different categories of objects (Dolfini and Crellin, 2016; Horn, 2013, 2014a).

Edge and tip wear are about even on halberds in the Nordic sphere. Therefore, they could be interpreted as an all-purpose weapon used for slashing and for stabbing and thrusting. Local, temporal, and morphological differences exist on European halberds indicating differences in the frequency and the specific modes of use. However, overall, halberds appear to be a well-rounded weapon form suited for use combining several different attacks and defences throughout Europe (Brandherm, 2011; Dolfini, 2011; Horn, 2013, 2014a, 2017; O'Flaherty et al., 2008).

Period I spears and daggers/swords in the Nordic sphere continue this trend. The detailed study of their wear showed no significant deviation in their pattern. This result was used to argue that period I daggers/swords and spears were used in a similar all-around style including thrusting, cutting, and slashing motions (Horn, 2014a). Contrary to notions put forward in older literature (Fontijn, 2005; Harding, 2007; Mercer, 2006; Tarot, 2000), these results show that early weaponry was efficient in combat, and that spears were not only used as a throwing weapon or that swords were only for thrusting. Molloy (most recently 2017) argued the same point for the Irish swords and spears. Considering the earlier results, diverging edge and tip wear patterns of swords and spears dating to period II may indicate a shift to more specialized combat roles. The increase in tip damage on period II spears may indicate that they were more frequently thrusted or thrown. However, edge damage is still present and could point to a continued use of spears for slashing or blocking motions in combat (see also Anderson, 2011). This means spears were still not thrown, but became a specialized thrusting and stabbing weapon.

Conversely, the higher quantity of edge damage on swords may point to more frequent slashing and cutting in combat in period II. If the small sample can be trusted, the trend of using spears more often for thrusting movements in combat continues during the Late Bronze Age while sword use was more balanced again. The diverging use of swords and spears during period II could be caused by changes in weapon design, but could also promote such changes. Such a development may have been the increase in sword length.

As also observed in the Irish material, for example, the size range of spearheads widens around 1500 BC (Molloy, 2017) although in Scandinavia this may happen somewhat earlier during the 16th century BC (Vandkilde, 1996). While there is some deviation in the use-wear between longer and shorter spears during period I that indicates some tendencies and preferences in the combat style depending of weapon form, it cannot be argued that a specialization or strong divergence took place (Horn, 2018). Since the edge wear rates seem to remain considerable throughout the Early Bronze Age, slashing may remain an important combat move using spears. Which means that, unlike the Irish spears, there seems to be no process in Scandinavia towards a fighting in more close ranks which culminates in the development of Hoplite warfare in Greece (Molloy, 2017; van Wees, 2004). This means that fighting stays more individualized at least until 1100 BC when the Early Nordic Bronze Age ends. This may be in line with the suggested contemporary social model of a decentralized power structure (Kristiansen, 2007).

In the following, we will suggest that the specialised roles of swords and spears in combat may have contributed to a shift in the use of daggers. The increase of edge damage by over 15% on period III daggers compared to the previous period could be interpreted analogously to swords. Daggers could have been used more often for cutting and slashing in combat. However, edge damage is likely cause through dynamic, high impact edge on edge action (Gentile and van Gijn, 2019). Considering the shortness of daggers this seems to involve a high risk of injury to the fighters themselves. Perhaps this means that the period III daggers do not exhibit combat damage. Bearing in mind the observation that the damage and repair pattern of daggers and knives start resembling each other, another interpretation may be put forward. The parallel use-wear patterns could indicate the possibility that daggers were less often used in combat altogether. Instead they may have become a tool without, or with a diminished role in combat. This is supported by the morphology of daggers dating to period III. These daggers do not have the thick mid-ribs of their predecessors (Oldeberg, 1974). This does not preclude a combat use per se but it will make these blades more prone to fractures and cracks if use for high velocity thrusting. Instead we see a rise in curvatures parallel to the levels of knives. These are caused by frontal forces leading pressure that is not high enough to exceed the strength of bronze and is subsequently not relieved in breakage but in deformation. That may mean that work using the tip was still carried out such as piercing something or cutting by pushing the tip downward. These are tasks that would also have been performed using knives which could be an explanation for the similarity in their damage pattern. Perhaps later daggers were not intended to be used for high stress tasks such as combat. A hypothesis could be that the specialisation tendencies of spears and swords for combat may have left the space for daggers to develop into tools with a greater emphasis on domestic functions. However, this should be tested in the future with a greater sample of knives to compare.

Overall, our results indicate that from the Late Neolithic through to period III of the Nordic Bronze Age, the use of bladed metal objects diversified their morphology from halberds to spears, swords, daggers and finally adding knives. A specialisation in use begins with the morphological shift, albeit with a delay. This process may have led to a decline in the importance of daggers as a major fighting implement. These changes are interlocking shifts that form a tight network in which changes in object design and use affect and influence each other even across object categories. Development and change seem to happen in increments and not through a sudden “revolution”.

The approach of analysing bladed objects of different forms and across longer time-spans was fruitful. It was possible to investigate trends in the use of weaponry in the Nordic sphere. Future studies analysing more bladed objects with a wider geographic and chronological extent should test and correct these observations and interpretations.

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Supplement

Table 1 (next page). Data overview (LMSH: Landesmuseum Schleswig-Holstein Schloss Gottorf; MUF B: Museum für Ur- und Frühgeschichte Berlin).

Inventory number	Museum	Context	Object	Period (Nordic Bronze Age)	Fissure (corrosion)	Fracture (corrosion)	Curvature	Fracture	Repair	Notch	Indentation	Pressure	Blow-mark	Fissure	Damage to blade tip	Decoration	Damage to hafting plate	Comments
1869	LMSH	grave	Full hilted dagger	II	x			x	x	x			x	x	x	x		Worn down sword
3783	LMSH	?grave	Full hilted dagger	II				x	x							x		
6027	LMSH	grave	Dagger	II			x	x	x	x				x	x			Inhumation
6958	LMSH	grave	Dagger	I			x	x	x	x			x	x	x	x		Inhumation
8742	LMSH	grave	Full hilted dagger	II			x	x	x				x			x		
8745	LMSH	grave	Dagger	I			x	x	x									Heavily corroded
11881	LMSH	grave	Dagger	I			x	x	x						x	x		Inhumation
12141	LMSH	?grave	Full hilted dagger	II			x	x							x			Strongly reconstructed, no cutting edge damage observable
12587	LMSH	grave	Dagger	I			x	x	x					x	x	x	x	Inhumation
13619	LMSH	?grave	Dagger	I			x	x	x						x	x		Casting error frontal third
14149	LMSH	grave	Dagger	II			x	x	x					x				Inhumation
16272	LMSH	single	Dagger	II			x	x	x	x				x	x		x	
10221a	LMSH	grave	Dagger	II			x	x	x	x	x			x			x	Sheath remains; inhumation
10454 a	LMSH	grave	Full hilted dagger	II			x	x	x		x				x	x		Casting error central part of the blade; inhumation
10803d	LMSH	grave	Dagger	I			x	x	x									Strong modern grinding; inhumation

Inventory number	Museum	Context	Object	Period (Nordic Bronze Age)	Fissure (corrosion)	Fracture (corrosion)	Curvature	Fracture	Repair	Notch	Indentation	Pressure	Blow-mark	Fissure	Damage to blade tip	Decoration	Damage to hafting plate	Comments
11405b	LMSH	grave	Dagger	I			x	x	x					x	x	x	x	Casting error on mid rib; inhumation
12008a	LMSH	grave	Full hilted dagger	II	x		x	x	x					x		x	x	Heavily corroded; inhumation
12058 III a	LMSH	grave	Dagger	II			x	x	x					x			x	Inhumation
12122b	LMSH	grave	Dagger	II			x	x										Inhumation
13707b	LMSH	grave	Full hilted dagger	II				x					x			x		Inhumation
14147y	LMSH	hoard	Dagger	II			x	x	x					x	x			
18214b	LMSH	grave	Full hilted dagger	II			x	x	x				x	x		x		Inhumation
19982e	LMSH	grave	Dagger	II			x	x	x						x	x		
5104b	LMSH	grave	Full hilted dagger	II			x	x	x		x			x		x		
6050a	LMSH	grave	Full hilted dagger	II	x		x	x	x						x	x		Inhumation
6240c	LMSH	grave	Dagger	II				x		x				x	x			Inhumation
8790.4a	LMSH	grave	Dagger	II			x	x	x					x				Inhumation
B 101.1	LMSH	grave	Dagger	II	x	x	x	x									x	Urn
B 120.2a	LMSH	grave	Dagger	II			x	x	x	x								Heavily corroded; inhumation
B 382.2	LMSH	grave	Dagger	II			x	x	x									Heavily corroded; inhumation
B163e	LMSH	grave	Dagger	EBA			x	x	x					x	x	x		Casting error on blade; inhumation
B166a	LMSH	grave	Full hilted dagger	II	x			x	x					x	x	x		Inhumation

Inventory number	Museum	Context	Object	Period (Nordic Bronze Age)	Fissure (corrosion)	Fracture (corrosion)	Curvature	Fracture	Repair	Notch	Indentation	Pressure	Blow-mark	Fissure	Damage to blade tip	Decoration	Damage to hafting plate	Comments
B171b	LMSH	grave	Dagger	I/II			x		x									Inhumation
B413	LMSH	grave	Full hilted dagger	II				x	x		x			x	x	x		Heavily corroded; inhumation
KS 11145_1 (k)	LMSH	hoard	Spear	II	x		x	x	x		x							
KS 11145_2 (l/e)	LMSH	hoard	Spear	II			x	x	x		x		x					
KS 11145i	LMSH	hoard	Spear	II			?		x	x	x				x	x		
KS 11186a	LMSH	?grave	Sword	EBA	x	x	x			x	x				x	x		
KS 11311	LMSH	grave	Sword	III	x	x	x			x	x					x	x	Sheath remains; heavily corroded
KS 11440a	LMSH	grave	Sword	III	x	x	x			x	x			x	x	x	x	
KS 11440b	LMSH	grave	Knife	III		x	x		x							x		Cremation
KS 11522	LMSH	grave	Spear	LBA	x	x	x	x	x							x		Urn
KS 11814a	LMSH	grave	Sword	II	x	x		x			x				x		x	Sheath and other organic remains
KS 11814c	LMSH	grave	Dagger	II	x	x	x	x							x			Heavily corroded
KS 1204	LMSH	single	Sword	II			x	x	x	x	x	x			x		x	Bog
KS 12288 c	LMSH	hoard	Sword	V	x		x	x	x	x	x			x	x		x	
KS 12288a	LMSH	hoard	Sword	V		x	x	x	x	x			x		x	x	x	Casting seam
KS 12288b	LMSH	hoard	Sword	V			x	x	x	x	x		x	x				Casting seam
KS 12292 g	LMSH	grave	Dagger	II	x	x	x	x	x	x	x				x			
KS 12307	LMSH	grave	Spear	III		x	x								x			Shaft remains
KS 13071a	LMSH	grave	Sword	III		x	x		x						x	x	x	
KS 13071e	LMSH	grave	Knife	III	x	x	x			x					x			
KS 13479	LMSH	grave	Dagger	III	x	x	x	x							x	x		
KS 14373	LMSH	single	Spear	LBA	x	x	x		x	x	x	x			x	x		
KS 19666b	LMSH	hoard	Sword	V	x	x	x	x		x	x		x	x	x	x		
KS 19982c	LMSH	grave	Spear	II		x	x		x	x	x			x	x	x		
KS 22297	LMSH	grave	Dagger	I		x	x	x	x	x	x		x				x	
KS 22913	LMSH	?grave	Sword	EBA							x							

Inventory number	Museum	Context	Object	Period (Nordic Bronze Age)	Fissure (corrosion)	Fracture (corrosion)	Curvature	Fracture	Repair	Notch	Indentation	Pressure	Blow-mark	Fissure	Damage to blade tip	Decoration	Damage to hafting plate	Comments
KS 2947	LMSH	hoard	Sword	V			x		x	x	x	x	x		x	x	x	Sinkhole frontal third; Casting seam hammered
KS 2948	LMSH	hoard	Sword	V			x		x	x	x			x	x		x	sinkholes
KS 3017	LMSH	grave	Spear	II			x						x		x	x		Wooden remains
KS 4983a	LMSH	grave	Dagger	III			x			x					x		x	Sheath remains
KS 4983c	LMSH	grave	Dagger	III		x	x		x	x							x	Organic remains
KS 5104	LMSH	grave	Spear	II	x	x	x	x		x	x					x		Shaft remains
KS 6240	LMSH	grave	Spear	II	x	x	x			x	x			x	x	x		
KS 6343_1	LMSH	hoard	Spear	II	x	x	x		x									
KS 6343_2	LMSH	hoard	Dagger	II		x	x	x	x	x			x					
KS 6414b	LMSH	grave	Spear	LBA			x		x	x	x				x	x		
KS 7367 a-f	LMSH	grave	Dagger	III	x	x	x	x	x	x	x			x				Organic remains
KS 8015f	LMSH	grave	Knife	III		x	x	x	x							x		
KS 8016a	LMSH	grave	Sword	III		x	x	x	x	x	x				x		x	
KS 8016c	LMSH	grave	Knife	III	x	x			x	x								
KS 8017a	LMSH	grave	Sword	III	x	x	x	x		x				x	x	x	x	Wooden remains
KS 8017f	LMSH	grave	Knife	III		x	x		x									
KS 8018a	LMSH	grave	Sword	III		x			x	x	x				x		x	Organic remains
KS 8018b	LMSH	grave	Knife	III		x			x	x								
KS 8019a	LMSH	grave	Sword	III	x	x	x	x	x	x	x			x	x		x	Wooden remains; heavily corroded
KS 8020a	LMSH	grave	Sword	EBA	x	x				x	x			x	x	x	x	
KS 8020d	LMSH	grave	Knife	III		x	x		x							x		
KS 8754b	LMSH	grave	Knife	V										x		x		Urn
KS 923	LMSH	hoard	Spear	LBA			x	x		x	x	x			x			Bog
KS 924	LMSH	unkown	Spear	II			x	x	x			x				x		
KS B 150 c	LMSH	grave	Dagger	II	x	x	x	x	x	x				x		x		
KS B 150 m	LMSH	grave	Dagger	II	x	x	x	x	x									

Inventory number	Museum	Context	Object	Period (Nordic Bronze Age)	Fissure (corrosion)	Fracture (corrosion)	Curvature	Fracture	Repair	Notch	Indentation	Pressure	Blowmark	Fissure	Damage to blade tip	Decoration	Damage to hafting plate	Comments
KS B 330	LMSH	grave	Spear	LBA			x		x	x	x	x	x		x			
KS B 559	LMSH	unkown	Spear	III		x	x	x	x		x	x	x		x			Organic remains
KS B26a	LMSH	grave	Dagger	III	x	x		x	x	x						x		Sheath remains
LA 46	LMSH	grave	Sword	II-III	x	x	x	x	x	x	x							Sheath remains
ll 2658	MUF B	grave	Sword	II				x	x	x								
ll 2660	MUF B	grave	Dagger	II		x	x			x		x					x	
ll 2697	MUF B	grave	Sword	II						x					x	x		
ll 9514	MUF B	single	Knife	III				x	x							x		
ll 9608	MUF B	grave	Sword	II				x								x		Heavily corroded
lm 1152	MUF B	hoard	Spear	I				x	x		x		x		x			
lm 1153	MUF B	hoard	Spear	I						x			x		x	x		
lm 1155	MUF B	hoard	Sword	EBA			x	x	x	x					x	x		
lm 2072a	MUF B	grave	Dagger	III				x	x		x							Cremation
lm 2159	MUF B	grave	Full hilted dagger	II			x	x	x		x		x			x		Heavily corroded
lm 2399	MUF B	grave	Dagger	III			x	x	x									Heavily corroded; urn
lm 2402b	MUF B	grave	Knife	III			x		x									Inhumation

The Ølby Woman: A Comprehensive Provenance Investigation of an Elite Nordic Bronze Age Oak-Coffin Burial

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ABSTRACT
The Early Nordic Bronze Age oak coffin burials include some of Europe's best preserved human remains. Although traditional typological examinations thereof have not always found clear foreign references, recent provenance investigations from Egtved and Skrydstrup suggest that the two women were of non-local provenance. In order to investigate potential mobility patterns and how these might or might not be related to the archaeological evidence at first sight, we conducted comprehensive multi-analytical investigations on the rich burial of the Ølby Woman, another key female oak coffin burial. Her grave included, *inter alia*, a large number of metal items, the remains of a corded skirt and a glass bead recently identified as of Egyptian origin. We conducted strontium isotope analyses of the dental tooth enamel of Ølby Womans's first, second and third molars to investigate her provenance and potential mobility through childhood. Furthermore, we conducted lead isotope and craft technical analyses of her belt plate and sword/dagger. Our results suggest that the Ølby Woman is of local provenance and that the belt plate and sword were manufactured in Scandinavia, while the raw materials for each item were imported from different places in Europe.

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KEYWORDS
Provenance; Mobility; Isotopes; Nordic Bronze Age; Ølby; Oak coffin

Introduction:

Often heralded as 'Europe's first Golden Age' (e.g. Demakopoulou et al. 1998, 5), the Bronze Age can best be characterized as a period of heightened and wide-ranging cultural transmission. Although scholars have confirmed various currents and trajectories for the movement of objects, materials and ideas in this dynamic period (Anthony 2007, Earle and Kristiansen 2010, Kristiansen and Suchowska-Ducke 2015, Kristiansen and Larsson 2005, Kristiansen 2017, Ling et al. 2014, Ling et al. 2012) and typologically demonstrated the presence of foreign-seeming personal objects (Jockenhövel and Kurbach 1994, Jockenhövel 1995, Jockenhövel 1991, Jockenhövel 1980, Wels-Weyrauch 1989b, Wels-Weyrauch 1989a, Treherne 1995), it is only fairly recently that strontium isotope analyses have been conducted on human remains from this period (e.g. Oelze et al. 2012, Frei et al. 2015a, Frei et al. 2017c, Knipper et al. 2017a, Bergerbrant et al. 2017, Cavazutti et al. 2019b, Price et al. 2017, Frei et al. 2019). In like fashion, in spite of the scholarly awareness of artefact mobility and the lack of prehistoric exploitation of Scandinavian metal sources (Ling et al. 2012), provenance studies on Danish bronzes are also relatively recent additions to the field, i.e. (Nørgaard et al. 2019, Melheim et al. 2018, Nørgaard, 2017b).

Strontium isotope analyses conducted thus far on southern Scandinavian human remains suggest a certain degree of mobility during the Nordic Bronze Age, (Bergerbrant et al. 2017, Frei et al. 2015a, Frei et al. 2017c, Frei et al. 2019). Furthermore, other recent studies in Germany and Italy (e.g. Knipper et al. 2017b, Cavazutti et al. 2019b, Cavazutti et al. 2019a) seem also to point to a rather high degree of mobility – more specifically, of female mobility – during the period as a whole. In order to investigate the provenance of the Ølby Woman who was interred with a glass bead of Egyptian provenance (Varberg et al. 2015, Kaul and Varberg 2017, Varberg et al. 2016) among other items, we conducted strontium isotope analyses of three of her molars. This mobility study was complemented with lead isotope analyses of the bronze belt plate and sword/dagger.

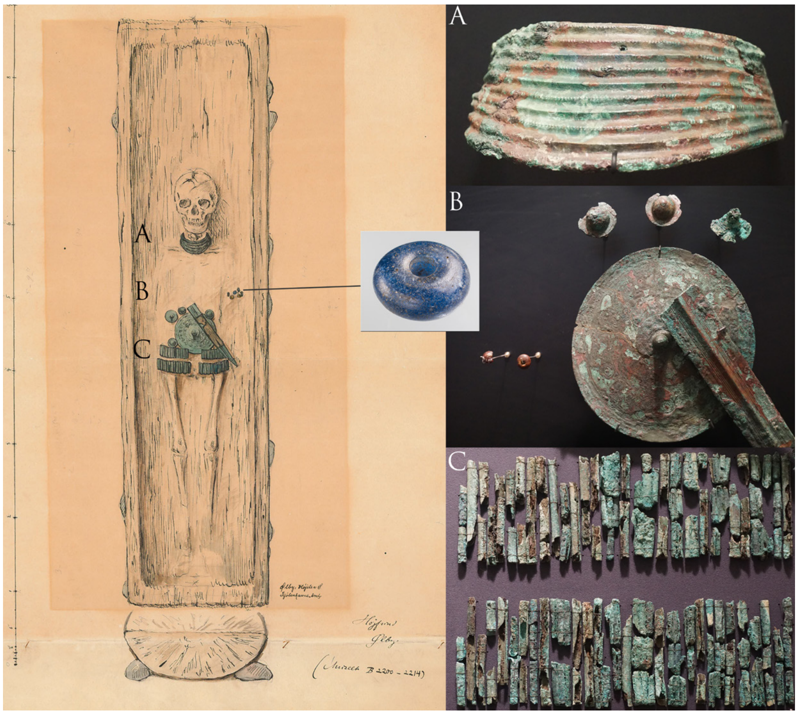
Figure 1. Ølby mound as it is at present (Photo by F. Kaul). Inset: Map of Denmark showing the location of the mound in which the Ølby Woman was buried (star). The mound is located south of Copenhagen near to the Bay of Køge (København Amt, Ramsø Herred, Højelse Sogn, Sb number 3). Montage by M.J. Walsh.

The Archaeological Context

Ølby is located on the island of Zealand south of Copenhagen near the town of Køge (Figure 1). The site consists of four burial mounds. The Ølby Woman was buried in the northernmost of the mounds (SB no. 3) (Boye 1896). The 'Nordhøj' (lit. 'North Mound') was excavated by the National Museum of Denmark by archaeologist Sophus Müller in 1880. Even today, the remains of Müller's excavations are still visible in the well-preserved prehistoric monument. Although the mound had been partially damaged by human activity and by a series of fox burrows, Müller was nonetheless able to ascertain the presence of a broken Iron Age cremation urn situated directly above the 250 × 63 cm coffin which predated it (Aner and Kersten 1973).

Placed on a NW-SE axis close to the centre of the mound, the Bronze Age oak coffin contained preserved human skeletal remains (See Figure 2). Müller (1880) remarked upon the good preservation of the skeleton's maxilla and mandible. Although other parts of the skeleton were recognizable, they were unfortunately not as well preserved as the maxilla and mandible, except where in contact with bronze objects (Boye 1896, Jensen 1998). The remnants of an animal hide as well as wool textiles (including the remains of finely woven cloth thought to represent a belt) were also discernible (Broholm and Hald 1939, 97). The Ølby Woman's grave goods include a series of small bronze spirals, a dark blue glass bead and two amber beads found in the area where the corpse's left arm is expected to have lain. Her midriff was graced with an ornate bronze belt plate decorated with two spiral rows. This was crossed by the broken off lower part of a small bronze sword (or dagger) in a wooden sheath (Aner and Kersten 1973, Boye 1896). The belt and the small sword/dagger were surrounded by four bronze tutuli. Additionally, the Ølby female had a bronze neck collar and 125 thin bronze tubes around the skeleton's pelvic girdle which offer mute testimony to the erstwhile presence of a corded skirt (Broholm, 1943, Bender Jørgensen, 1986). The contents of the grave (See Figure 2) allow for a date within Period II of the Nordic Bronze Age, a period corresponding to 1500-1300 BC (Jensen 2006, Montelius 1986, Vandkilde et al. 1996). More concretely, the Ølby burial has been suggested to date between 1400 and 1300 BC based on typology (Randsborg 2006).

Figure 2. At left, annotated watercolour of Ølby grave (V. Boye 1880; digital reconstruction by M.J. Walsh). At right, pictures of the A) neck collar, B) tutuli, belt plate, sword/dagger and amber beads and C) bronze tubes from corded skirt (photos by S.S. Reiter). Inset with arrow shows blue glass bead (photo by A. Mikkelsen, National Museum of Denmark). Montage by M.J. Walsh.



Material and Methods

Material

Although Müller (1880) remarked upon the preservation of the mandible and maxilla, the only physical remains of the Ølby Woman that were conserved after the 19th century excavation were her teeth. Today, these form part of the National Museum's human remains collection. Although little dentine remained (NM B2200-14), the enamel crowns from the first (maxillary left), second (mandibular right) and third (mandibular right) molars were well preserved, providing the opportunity to conduct multiple strontium isotope analyses. While dental enamel alone is not suitable for an age estimate, it was the only material available for study. The fact that Ølby Woman's third molars had fully erupted, and also show some signs of wear suggests that Ølby Woman was an adult at the time of her death (after Brothwell 1981, 72).

Ølby Woman's grave goods are curated by the National Museum of Denmark and are partially on display in the museum's Bronze Age permanent exhibition and partially in storage. Unfortunately, the metal accoutrements analysed here are in an advanced state of corrosion. As is visible on the majority of artefacts from other oak coffin burials, the metal items buried with Ølby Woman are covered by a thick greenish layer of what is very likely copper carbonate and copper chloride, indicative of deposition in a moist environment (Nørgaard 2017c, Oudbashi et al. 2013, Robbiola et al. 1998, Chase 1994). The corrosion makes craft technical analysis difficult and requires specific precautions for the provenance analyses (see below).

Strontium Isotope Analyses

Tooth enamel samples were pre-cleaned by removing the enamel's surface with a drill bit. Subsequently, a few milligrams of enamel were sampled from each tooth. The tooth enamel samples were dissolved in 7 ml Teflon beakers (Savillex™) in a 1:1 solution of 0.5 ml 6 N HCl (Seastar) and 0.5 ml 30 % H_2O_2 (Seastar). The samples typically dissolved within a few minutes, after which the solutions were dried on a hotplate at 80° C. Thereafter, the enamel samples were taken up in a few drops of 3N HNO_3 and then loaded onto disposable 1 ml pipette tip extraction columns into which we fitted a frit to retain a 0.2 ml stem volume of pre-cleaned mesh 50-100 SrSpec™ (Triskem) chromatographic resin. The elution recipe essentially followed that of Horwitz et al. (1992), albeit scaled to our needs (insofar as strontium was eluted/stripped by pure deionized water and then dried on a hotplate).

Thermal ionization mass spectrometry was used to determine the Sr isotope ratios. Samples were

Location 1: Skensved Å			
Sample No.	**Sample Type**	**$^{87}Sr/^{86}Sr$**	**(+/- 2SE)***
KF1532	Water	0.70911	0.00001
Location 2: Køge Å			
Sample No.	**Sample Type**	**$^{87}Sr/^{86}Sr$**	**(+/- 2SE)***
KF1538	Soil	0.70975	0.00001
KF1541	Plant	0.70912	0.00001
KF1534	Water	0.70879	0.00001
Location 3: Tranemose Bæk (A)			
Sample No.	**Sample Type**	**$^{87}Sr/^{86}Sr$**	**(+/- 2SE)***
KF1542	Plant (both plant samples from site A+B mixed)	0.70924	0.00001
KF1533	Water	0.71031	0.00001
Location 4: Tranemose Bæk (B)			
Sample No.	**Sample Type**	**$^{87}Sr/^{86}Sr$**	**(+/- 2SE)***
KF1535	Water	0.70871	0.00001

Table 1. Strontium isotope results of bioenvironmental samples from four locations in the area surrounding the Ølby burial mound *2SE = uncertainty of the mean at a 95 % confidence level.

dissolved in 2.5 µl of a Ta_2O_5-H_3PO_4-HF activator solution and directly loaded onto previously- outgassed 99.98 % purity single rhenium filaments. Samples were measured at 1250-1300° C in a dynamic multi-collection mode on a VG Sector 54 IT mass spectrometer equipped with eight Faraday detectors (Institute of Geosciences and Natural Resource Management, University of Copenhagen). Five nanogram loads of the NBS 987 Sr standard that we ran during the time of the project yielded $^{87}Sr/^{86}Sr = 0.710239 +/- 0.000011$ (n = 15, 2σ and results normalized to 0.710245).

In order to interpret the results obtained in this manner, it is important to have an understanding of the local bioavailable strontium isotope baseline range. However, there is as yet no consensus regarding which type of proxy (e.g., surface waters, plants, soils, fauna, etc.) is the most suitable for delineating the isotopic range of bioavailable strontium signatures of an area (Grimstead et al. 2017). For the area of Zealand (where the Ølby Woman was buried), several baselines have been established based on different types of environmental samples including surface waters, soil samples and faunal remains (Frei and Frei 2011, Frei and Frei 2013, Frei 2013, Frei and Price 2012, Price et al. 2011, Price et al. 2007). Furthermore, though more general, a recently published baseline study from almost 1200 soil samples taken throughout Europe adds yet another layer of data (Hoogewerff et al. 2019). All in all, these studies seem to indicate that the local bioavailable baseline of this region ranges between $^{87}Sr/^{86}Sr = 0.708$ to 0.711. In our present study, we complemented the existing data with seven additional environmental samples from plants, surface water and soils collected from the surroundings of the Ølby site. As the area of Køge is partially agriculturally cultivated, it was difficult to avoid samples from farmed areas entirely (See Table 1). However, we tried to avoid sampling within farmed areas as much as possible.

Metallurgical Analyses

The sampling and preparation of the metal artefacts for provenance analyses, namely the neck collar (NM B2200), belt plate (NM B2202) and sword/dagger blade (NM B2201) took place at the National Museum in Copenhagen. Sampling consisted of drilling a hole with a 1mm drill in the back side of the collar and the belt plate and in the broken edge of the sword/dagger blade. Corroded material within the drill shavings was carefully removed before sampling. The elements Cu, Mn, Fe, Co, Ni, Zn, As, Se, Ag, Cd, Sn, Sb, Te, Au, Pb and Bi were measured using energy-dispersive X-ray fluorescence (EDX-

RF) at the CEZA in Mannheim (Germany) using an Thermo Scientific ARL Quant X instrument with a 20-position sample changer. Two reference materials obtained from the *Bundesanstalt für Materialprüfung* in Berlin (BAM211 and BAM376) were included in each run. The detection limits are 0.05 % for Fe, around 0.01 % for Co, Ni, and As and around 0.005 for Ag, Sb, Sn, Au, Pb and Bi. Mn, Cd, Se and Te were also measured, but were below 0.005 % in all samples. Zn was below the detection limit of 0.1 % in all samples.

Common Pb lead-isotope analyses (^{208}Pb, ^{207}Pb, ^{206}Pb, ^{204}Pb) were performed at the same laboratory by multiple collector inductively coupled plasma mass spectrometry (MC–ICP–MS, Thermo Scientific Neptune Plus mass spectrometer). The chemical pre-treatment resulted in solutions with 100ng ml^{-1} of lead. The procedure was as follows: the samples were rinsed with dilute HNO_3 to remove surface contamination and were then dissolved in half-concentrated HNO_3 in an ultrasonic bath (70° C) for several hours. Insoluble residues were removed by decantation from the resulting solution, which was then diluted with deionised water (Niederschlag et al. 2003). Columns were prepared with PRE filter resin and Pb resin and were preconditioned with 500µl 3N HNO_3 before the solution was added. In four steps, the matrix was eluted using HNO_3, and the Pb was eluted using HCl. After drying (48 h), a volume of a 50 ppb thallium solution was added to the sample solution as a control solution. During analysis, standard measurements were interspersed between every four sample batches and intensive rinsing of the system was conducted after every sample. Recording of ^{203}Tl and ^{205}Tl (added to the sample solutions as an internal isotopic standard) allowed for the correction of an internal mass fractionation of the lead isotope ratios (Dunstan et al. 1980).

Results

Strontium Isotope Analyses

Strontium isotope analyses of the environmental samples yielded a range from ^{87}Sr/^{86}Sr = 0.70871 (surface water from Tranemose Bæk, location B) to ^{87}Sr/^{86}Sr = 0.71031 (surface water from Tranemose Bæk, location A) (Table 1), which fall within the baseline range from previous studies covering the area of Zealand (Frei and Frei 2011, Frei and Frei 2013, Frei 2013, Frei and Price 2012, Hoogewerff et al. 2019, Price et al. 2011, Price et al. 2007). The results of the strontium isotope analyses conducted on Ølby Woman's three molars ranged between ^{87}Sr/^{86}Sr 0.70998 to 0.71085 (Table 2). Mineralization of tooth enamel occurs within different times over the life course from childhood to early adolescence (i.e. the formation of the first molar's tooth enamel takes place *in utero* until ca. 3 years of age, the second molar between the ages of ca. 2-8 years and the third molar from ca. 7-16 years) (Montgomery 2010, Hillson 1996). Thus, it is possible to provide a temporal dimension to individual life stories of detectable geographic mobility. The results of the multi-molar sampling strategy of Ølby Woman's first, second and third molars suggest that the Ølby Woman was local to the island of Zealand. Furthermore, the isotopic differences exhibited by her tooth enamel – between the second and third molars – suggest the possibility of internal mobility within the region probably after the age of ca. 8 years, or during early adolescence.

Sample No.	Molar	^{87}Sr/^{86}Sr	(+/- 2SE)*
KF1872	M1	0.70998	0.00001
FK1873	M2	0.71002	0.00001
KF1874	M3	0.71085	0.00001

Table 2. Strontium isotope results of the human remains of the Ølby Woman (NM B2200-14). *2SE = uncertainty of the mean at a 95 % confidence level

However, as the mineralization period in the third molar represents an average of several years (ca. 8), it is difficult to elaborate further on the type of mobility in which the Ølby Woman might have engaged. It is also not possible to exclude mobility outside of this region. However, even though this female seems to have been local, some type of mobility seems to have been part of her life.

Metallurgical Analyses

The results of the metallurgical analyses of the samples taken from the three large bronze objects from the Ølby burial were surprisingly diverse. While all

Sample No.	Object	Museum No.	$^{208}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$ (+/- 2 SE)*	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$ (+/- 2 SE)*	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$ (+/- 2 SE)*
MA-180945	Sword/ dagger	B2201	2.08330	0.00001	0.84089	0.00001	18.6490	0.0001
MA-180946	Neck collar	B2200	2.09410	0.00001	0.85117	0.00001	18.4120	0.0001
MA-180947	Belt plate	B2202	2.12160	0.00001	0.86906	0.00002	18.0040	0.0001

Table 3. Lead isotope ratios of the artefacts from the Ølby burial. *2SE = uncertainty of the mean at a 95 % confidence level.

Sample No.	Object	Museum No.	Cu	Fe	Ni	As	Ag	Sn	Sb	Pb	Bi
			wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %
MA-180945	Sword/ dagger	B2201	88	0.07	0.57	0.403	0.008	10.2	0.117	0.011	< 0.000
MA-180946	Neck collar	B2200	92	< 0.01	0.67	0.511	0.010	6.9	0.154	0.087	< 0.001
MA-180947	Belt plate	B2202	88	0.20	0.91	0.468	0.022	10.1	0.166	0.091	0.006

Table 4. Element concentrations of the copper measured in the artefacts from the Ølby burial. Concentrations of elements Mn, Co, Zn, Se, Cd, Te and Au were below detection levels.

three artefacts were made of low-impurity copper with tin concentrations of 7-10 % (as Tables 3 and 4 indicate), which would be normal for the bronzes of this time, the differences in the trace element compositions (though minor) preclude that the artefacts were made from a single batch of raw material. The lead isotope ratios further highlight these differences (See Table 4 and Figure 3). Moreover, the results shown in Figure 3 indicate that the three artefacts were made of copper from different ore sources.

The belt plate (NM B 2202), isotopically characterized by values of 2.1216 for $^{208}Pb/^{206}Pb$, 0.86906 for $^{207}Pb/^{206}Pb$ and 18.004 for $^{206}Pb/^{204}Pb$, fits very well with the signatures of the Trentino region in the

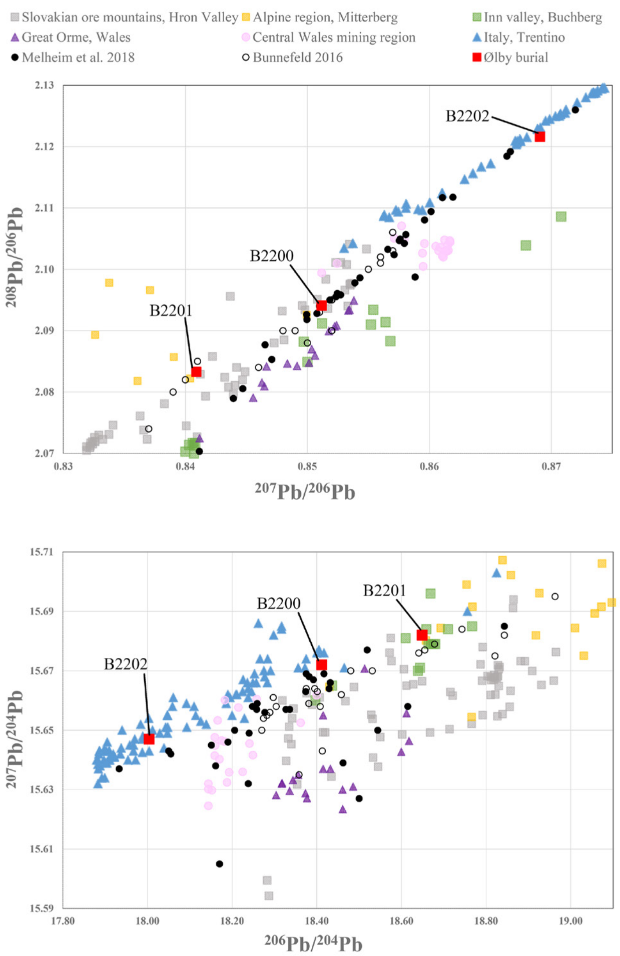
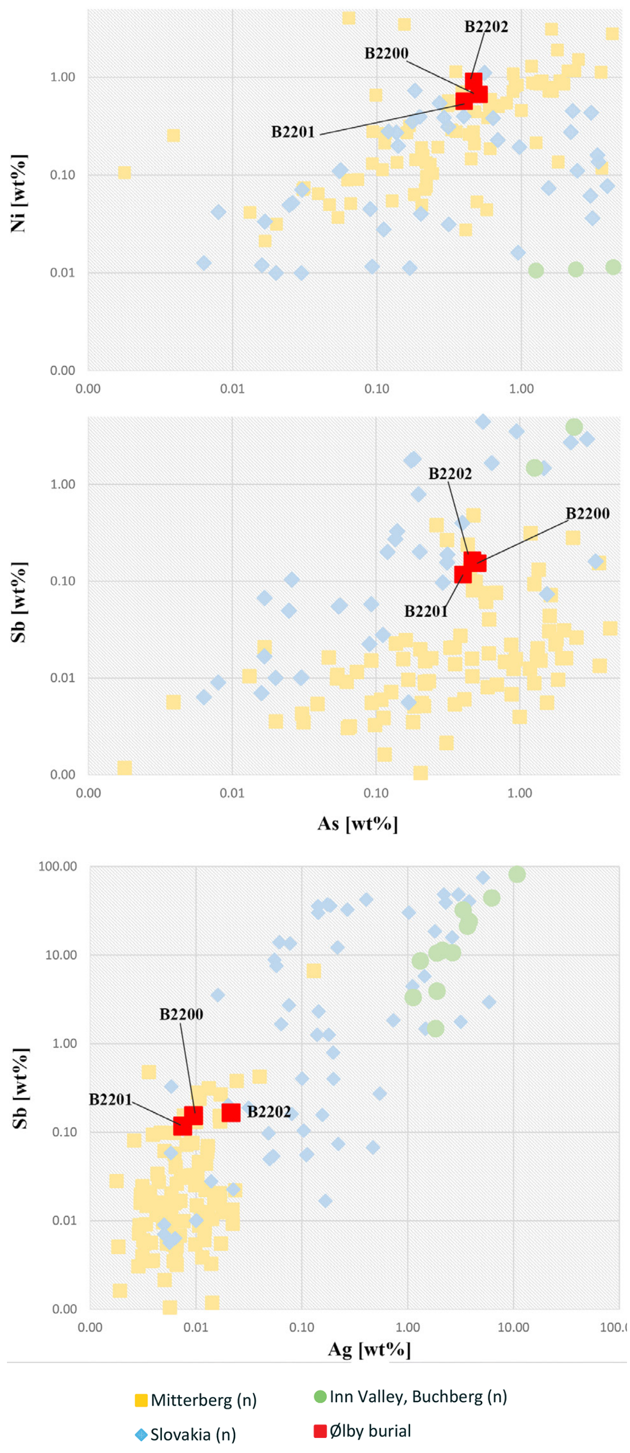


Figure 3. Lead isotope ratios of the artefacts from the Ølby burial compared with possible ore sources. Data from Mitterberg ore district (Pernicka et al. 2016), Hron Valley, Slovakia (Schreiner 2007, Modarressi-Tehrani et al. 2016), the Buchberg and the Inn Valley in the Alpine region (Schubert and Pernicka 2013), Great Orme and central Wales mining regions (Williams 2018, Williams 2014, Joel et al. 1997, Rohl and Needham 1998, Rohl 1996) and contemporary data (Melheim et al. 2018, Bunnefeld 2016). The analytical uncertainties are comparable with the size of the symbols.

Figure 4. Trace element concentrations of As–Ni, As–Sb and Ag– Sb of the artefacts from the Ølby burial compared to the relevant ore bodies in the Slovakian Ore Mountains and the eastern Alps. Ore values are normalized to copper and based on regional, interdisciplinary investigations of the specific mining regions (Höppner et al. 2005, Schubert and Pernicka 2013, Schreiner 2007, Modarressi-Tehrani et al. 2016, Pernicka et al. 2016).



eastern Italian Alps (Addis et al. 2016, Addis 2013, Nimis et al. 2012, Artioli et al. 2015). On the other hand, the lower value of 2.0833 for $^{208}Pb/^{206}Pb$ and the higher value of 18.649 for $^{206}Pb/^{204}Pb$ measured in the sword/dagger blade (NM B2201) indicate a closer match with Mitterberg ore sources (Pernicka et al. 2016). The neck collar (NM B2200), isotopically characterized by values of $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios of 0.85117 and 2.0941, respectively, seems to be compatible with leads from Slovakian ores (Schreiner 2007, Modarressi-Tehrani et al. 2016). Although these differences are not as clear-cut as those exhibited by the trace elements (Figure 4; excluding the Trentino region due to its lack of comparable trace element data), the trace element concentrations of silver (Ag) and antimony (Sb) lend further support to the idea that the objects were made from metals originating from different sources. At present, it seems, therefore, as though the three objects analysed herein were made from metals sourced from different areas.

Discussion

An overarching examination of the style and material goods associated with Ølby Woman would categorize her burial as being a wealthier version of an otherwise typical Nordic Bronze Age elite style female grave, like e.g. that of the Egtved Girl. Of these, what would be considered one of the most iconic elements is Ølby Woman's corded skirt (Bergerbrant 2014, Bergerbrant 2005, Skals and Mannering 2014, Bergerbrant et al. 2012, Nosch et al. 2013, Randsborg 2006, Randsborg 2011). However, this association might be due to the fact that the environmental conditions of Northern Europe are more favourable to the preservation of textiles on the whole than to any apparent regional preference for corded skirts (Broholm 1943, Broholm and Hald 1935). In fact, not only have corded skirts been found throughout Scandinavia (Bergerbrant 2007, Bergerbrant 2014, Randsborg 2011, Broholm and Hald 1935) but also in various other places in Europe (Fages 1986, Fagles 1990, Furmánek and Pieta 1985) as well as elsewhere (Wade 2010, Bian and Xin 2014, Sanz et al. 2014,).

The only remaining recognizable aspect of Ølby Woman's corded skirt is the bronze tubes that adorned the cords (Aner and Kersten 1973, Broholm 1943, Boye 1896, Randsborg 1973, Randsborg 2006, Randsborg 2011, Broholm and Hald

Figure 5. The spirals on the belt plate (B2202) were very likely made with a spiral-stamp in the wax model. The spirals of the inner and outermost row can be projected onto each other and make a perfect match with their centres and the width of the grooves at the distance between each turn. Importantly, these similarities hold for both of the two spiral rows (Photo: H.W. Nørgaard).

1935). Further examples of metal tubes are known from other grave contexts (e.g. Danish Hverrehus and Hagendrup and Swedish Åskarps Villans among others) (Broholm 1943, Aner and Kersten 1976, Oldeberg 1974) as well as from votive deposits, such as that at e.g. Vognserup Enge (Aner and Kersten 1976, Randsborg 2006, Rieck 1972, Frost 2011). Metal tubes have had a long history of use (Bergerbrant 2005). Cold-hammered copper tubes such as those recovered from 7th to 6th millennium BC contexts at Çatal Hüyük (Barber 1993) are thought to have served a similar function as their later Danish equivalents. Still other metal tubes have been found in the Carpathian Basin, Austria and Saxony (Bergerbrant 2005, Gimbutas 1982). Within Denmark, the tradition seems to have continued at least into the Late Bronze Age, as can be seen from the Period V grave at Bevtoft (southern Jutland), which included sheet metal tubes alongside a bracelet and horse gear (Broholm 1943).

The richness of Ølby Woman's metal accoutrements as a whole is also worthy of particular note, because of the sheer quantity of metal with which she was interred (although the presence of metal in the grave has been interpreted as a sign of increased social status) (Sprenger 1995, Randsborg 1974, Vandkilde 1996). In recent years, our knowledge of the metal supply of the Nordic Bronze Age has risen steadily (Nørgaard et al. 2019, Melheim et al. 2018, Bunnefeld 2016), especially between 1600-1100 BC. Likewise have opportunities to compare the analyses made from objects coming from that period also increased. The three possible sources for the raw material used for the metal artefacts of the Ølby burial, as suggested by our data, mirror the three main metal suppliers that have recently been recognized for Scandinavian artefacts during this period: the Slovakian mountains, the Trentino region in northern Italy and the Mitterberg mining area in Austria (Melheim et al. 2018; Bunnefeld 2016) (Figure 3). Although not evident in the material from Ølby, other metal objects from period II of the Nordic Bronze Age also show evidence of raw materials from an additional metal source from the Welsh mining region (Ling et al. 2019, Melheim et al. 2018).

Interestingly, the different metal sources within the Ølby material do not seem to be related to specific artefact categories. For example, at least five artefacts within the body of data used for comparison with the Ølby material indicate the crafter's use of metals from the Trentino mining region (See Figure 3). The artefacts produced therefrom include Ølby Woman's belt plate (NM B2202), a tutuli, sickle fragments and a tube (data from Melheim et al. 2018). Further, the swords analysed from period II (Bunnefeld 2016) show a wide lead isotope range matching both the ores from the Slovakian and the Mitterberg mining regions. We would suggest, therefore, that the motivation for using a specific metal from a specific source must have some other guiding principle than the requirements of the object being produced.

To this end, a craft technical investigation was conducted on the three artefacts from the Ølby burial in order to determine whether they might be allocated to a specific production workshop, and thereby shed more light on the choice of metals

Figure 6. The centre part of the sword blade (B2201) is very well preserved and displays four parallel running grooves along the centre ridge (Photo: H.W. Nørgaard).

utilized for each item. It is very likely that both the belt plate and the neck collar were made within the technological traditions of the Nordic Bronze Age (See Nørgaard 2011, Nørgaard 2018). Moreover, it can be shown that the belt plate´s decoration corresponds with the specific technological repertoire of the Danish Islands (See Nørgaard 2017a), as the spirals were made using a stamp-like tool impressed in what was probably a decorated wax-model of the belt plate (Figure 5). As such, the spirals from the neck collar (NM B2200) and the belt plate (NM B2202) might help to clarify a workshop affinity. The sword/dagger blade itself (Figure 6) unfortunately does not provide enough characteristic crafting traces to draw a clear conclusion. Previous studies documented the use of identical stamps and allowed for the identification of what one might call 'analytical' workshops (i.e. workshops with an unknown physical location) during period II in NBA (Nørgaard 2018). Each workshop seemed to use one or two specific stamp tools. However, due to advanced corrosion, the Ølby belt plate unfortunately does not allow for a one-to-one comparison of the spirals (i.e. one in which the spirals of the different artefacts are placed on top of each other in order to align characteristic tool traces, such as the shape of the centre of the spiral and the width of the grooves at the distance between every turn).

Therefore, we conducted direct comparison analyses with several contemporary artefacts instead. These yield some information about possible workshop affiliation. Firstly, it seems that the spirals on the neck collar and belt plate were made using different tools. Secondly, both were impressed in a wax model and were only slightly reworked post-casting, indicating a high level of skill in the craftsperson. Thirdly, the belt plate´s spirals display a very characteristic centre with rounded pointy ends; the space between the ends at the single groves is above average and the grooves themselves are narrow and very regular. Similar characteristics have been documented on the spirals from the belt plate from Rye (NM B7615), Frankerup (NM CMXIII) and Lavø, Zealand (NM 11686)(See Figure 7). The spirals on the neck collar, however, cannot be compared with the artefacts mentioned above, as they are much smaller (0.9 cm compared to 1.5 cm at Frankerup, Rye and Ølby Woman's own belt plate) and have a parallel running centre in which one part is distinctively straight (Figure 8). Documented tool traces (see arrows Figure 8) are similar to traces found on the belt plate from Vognserup (VM1680KD).

The preservation of the Ølby artefacts does not fully allow for an allocation of the artefacts to an analytical workshop as defined by Nørgaard (2018). However, when the detectable crafting traces were compared to artefacts it seems likely that they were made by different craft groups, i.e. workshops (See Nørgaard 2018).

Somewhat similar complex patterns for the import of raw materials with a local crafting affinity have been suggested previously by Frei et al. (2017a) regarding wool trade and production of textiles within the Nordic Bronze Age. Research on wool threads from textiles dating also to the Nordic Bronze Age and partially contemporaneous with that which must have been present at Ølby suggests that approximately 75 % of the wool analysed was spun

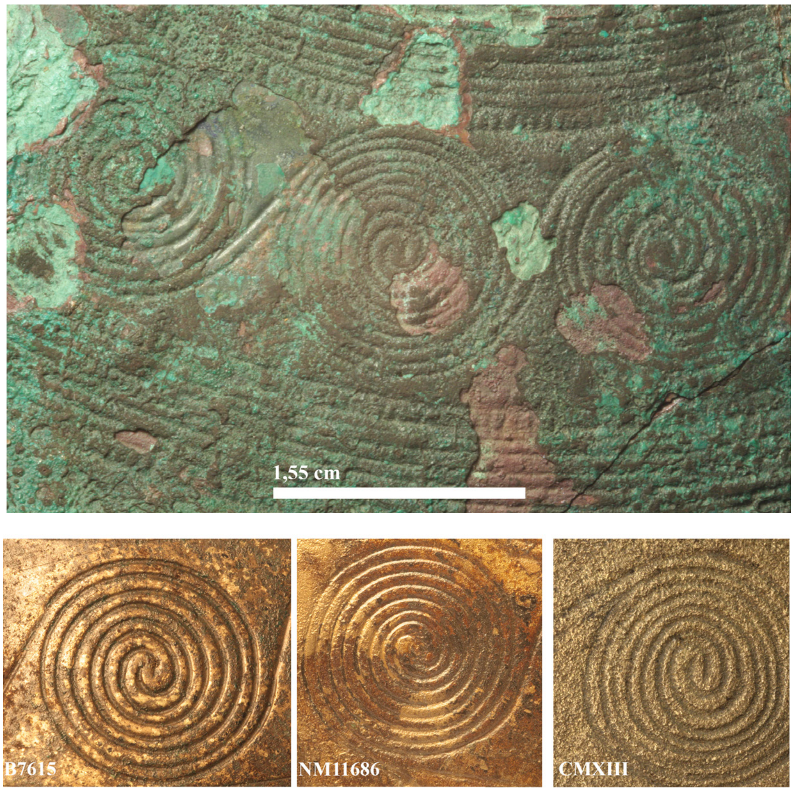


Figure 7. The spirals on the Ølby belt plate (B2202) are on average 1,5 cm wide and can be compared in their characteristics with the spirals on the belt plates from Rye (B7615), Lavø (NM 11686) and Frankerup (CMXIII) found on Zealand (Photos: H.W. Nørgaard).

from the wool of animals that had grazed outside of present day Denmark (excluding Bornholm). While this trend seems to drastically decrease to 25 % in the Early Iron Age (Frei et al. 2017a), it has been suggested that the marked technical similarities in the production of many of the preserved Nordic Bronze Age textiles would suggest 'local' (i.e. Nordic) weaving production (Strand et al. 2016). In this way, wool and bronze seem to point to similar patterns of trade and production insofar as raw materials were imported to Scandinavia for local crafting.

Other materials included as part of Ølby Woman's grave goods which merit further discussion are the amber and glass beads. Nordic amber is found locally in Denmark (especially in the west coast of Jutland) and around the Baltic Sea. It should also be noted that the shores along Køge Bugt (the Bay of Køge, not too distant from the Ølby burial) are considered 'amber beaches' (Faber et al. 2000). As a raw material, amber was traded across long distances during this period, even reaching the eastern Mediterranean and Syria (Bouzek 1993, de Navarro 1925, Czebreszuk 2009, Sprincz and Beck 1981, Krause 2003, Beck 2000, Mukherjee et al. 2008, Czebreszuk 2013), and seems to have had ties to the northward-bound glass trade (Bellintani 2014, Kaul et al. 2015, Varberg et al. 2015, Purowski et al. 2016). Both glass and amber represent materials often associated with status. The latter is thought to have served as a crucial part of Scandinavia's overall economic importance in the Bronze Age (Sprincz and Beck 1981, Beck 2000, Bátora 1995).

However, glass was not locally produced within Scandinavia. Müller (1882) was the first to specifically point at Egypt while discussing the potential Middle Eastern origins of the Danish glass beads, and he did this just two years after his excavation of Ølby mound in 1882. Recent chemical analyses seem to have confirmed his hypothesis, as two beads from Danish oak coffin burials (both from Nordic Bronze Age Per. II) were made of Egyptian glass, one from a rich female burial from Hesselager (Funen, Denmark) and the other from Ølby (Varberg et al. 2015, Varberg et al. 2016)(See Figure 2). The remaining Danish beads which have been analysed date from Nordic Bronze Age Per. II-III (1500-1100 BC) come from a further 20 burials and are of Mesopotamian glass (Varberg et al. 2016).

The Ølby bead and the Hesselager bead are both characterized by low chromium/lanthan and variable zirconium/titanium ratios, indicating an Egyptian origin. The remaining Danish glass beads exhibit higher chromium/lanthan and lower zirconium/titanium ratios, thus indicating a Mesopotamian origin (Varberg et al. 2015, Kaul et al. 2015, Varberg et al. 2016, Kaul and Varberg 2017). The Egyptian

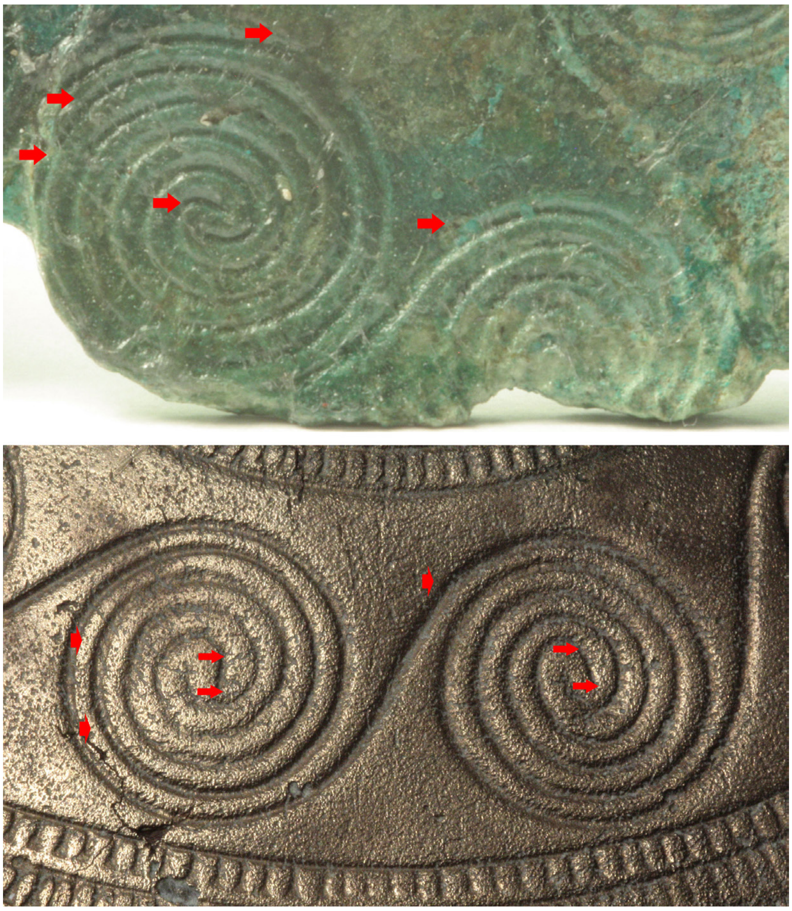


Figure 8. The spirals on the neck collar from the Ølby burial (B2200, pictured above) display a much sharper impression in the spirals' centres and also have wider distances between the grooves. Similar characteristics (see the red arrows) were documented on the spirals from the small belt plate in Vognserup (VM1680 KD, pictured below) (Photos: H.W. Nørgaard).

origin of the glass bead of the Ølby grave seems to be confirmed by the colorant composition, consisting of cobalt with nickel, zinc and manganese. This type of colorant combination has been shown to be typical of the cobalt colorant extracted from Egyptian alum deposits, such as those at the Kharga and Dakhla oases in the Western Desert (200 and 350 km west of the Nile). Similar trace element compositions related to the cobalt colorant have been observed in glass waste from a 14th century BC glass workshops at Malkata and Amarna (Egypt), in the glass ingots found on the Uluburun shipwreck off the southwest coast of Turkey and in Mycenaean glass beads as well (Shortland et al. 2006, Shortland et al. 2007, Jackson and Nicholson 2010, Smirniou and Rehren 2013).

Recent work by a Polish research team has documented the presence of a blue bead of Egyptian cobalt glass from a Middle Bronze Age burial at Kietrz in southwest Poland (Purowski et al. 2016). This bead showed a similar composition to that of the Ølby and Hesselager glass beads. The Kietrz find site is near the source of the Oder River and the watershed for the Danube tributaries. Thus, the Kiertz Egyptian cobalt bead marks another node along Bronze Age trade route following along the Oder River to the Baltic Sea and from the Baltic to Ølby on Zealand. Naturally, one must also consider other routes. Recent chemical analyses have also demonstrated the occurrence of four beads Egyptian glass at the Bronze Age settlement sites at Landunvez and Plomeur in Finistère (Brittany, France)(Cherel and Gratuze 2018).

The cobalt blue Ølby bead stands among the northernmost finds of Bronze Age material from Egyptian origin, nearly at 'the northern end' of the ancient routes of exchange of valuable and prestigious commodities. Given the other goods from the Ølby Woman's rich equipment, including the corded skirt adorned with bronze tubes, it is likely that she would have held a particular status within her society. Perhaps the decorated corded skirt was used in a cultic or ritual manner, as has previously been suggested (Kristiansen and Larsson 2005. Thomsen 1929).

The fact remains that Ølby Woman was interred with both local trade goods (the amber beads) and imported trade goods (the bead of Egyptian glass). Analysis of the metal objects interred with her acts as further evidence for diverse and wide-reaching networks of trade and exchange, both abroad (for the procurement of the raw materials) and within present-day Denmark (for the production of the metal objects themselves as well as the material needed for her amber beads). Her central position within the mound speaks to the importance she may have had within the local community. .

The European Bronze Age has long been conceptualized as a period in which society was founded on systems of gift exchange and kinship networking suspected to have been anchored in the movements of elite females for marriage alliances (Rowlands 1980, Kristiansen 1998). The idea of women travelling within these networks as breathing manifestations of Lévi-Strauss' 'supreme gift' (Lévi-Strauss 1969, 65) has become emblematic of Bronze Age research, especially within the many fine-grained typological studies that have been undertaken in this vein (Jockenhövel and Kurbach 1994, Jockenhövel 1995, Jockenhövel 1991, Wels-Weyrauch 1989b). However, the results discussed in this article, as well as those recently published on the mobility patterns exhibited by the Egtved Girl (Frei et al. 2015b) and the Skrydstrup Woman (Frei et al. 2017b), show that elite women buried in oak coffins during the Nordic Early Bronze Age appear to exhibit highly divergent mobility patterns. Moreover, women's origins seem not always readily apparent within the funerary context. Recent work in Scania suggests that non-elite Bronze Age individuals were also mobile (Bergerbrant et al. 2017b). These results can be contrasted with recent work from Italy, showing tendencies for higher elites to have been mobile (Cavazutti et al. 2019a).

Roughly contemporary evidence from other parts of Europe is gradually mounting. Results from Early Bronze Age Singen near Lake Constance exhibit a similar disconnect between movement/non-movement, social status and the apparent local/nonlocal origins of the deceased (Oelze et al. 2011). Similarly, while the investigations of the Lech Valley in southern Germany disclosed an unexpectedly large number of females that were non-local, their nonlocal status was otherwise not apparent through investigation of archaeological context alone (Knipper et al. 2017). The increasing amount of data emerging from strontium isotope analyses from the Bronze Age thus far indicates that persons from that time seem to have engaged in highly complex mobilities with potential regional differences. More research is needed in order to gain a better handle on the emerging picture of the European Bronze Age.

Conclusion

The Ølby Woman, one of the well-known oak coffin female burials from the Early Nordic Bronze Age, was buried with a rich assemblage of grave goods. These include several large bronze items, a corded skirt with the characteristic bronze tubes and a bead of Egyptian glass, among other things. Our strontium isotope analyses of three of her molars yielded values that seem to indicate a local provenance. Additionally, differences in the strontium isotopic signatures (between the second and third molar) suggest the possibility of mobility during early adolescence, most probably within the local region of Zealand. While the crafting tradition of the metal items in her grave as well as the presence of amber reveal connections to local traditions, the metals used in the production of her bronze goods and the Egyptian glass bead are testimony to the wide range of long-distance trade networks. Hence, Ølby Woman's local provenance provides yet another layer of complexity to our understanding of the oak-coffin graves of elite women from the Early Nordic Bronze Age. This study points to the necessity for further investigation of elite burials combined with context and the objects with which they were buried to better understand the socio-economic dynamics of this formative period in Scandinavia.

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Declaration of Interest Statement

No conflicts of interest are known at present by the authors in relation to the material addressed in this manuscript.

Bibilography

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A new Throne-Amulet from Hedeby. First Indication for Viking-age Barrel-chairs

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ABSTRACT
In 2017 a throne-amulet made from bone, once retrieved from the diggings of the harbour excavation 1979/80 in Hedeby, was committed to the *Wikinger Museum Haithabu*. It constitutes the second specimen known from the site and fits well into the larger group of throne-amulets known from south-eastern Scandinavia. The academic discussion of these amulets as devotional pagan objects either in connection with the worship of *Óðinn* or else as thrones of *vǫlur* is controversial. The piece from Hedeby harbour does not seem to depict the typical block-chair, though, but represents the first indication of the existence of Viking-age barrel-chairs used continuously until Early modernity.

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Figure 1. Hedeby harbour. Throne-amulet made from bone. Note the remnants of a barnacle on its barrel-shaped body (Photo: Museum für Archäologie, Schloss Gottorf).

Introduction

In late September 2017, during the ongoing excavation-campaign within Hedeby's inhumation burial ground '*Flachgräberfeld*' (cf. Kalmring 2017), conducted in an excavation tent open to the general public, a visitor came forward presenting a little plastic case for jewellery.[1] He reported that it held an unknown object from Hedeby, held dear in family possession since decades, which he now would like to have identified. On further inquiry it turned out that the object was found on one of the heaps of excavated material from the harbour excavation in Hedeby, which was conducted in the years 1979/80 (Kalmring 2010). At the point of discovery, the sheet pile box, in which the excavation within the harbour basin had been executed, had already been removed. The object was met as broken into three pieces, but glued together by the finder. When he finally opened the lid of the little case, embedded in cotton wool, a miniature chair came to light.

The Miniature Chair from Hedeby Harbour

The presented object was made from a worked piece of long bone (Figure 1). It possesses a total height of 2.4 cm and an outer diameter of 1.9 cm as a maximum. The 3 cm thick back above a barrel-shaped body measures 0.9 cm in height and features a central perforation of 0.5 cm in diameter (including a triangular gap due to the original rupture). The hollow interior of the long bone is slightly conical and possesses a diameter of 1 cm as a maximum width at its base. The barrel-shaped body is ornamented with an encarved rotating double-line at its base, midst and top, while the back's rear side is ornamented with yet another double-line at its base and top. Here it also features another pair of diagonal double-lines meeting at an imaginary point some 1.4 cm above the top of the back centred above the perforation. The lower half of the barrel-shaped body's front shows the remnants of a barnacle stressing an original find context in Hedeby's harbour basin and not from the landward shore sections of the trench equally examined in 1979/80.

Block-Chairs

At first glance by its shape the small piece from Hedeby harbour resembles full-sized block-chairs (Sw. *kubbstol*, No. *kubbelstol*). These basic chairs – in contrast to the more elaborate square box-chairs as e.g. known from the Oseberg boat-burial (Grieg 1928: 105–118; cf. Pedersen 2017: 114 Fig. 1) – are carved from a simple, hollowed-out trunk and feature a rounded back rest following the contours of the log (Grodde 1989: 55–61). One of the oldest preserved North European specimens of such a block-chair from the 5th century AD, made from alder and decorated with chip carvings, was found in a log boat-burial at Fallward in Lower Saxony, where it was accompanied by a corresponding footrest (Schön 1995: 20–23). From Scandinavia, the oldest preserved block-chair was, for a long time, thought to be the one of Sauland from Telemark in Norway. Its animal style-like decoration gave reason for speculation on its age with suggested dating's to 'the very oldest part of the Middle Ages', the '11th century' or even 'around and shortly after the year AD 800'. Yet a ^{14}C-dating resulted merely in a late medieval dating of AD 1460±160 (Nodermann & Damell 1981: 110–114, with ref. therein). Contemporary figurative depictions of Viking-age block-chairs, though, can e.g. be found on a few Gotlandic Picture stones (cf. Lindqvist & Hult de Geer 1939: 108 Fig. 8–9; Drescher & Hauck 1982: 258–260; Grodde 1989: 59): Each two block-chairs are featured on the type C picture stone Änge I, Buttle parish from the late 8th to early 9th century AD (Lindqvist 1942: 36–39) and on the type E cist-stone Sanda churchyard I, Sanda parish (= G181) from the 11th century AD (Lindqvist 1942: 107–109). In the depiction of the cart-procession of the Oseberg-tapestry (fragment no. 2) one carriage holds two occupied block-chairs ornamented with a zigzag-pattern (Hougen 2006: 17–24, 95–98 Fig. 1–3; cf. Grodde 1989: 59). Finally, even the chair of the god *Þórr* depicted in a gaming pieces from Lund was addressed as being about a *kubbstol* (Trotzig 1983: 365; cf. Grodde 1989: 59), yet its identification seems less secure. Generally, it can be stated that block-chairs were continuously in use in the folk culture of Norway and Sweden up until the early modern times (Salin 1916; Erixon 1938: 115).

Throne-Amulets

The suspension hole of the miniature chair from Hedeby harbour reveals that it was once worn as an amulet pendant.[2] Therewith it can be recognised as belonging to the larger group of Viking-age throne-amulets. Hitherto just one single throne-amulet was previously known from Hedeby, deriving from burial Hb 497 of the western part of the Southern Burial Ground ('*Südgräberfeld-West*') outside the town ramparts. The interment concerns a richly equipped, female coffin-grave containing a Terslev-fibula (uncertain affiliation), two bead-necklaces including four pendants[3], a belt buckle and strap end and a knife as personal equipment. Moreover, it contained a meat fork, a wooden chest with scissors, awl and tweezers, a bronze bowl with a painted wooden figurine, a splint box, a lead bowl with a wooden spoon and a wooden bucket as additional grave goods (Arents & Eisenschmidt 2010b: 147–150, pl. 69–73; Drescher & Hauck 1982: 243–244). A denarius of Louis the Child gives a *terminus-post quem* of AD 899–911 for the interment, which accordingly had been placed in the first half or middle of the 10th century (Arents & Eisenschmidt 2010a: 133, 166, 175; cf. note 2). The find-context of the throne-amulet itself is somewhat uncertain; it is said to have been found with the remnants of a gold-thread close to the left arm of the individual (Arents & Eisenschmidt 2010b: 146–147). The merely 2.5 x 2 cm large and 1.5 cm high pendent is made of alloyed silver and shows a square box-chair with a tapering back rest crowned by a disc. It features arm rests in the shape of forward-pointing quadrupeds with tails. The quadrupeds might embody lions (or wolfs [Freki and Geri]). Two antithetically arranged swans (or ravens [Huginn and Muninn]) with long, bent necks roost on the chair's rear corners framing the back rest. The embedded seat seems to point to an original existence of a enthroned figurine, possibly made of organic material. Traces of wear as well as a repair of the mounting prove a long period of utilisation (Drescher & Hauck 1982: 238–241 Fig.1; Vierck 2002: 42–44, Fig. 10.2; Arents & Eisenschmidt 2010a: 127; 2010b: pl. 69.2).

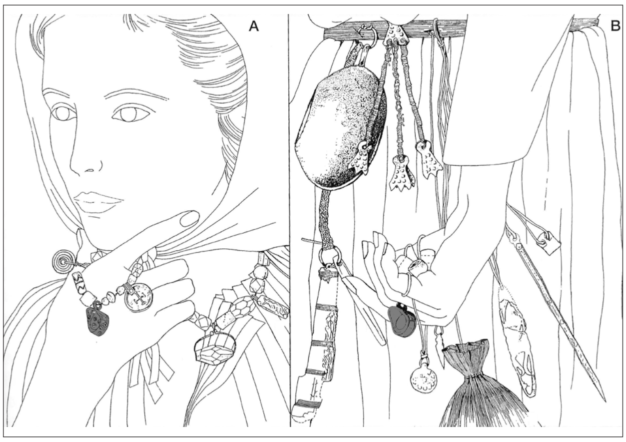

Figure 2. Throne-amulets (grey) combined with additional pendants on a necklace or charm bracelet. Reconstructional drawings after features Birka chamber-grave Bj. 632 (A) and Fyrkat wagon body-grave 4 (B) (modified after Vierck 2002: fig. 12).

Throne-amulets as an artefact-group are predominately known from female burials and hoards from the middle and second half of the 10th century (Arents & Eisenschmidt 2010a: 128–129). Pendants as miniatures of box-chairs, beside the one from Hedeby-grave Hb 497, have been found in the female coffin-grave Bj. 844 from Birka-Hemlanden (grave district 1B) as well as in the hoards from Eketorp, Edsberg parish, Närke, and from Tolstrup, Aars parish, Vesthimmerland. In Gudme, Gudme parish, Fyn, most recently another box-chair pendant has been identified among the detector finds from the late 1980s deriving from the vicinity south of Gudme IV, where a Viking-age farmstead is believed to have been located (Dengsø Jessen & Majland in prep.; cf. Nielsen et al. 1994). All of them have in common, that they were made from silver, in case of the Eketorp-hoard even in gilded silver. The latter, too, featured an embedded seating pointing to the former existence of a enthroned figurine. The larger group of throne-amulets, however, are about pendants as miniatures of block-chairs: One specimen is a part of the collections of the Historiska museet in Stockholm with previously unknown find-context[4], while each on piece was found in the female chamber-graves Bj. 632 from Birka-Norr om borg (grave district 2A) and Bj. 968 in Birka-Hemlanden (grave district 1A). From Gotland block-chair pendants are known from both the female inhumation burial 159 at Stora Ire, Hellvi parish, and the inhumation cist grave 1966:08 at Barshalder, Grötlingbo parish (SHM 32181: 23605; Rundkvist 2003: 186), while from Öland one example was found in grave 8 at Folkeslunda, Långlöt parish. In Denmark, one block-chair amulet was found in the famous female wagon body-interment grave 4 from the ringfortress of Fyrkat. However, block-chair pendants are not exclusively found in graves, but also in hoard-contexts: The Fölhagen-hoard in Björke parish on Gotland even contained two throne-amulets. Another piece was found as a part of a hoard from Bornholm with unknown find-context and one in the Gravlev-hoard in Hornum parish, Vesthimmerland (Drescher & Hauck 1982: 248–256, 301, with ref. therein; cf. Price 2002: 163–167). Among the known block-chair throne amulets the variety of basic materials seems to be more heterogeneous; while silver dominates the picture (Bj. 632, Bj. 968, Fyrkat, Fölhagen, Bornholm, Gravlev), there are even specimens worked from bronze (Riddare by), amber (Stora Ire, Barshalder) and antler (Folkeslunda). All of the throne-amulets listed above have in common that they were found unoccupied without featuring an actual sitting individual. Two recent detector finds of silver box-chair amulets from Denmark, however, are occupied by a figurine. And while the individual on the amulet from Nybølle, Horslunde parish, on Lolland is quite basic and lacks any greater details, the one from Lejre shows a person dressed in a knee-length robe, a pectoral of pearled lines and wrapped in a cloak wearing some kind of hood or hair decoration (Christensen 2009; Pesch 2018).

Semantics – Magic Thrones?

The discussion of the semantics of throne-amulets, often carried on a necklace or charm bracelet and in combination with beads and additional amulet pendants (Figure 2), is considerable. Their identification as symbolic thrones of 'an earthly or other spiritual power', possibly of the Norse god *Óðinn*, was recognised from early on (Arrhenius 1961: 156–157; cf. Roesdahl 1977: 141; Koktvedgaard Zeiten 1997: 21–22; Gräslund 2005: 380–381). H. Drescher & K. Hauck (1982) composed a comprehensive catalogue on throne-amulets and categorised them into 'solium (box-chair) amulets' – according to the royal throne (Gr. *θρόνος,* Lat. *solium regale*) of the occidental Emperors, modelled after Mediterranean antetypes – and into 'block-chair amulets'. In the Scandinavian cultural area both categories of empty thrones as a devotional object seem to 'glorify the divine in adoration and ensures its presence', since the seat 'invites the supernatural to abide by'; occupied thrones with indications for lost figurines (or actual sitters) praise the glory of the depicted divinities. The authors, however, have reservations in ascribing both types of thrones solely to *Óðinn* (or this wife Frigg), which they consider imprudent (Drescher & Hauck 1982: 244–245, 299). In his chapter 'throne – bishop's throne – magic throne' H. Vierck (2002) elaborates on the point of a Norse pagan transformation of an Antique and Jewish-Christian throne symbology going back to the throne of Solomon ('the Wise'), its adaption in the Byzantine and Carolingian Emperor's thrones as well as their imitation for Bishop's thrones as heirs to the Davidic kings. Despite the fact, that he emanates from Christian Bishop's thrones as being the actual models for these solium-amulets, Vierck argues that the semantic is less likely to be found in their immediate significance as manorial insignia of gods and men. The fact that most of the throne-amulets were found without a sitter to Vierck (2002: 50, 54) does not necessarily have to be related to the *hetoimasia* (Gr. ἑτοιμασία, 'ready throne') in expectance of an *epiphany* (Gr. ἐπιφάνεια, manifestation/appearance), but can also be understood as the thrones possessing some magical inherent *Gestaltheiligkeit* ('shape-holiness') themselves. In their Norse, transformed appearance he links the latter to *seiðr* and to the thrones of the female seeresses *vǫlur* (Vierck 2002: 57–58). This connotation is also taken up by N. Price (2002: 167) who argues that their combined appearance with other amulets on necklaces 'strongly suggest that such chairs were among the symbolic equipment of the *vǫlur* [themselves] and their kind' (critically Jensen 2010: 58–61, 189). The controversial discussion within the scientific community, which enflamed subsequent to the discovery of the throne-amulet from Lejre with its occupant addressed as either 'Odin from Lejre' or – in its interpretation as a *vǫlva* – as the 'Lejre Lady', shows the great difficulty which lies in the interpretation of this particular group of devotional pagan objects (Pesch 2018, 464-470).

Barrel-Chairs

The barrel-shaped body of the „block-chair" miniature from Hedeby harbour in question, taken together with the rotating double-lines at its base, midst and top, however, seems insistently to point to the fact that we are not looking at a block-chair, but rather at a miniature of a tube-chair (Ger. *Tonnenstuhl*, Dut. *tonnestoel*) with barrel hoops (cf. Roesdahl 1999: 103). Vertical planks representing staves seem not to have been indicated with additional carvings by the artist. While *realia* of tube-chairs are rarely preserved, they commonly appear in Renaissance' tavern scenes of Dutch paintings or Books of hours. Generally, tube-chairs as a generic term are differentiated into barrel- and pail-chairs (Ger. *Fass-* and *Kübelstuhl*) depending on the moulding of the staves themselves (von Stülpnagel 2016): Pail-chairs consist of straight, unbent staves and are thus either cylindrical or frustum-like tapered in shape.[5] Barrel-chairs instead consist of fined-down lanceolate staves, which were bent on a fire forming a bulge held in place with winded hoops. This constructional fact implies that barrel-chairs always had to have been complete barrels in the first place and are thus solely about secondary products.[6] While pail-chairs can be further distinguished into pail-chairs with simple armrests (von Stülpnagel 2016: 13, drawing 6-9) and armrests from additional boards (von Stülpnagel 2016: 13, drawing 1-5), barrel-chairs can be discriminated by their bulge somewhat vaguely into barrel-chairs with lesser- (von Stülpnagel 2016: 13, drawing 10-15) and greater bulge (von Stülpnagel

Figure 3. a. Barrel-chair as depicted in a 17th-century pen-drawing. Detail from Isaac van Ostade (1621–1649), 'Hungry peasants having a frugal meal' (PK-T-1715. Digital Collections, Print Room. Leiden University Libraries, Leiden University [Creative Commons]).
b. Rendering of the bulgy barrel-chair depicted in Isaac van Ostade's 'Hungry peasants having a frugal meal' (after von Stülpnagel 2016: drawing 19 [mirrored]; drawing K. von Jeinsen).

2016: 13, drawing 16–19). Based on this comparative body the amulet from Hedeby harbour with its squat, bulgy shape thus can be positively identified as a miniature of a barrel-chair with greater bulge. It has an almost identical, full-sized counterpart in the tube-chair depicted in a 17th century-pen drawing by Isaac van Ostade (Figure 3a–b) dramatically stressing the persistence of this type of basic seating furniture up into Early modernity.

Staves from coopered vessels do appear in great quantities in Hedeby: 204 specimens derive from settlement contexts, while 31 were found in the harbour. This group can be complemented by another 137 stave vessel-heads or lids from the settlement and 11 from the harbour (Westphal 2006: 29–31, 37–44, pl. 13–15). Among the former there are 17 so-called 'well-staves' – named after wells made of imported barrels in secondary usage – of which 14 samples were found in well-contexts (Westphal 2006: note 31). Wells made from large transport barrels constitute the most frequent type of well in Hedeby. Due to the fact that they were dug down deep into the humid, waterlogged ground some were almost fully preserved. These barrels, made from alien silver fir (*Abies alba*) and thus imported to Hedeby as containers from the upper Rhine area, possessed a height of 2.5 m, a maximum of 0.8 m in diameter and a volumetric capacity of 800 l (Schietzel 1969: 41–45; 2014: 146–149; Behre 1969: 10–13; cf. Schultze 2008: 364–365 note 41). In terms of fastening of stave-vessels in general in 63 cases wooden hoops with a length of up to 0.953 m are documented in Hedeby (Westphal 2006: 43), but in 102 cases even metal hoops, too (Westphalen 2002: 168–169, pl. 64). Due to the fragmentation of the latter the reconstruction of their original length certainly is hindered; yet only in six cases they might actually have belonged to vessels other than buckets with a diameter of ≥ 0.3 m. The preserved barrels from the wells exclusively featured wooden hoops. Whether or not one of the remaining three of the 17 'well-staves' in secondary usage might possibly have belonged to a barrel-chair has to be regarded as highly uncertain; for now, they must be reckoned as mere remnants of demolished, imported barrels (Schietzel 1969: 44).

Discussion

Until today, the find of one stool from 1937 is the only surviving piece of an actual seating furniture known from Hedeby (Grodde 1989: 51 pl. 66.1; Westphal 2006: 87 pl. 66.3).[7] The throne-amulet from grave Hb 497 at least suggests a familiarity with the solium-box chairs of the leading clergy as models for the (miniature) *vǫlva*-thrones in an underlying process of adaption, imitation and transformation. Therewith, also this artefact group, as earlier demonstrated for the Thor's hammer pendants (cf. Staecker 1999: 234–237), has to be understood as a pagan reaction to Christian influences, which is also in accordance with their suggested 10th century appearance. Even for the amulets depicting a miniature of a more basic form of seating furniture such as block-chairs, the same semantic qualities – possessing some magical content – are apparently allotted. The throne-amulet from Hedeby harbour, however, does not depict a block-chair in miniature, but in fact a barrel-chair. Hitherto, barrel-chairs in general have not been archaeologically documented, though 'a manufacture in pre- and protohistoric time [in Central- and Northern Europe] is completely conceivable' (Grodde 1989: 60; transl.: author). While it is tempting to deduce an actual existence of full-size barrel-chairs in Hedeby, too, which might have served as a model for the amulet, one might wonder why even a seating furniture only created as a recycled, secondary product, could become the model for a throne-amulet and thus ascribed magical qualities – the 'Viking mind' obviously can hardly be equalised with our modern perception of values. The usage of bone for the pendent from Hedeby harbour not only enhances the variety of basic material – bronze, amber and antler next to the predominating silver (Jensen 2010: Fig. 3.6.3) – displayed within the group of block-chair amulets. Also, and even more importantly, the artefact constitutes the first indication of the existence of barrel-chairs in the Viking world.

Notes

1. The author is grateful to assistant medical director Dr. H. Seifert, Busdorf, who kindly ceded the object to the collections of the *Wikinger Museum Haithabu* (SH1979-221.1).
2. For a critical discussion of the terminology cf. Koktvedgaard Zeiten (1997: 3–5) and Jensen (2010: 5–8).
3. Cf. Delveau (2017: Fig. 8), bead period BP VII (= AD 905–935). Divergent dating given by Delveau (2017), who by mistake applied the "hypothetical dating" instead of the "tentative absolute chronology" to J. Callmer's bead periods (cf. Callmer 1977: 77, 170).
4. Henceforth identified as deriving from Riddare by, Hejnum parish, Gotland (SHM 876: 106656).
5. Among the collection of block-chairs of the Nordiska museet in Stockholm there are two tube-chairs of uncertain age misguidedly addressed as "kubbstol". Since both feature straight, unbent staves they are as a matter of fact about coopered pail-chairs (von Stülpnagel 2016: 13, drawing 7–8).
6. The secondary usage of transport-barrels in Viking-age contexts is e.g. well documented in the context of wells (see below).
7. In a burnt pit-house, feature "Haus I/[19]33" from the trial trench-cross section (N 98–106 metres), another charred stool was met. It could not become recovered though (photo-binder "Hedeby 1933 Photo 201–249", picture 213/[19]33 from November 1st 1933; cf. Jankuhn 1933/34: 346; Hilberg 2007: 195 Fig. 5).

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Rune Carvers and Sponsor Families on Bornholm

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ABSTRACT
The runestones on Bornholm have for a long time aroused discussion due to their singular character and dating as compared to most runestones in other parts of Denmark. In this paper, the relations between sponsors and rune carvers have been investigated through analysis of the carving technique by means of the first 3D-scanning and multivariate statistical analysis ever carried out on the Danish runestone material. The results indicate that the carvers were attached to the sponsor families and that the carvers were probably members of those families. During the fieldwork, a fragment of a previously unknown runestone was documented in the church of St. Knud.

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Introduction

When the runestones of Bornholm were raised, the practice of erecting runestones had already decreased dramatically in other Danish areas, where the number of runestones had fallen to the same level as before around 965, when the king claimed to have introduced Christianity. After *c.* 1020 we know of no more than 15-20 runestones in the old Danish territory, with the exception of Bornholm where we know that the period *c.* 1025-1125 produced 40 runestones (Imer 2016, 282-284). The Bornholm runestones have greater linguistic and ornamental similarities to the runestone tradition of central Sweden in the eleventh century than to the Danish tradition, but there has long been debate about whether this is due to particularly close connections with areas in central Sweden or if the similarity perhaps mostly has to do with chronology. There are arguments both for and against, and it cannot be said that the issue has been resolved.

One question is whether the carvers came from outside and what connection they had to the families that raised the stones. The runestones can be grouped according to the kinship relations in the inscriptions and according to the ornamentation. The aim here is to investigate how these runestone groups and family groups coincide with the carvers' identity. A completely different source of evidence will be used here, namely the carving technique, which will be studied by 3D-scanning and multivariate statistical methods, following a method developed at the Archaeological Research Laboratory, Stockholm University (Kitzler Åhfeldt 2002) and further refined in various research projects (e.g. Kitzler Åhfeldt 2015, 2016).

During the fieldwork on Bornholm, an important discovery was made too, when the 3D-scanning of a runic carving in St. Knud's church – whose authenticity had previously been in serious doubt — had the result that it could be read and authenticated (Eilsøe 2017; Kitzler Åhfeldt 2017; Imer and Kitzler Åhfeldt forthcoming).

The Runestones of Bornholm

At present there are 40 known runestones on Bornholm. The rune shapes and linguistic forms place them from the middle of the eleventh century until some way into the twelfth century (Imer 2015). Long ago Ludvig Wimmer assigned the majority of them to the latter half of the eleventh century and the start of the twelfth (Wimmer 1905, 186, 190; Olsen 1906, 30). Lilliane Højgaard Holm, who has recently re-examined the runestones of Bornholm from a linguistic viewpoint, believes that the orthography, vocabulary, and the Christian message speak in favour of this late date (Højgaard Holm 2014, 262). The presumed time of Christianisation has been an important benchmark, namely, around 1060 when Bornholm, according to an earlier view, was converted by Bishop Egino. Marie Stoklund, however, argues that the boundary is too narrow, Bornholm could have been Christianised earlier and runestones could have been erected both before and after the suggested period (Stoklund 2006, 372). Erik Moltke thought that Bornholm started raising runestones one generation after people in Denmark had stopped (Moltke 1976, 269), but this gap may have shrunk now that they can be dated earlier.

Many of the runestones saw the light of day during church restorations and rebuilding in the second half of the nineteenth century. When Østermarie church was demolished at the end of that century, no fewer than three runestones were found at different places in the medieval church building, and a fourth runestone was lying in the churchyard (Jacobsen and Moltke 1942, 449-454). The Bornholm stones, however, were regarded as the least interesting in Denmark. Wimmer notes that, unlike other Danish stones, they are flat and thin (Wimmer 1905, 183, 186-187). Also, it was considered remarkable that no runestones were raised on Bornholm during the time when many were being set up in Skåne. It was furthermore noted that the formulas 'had the stone carved' or 'had the stone raised' and the prayers resemble those on Swedish runestones (Olsen 1906, 30-31).

Judging by the preserved finds, runes were very sparsely used on Bornholm in the Viking Age and Middle Ages. Apart from the runestones, all that survives is, in principle, some metal foils with runes. The exceptions are the medieval font in Åkirkeby (DK Bh 30), which was imported from Gotland; a horizontal grave slab, Vestermarie 4 (Dk Bh 44), under which, according to the inscription, at least three persons were buried (Bæksted 1935, 49); and a few inscriptions on the church walls in Ibsker (Dk Bh 44) and Nyker (Dk Bh 32)(Moltke 1985, 432). However, as we know from other sites, runes may have been written on perishable materials, such as wood. The number of metal amulets with runes and minuscules is increasing each year as a result of the systematic metal detector surveys of ploughed-out settlement sites. According to Højgaard Holm (2014, 262), the runic foils were probably not made on Bornholm, but she does not engage in any further discussion or explanation of her thesis. Most recently, Lisbeth Imer and Rikke Steenholt Olesen have shown that most of the amulets that make sense linguistically were created by church people (Imer and Steenholt Olesen 2018, 154), indicating that Bornholm too had a (runic) writing culture in the late Viking Age and early Middle Ages.

In Favour of Swedish Influence

In order to understand the importance of the runestones on Bornholm, we need to consider the role they have played in earlier discussions about Bornholm, as an island community and its affiliations to other Scandinavian communities and contemporary power spheres. Earlier research proposed Swedish influence as the explanation for the late runestones on Bornholm. Marius Kristensen argued that naming practices linked the Bornholm runestones to those in Sweden, and that Bornholm was heavily influenced by Swedish rune carvers (Kristensen 1930, 155-156). Moltke cited similarities in ornamentation, in certain rune forms, and in the runic prayer 'God help his spirit and God's mother', which is common in Sweden but does not occur in Denmark (Moltke 1934, 17). Moltke believed that it was Swedes with a knowledge of runes, for example from Södermanland and Östergötland, who brought the runic art to Bornholm. Other areas mentioned in this connection are Öland, Gotland, and Uppland. The runic beasts on Bornholm indeed have great similarities to those in Middle Sweden. The Swedes, according to Moltke, had not only taught the runes but had also themselves raised runestones on Bornholm (Moltke 1976, 269, 271). He said that, while the ornamentation shows that the people of Bornholm learned from Swedish rune carvers, the personal names suggest even closer influence (Moltke 1934, 19). Moltke even saw Swedish influence in the forms of certain runes (Moltke 1976, 269). A linguistic feature that has been considered to indicate that certain rune carvers had a Swedish background is the word *retta* 'to erect' on two runestones, Bodilsker 5 (DR 378) and Østerlarsker 1 (DR 397). This is unknown in

Danish runic inscriptions except on Bornholm, but is most commonly found in Uppland (Højgaard Holm 2014, 269).

Against Swedish Influence

There may be explanations for the similarities between the runestones of Bornholm and those of central Sweden other than direct influence from Swedish rune carvers. One example is that, whereas the rune **o** and the diphthong *ei* in *Danmarks Runeindskrifter* were regarded as examples of Swedish influence, especially on Bornholm, Stoklund states that these are also found on runic coins and could be explained as a feature used throughout the Danelaw (Stoklund 2006, 373). There are also finds from Schleswig and Lund with these features (Lerche Nielsen 1997, 69; Stoklund 2006, 373), which is, if anything, evidence that this is a chronological feature, since Svæinn Estridsen's runic coins and the finds from Schleswig and Lund are closer in time to the Bornholm runestones.

Højgaard Holm rejects the idea that the eleventh-century central Swedish expansion lay behind Bornholm's runestones and proposes other factors that speak against Swedish influence (Højgaard Holm 2014, 296). One feature that is claimed to suggest that Bornholm's runestones show Swedish influence is the formula *lāta* 'to have (something done)' + a main verb meaning 'raise, carve, make'. Højgaard Holm, however, thinks that the formula with an auxiliary verb is rather an expression of chronology, as it occurs on a younger group of runestones and was initially an upper-class marker (Højgaard Holm 2014, 269). Moreover, the preposition at 'after', which is common around Lake Mälaren, appears to be unknown on Bornholm (Højgaard Holm 2014, 270).

Carvers' signatures have also been held up as a Swedish feature, but there are only two runestones with a carvers' signature on Bornholm, too few to allow us to speak of Swedish influence (Højgaard Holm 2014, 276-277). In opposition to Kristensen and Moltke, who argued that the names pointed directly towards Sweden (Kristensen 1930, 155; Moltke 1976, 269), Højgaard Holm thinks that a large share of them belong to the common store of Norse names, whereas some of the names are associated with old Danish provinces, examples being *Hallvar*ðr, *Bōsi*, *Guðki*, *Sassurr, Svartr, Tōli*, and possibly *Fullugi* (Højgaard Holm 2014, 295). Others are distinctively Bornholm names, for example, those with the first element *Alf-* and *Øy-* or *Auð-* and those with the second element *–gæiʀʀ*. Attested Bornholm names that are known in Swedish sources have an eastern orientation, that is to say, they are known from the provinces facing the Baltic, but there are few Bornholm names on Öland and Gotland (Højgaard Holm 2014, 295). The principle of naming people after earlier generations was still alive on Bornholm in the eleventh century. Kristensen (1930, 155) held the view that Bornholm adopted this principle from Sweden, but Højgaard Holm sees Bornholm as a relict area for an old naming tradition. The tradition persisted longer in the east Norse than the west Norse area (Højgaard Holm 2014, 293). Michael Lerche Nielsen (1994, 176–177) has nevertheless shown in an earlier work that traditions of naming people after past generations were widespread throughout the Danish area in the Viking Age.

In Favour of the Danish realm

Instead of viewing Bornholm's runestones as a result of Swedish influence, others have seen them as indications that Bornholm was incorporated in the Danish realm. Klavs Randsborg discusses the distribution of runestones in the light of centralisation. He believes that the Danish realm was largely united under King Svæinn Estridsen, possibly with the exception of Bornholm and Blekinge (Randsborg 1980, 33; cf. Wagnkilde and Pind 1989-1990, 64). Bornholm's runestones are assumed to belong together with Christianisation and the incorporation of Bornholm in the Danish administration after the middle of the eleventh century (Randsborg 1980, 44). Thegns and drengs are concentrated in southwest Bornholm, which is suggested to be due to royal vassals being found only in that part of the island. Randsborg goes on to interpret the large number of Bornholm runestones raised to women as being a consequence of newcomers marrying the daughters of Bornholm magnates (Randsborg 1980, 44). As regards this interpretation, one should note that there are only three runestones on Bornholm that mention the title 'dreng', and only one with a mention of a 'thegn'. These few runestones can hardly form a basis on which to make too far-reaching conclusions on the political situation and the royal power.

Against the Danish Realm

Randsborg has been criticised by runologists for drawing excessively far-reaching conclusions based on the distribution of the runestones, since he believes that they reflect the consolidation phase of royal power. Michael Lerche Nielsen asserts that the distribution can be heavily affected by how people in different areas reused them as building material, and by the now antiquated division into Pre-Jelling, Jelling, and Post-Jelling stones, which should rather be considered as relative typological groups (Lerche Nielsen 1997, 6 with further reference to Stoklund 1991, 295-296).

Bornholm's incorporation into the Danish realm has been assumed to have taken place sometime between the tenth century and the end of the eleventh century, with varied dates proposed by different researchers (Randsborg 1980; Watt 1985; Wienberg 1986: 45-46; Wagnkilde and Pind 1991; Nielsen 1998; for summaries of arguments, see Lihammer 2007, 242 and Gelting 2012: 107-10). Michael Gelting believes that elements in the *Slesvig Stadsret* and *Knýtlingasaga* contradict that Bornholm was a part of Denmark in Egino's time (Gelting 2012: 109-10). Anna Lihammer for her part thinks that there is too little evidence of this, and that it did not occur until near 1100 (Lihammer 2007, 262). Lihammer's argument against Bornholm having been part of the Danish realm earlier than this is, among other things, that the ecclesiastical structure differs from that in western Denmark and that the archaeological circumstances indicate that conversion to Christianity took place from below. All in all, Lihammer thinks that there are no signs of belonging to Denmark in the eleventh century, as the first certain note of Danish royal power comes with twelfth-century Lilleborg (Lihammer 2007, 260-261, 273). In that chronological perspective the runestones need not be viewed in a specific Danish context.

Numismatic studies by Cecilia von Heijne show that the content of Bornholm's silver hoards differs from comparable hoards in Denmark at the time around 1100 and that they show instead much greater similarities to Blekinge's silver hoards (von Heijne 2004, 166). The hoards are dominated by foreign coins and include many non-monetary objects (von Heijne 2004, 152-156; Ingvardson 2010, 20). The prolongation of the weight economy and the lack of Danish coins for much of the period up to the thirteenth century shows that Bornholm was not integrated in Denmark's monetary system, which can also be interpreted to mean that the island was not wholly integrated in the Danish realm (Lihammer 2007, 292; Horsnæs 2013, 42). A survey of all the hoards shows that Bornholm's economic system differs greatly from that in the Danish kingdom and that Bornholm in the late Viking Age was still an independent economic and political unit (Ingvardson 2014, 329, 335). Bornholm never acquired a mint of its own, it lacked urban centres, and settlement was decentralised in single farms and small villages. Runestones on Bornholm bear few titles and, like the silver, they are scattered over the whole island, which is said to suggest a flat power structure and a decentralised trade structure (Nielsen 1994, 125–129; Ingvardson 2010, 334-345).

The Christianisation of Bornholm

The runestones of Bornholm are also related to the discussion of Christianisation. Moltke believed that the runes came to Bornholm when the island was converted to Christianity by the bishop Egino in Dalby around 1060 (Moltke 1976, 269). It has also been suggested that the mission to Bornholm could have taken place in connection with the incorporation of the island in the Danish realm under Svæinn Estridsen (Randsborg 1980; Wagnkilde and Pind 1991, 64). The picture of Christianisation, however, is different in more recent research. Graves oriented east–west are found from the late tenth century (Watt 1983, 30-33). The mortuary practice in the Viking Age is said to be relatively distinctive and uniform on the island, but it changed around 1000. Four early Christian burial places can be named in particular: Slamrebjerg, Munkegård, Runegård, and Grødbygård; they are all from the eleventh century, and with their mixture of Christian and pre-Christian burial traditions they show different stages of Christianisation (Svanberg 2003, 149; Lihammer

2007, 247, 250). There is a large element of grave goods and Slavic features in the graves.

The Problem

As we have seen, several earlier assumptions about Bornholm have recently been questioned, namely, whether the runestones suggest Swedish or Danish influence, the late conversion of Bornholm, and the strategic position of the island. It seems to be clear, however, that some change occurred in the eleventh century. Analyses of weights, hoards, and Baltic pottery show that there was a noticeable change in the organisation of settlement and trade on Bornholm around 1000 (Ingvardson 2014, 334).

Whereas some scholars argue that the similarity of the Bornholm runestones to those in central Sweden is primarily a chronological feature (Lerche Nielsen 1997; Højgaard Holm 2014; Imer 2016), not everyone appears to be convinced. For example, the similarities in ornament appear far too great to be wholly independent of each other (Gräslund 2016, 184-185).

These questions have not been resolved, as was obvious from the discussions at the international field runologists' meeting on Bornholm in 2015, arranged by Lisbeth Imer of the National Museum of Denmark and Rikke Steenholt Olesen of the University of Copenhagen. Rather than choose between Swedish influence and chronology, a Baltic tradition is emphasised, with the Baltic islands being part of the same cultural sphere as eastern Svealand. Other parameters include, for example, settlement history, with row-villages in Uppland and on Öland. Something happened to the language on Bornholm, however, as is obvious on the runestones. There is also a large span in the forms of the runes. Moltke's interpretation of the situation was that the written language was in a state of dissolution or development, as manifested in new runes, linguistic forms, and spelling variants, with a mixture of old and new (Moltke 1976, 279-280).

The archaeological issues, on the other hand, were discussed at a workshop in Visby in 2017 with archaeologists, runologists, and numismatists, when we dwelt on the question of Bornholm's presumed strategic position along the trade routes.[1] This was questioned by the numismatists; at any rate the people of Bornholm do not appear to have made very much of it during the Viking Age.

Questions

As seen above, the runestones of Bornholm take a prominent place in important research issues concerning Bornholm's political status and Christianisation. They have been scrutinized from the perspectives of runology, ornament and archaeological context. We suggest that part of the problem concerning the rune carvers of Bornholm can be approached from a different angle, namely, the carving technique. In the following we will look more closely at the rune carvers in one context on Bornholm and their relationship to the families that sponsored the raising of the stones.

In this article we primarily discuss internal relations on Bornholm. The important question of whether the rune carvers were in contact with any part of Sweden is considered elsewhere (Kitzler Åhfeldt 2019), and will only be mentioned briefly below.

The Study

The fieldwork for the study was performed during a week in September 2017, when eight runestones underwent 3D-scanning by the company s3Di using Artec Eva and Artec Spider (Figure 1). The runestones were selected to represent some different groups linked by family relations, ornamentation, or distinctive runological features. We want to examine how these runestone groups and family groups coincide with carver identity. By carver identity, we here mean the handcrafter who made the actual stone cutting work. The rune carvers can be considered the first carriers of literacy in a generally oral society. Probably, they were much sought after for their special competence and their contacts and travels may tell us something about social interactions and networks. On the local level, the relations between the rune carvers may indicate kinship and friendship among families and households; across regions the presence of rune carvers may indicate networks and alliances on a larger scale. This made it desirable to include also runestones with ornamentation, pri-

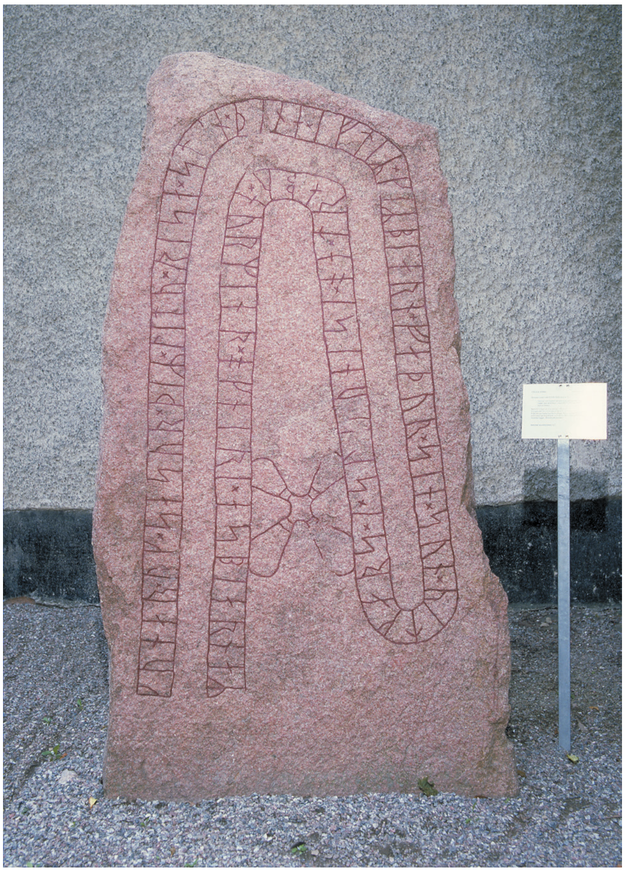


Figure 2. The Fresta stone U 258. Photo: Bengt A Lundberg 1986, CC/BY Swedish National Heritage Board.

marily runic animals, which can be classified according to Anne-Sofie Gräslund's runestone chronology (Gräslund 2006) and which display similarities to many Swedish stones.

Three stones are of sandstone and five of granite (Andersen 1992; database Danske Runeindskrifter). These are:

Nylarsker 1 (DR 379, DK Bh 33). Sandstone. The inscription order on Nylarsker 1 has parallels in Sweden, e.g. Ög 129 (Moltke 1934, 17). Judging by closely related rune forms, especially the **s**, **t**, and **r** forms, Nylarsker 1 and Nylarsker 2 may belong to the same carver school, while the ornament resembles Nyker (Jacobsen and Moltke 1942, 435).

Nylarsker 2 (DR 380, DK Bh 34). Sandstone. According to Moltke the writing order resembles what one can see on Swedish stones, e.g. the older Fresta stone in Uppland (Moltke 1976, 277; U 258; Figure 2) and in Moltke's view it probably comes from the same workshop as Nylarsker 1, despite typological differences in the inscriptions (Jacobsen and Moltke 1942, 438).

Nyker (DR 389, DK Bh 31). Sandstone. Nyker has been assumed to have been made by the same carver as Vester Marie 5, Nylarsker 1 and Nylarsker 2 (Moltke 1976, 274). According to Moltke, Nyker resembles Nylarsker 1 in the ornamentation and Nylarsker 2 in the irregular rune forms, with the slightly rounded twig of the **t**-rune. Lis Jacobsen and Erik Moltke call this carver Træbene-Sønne and also ascribes Østermarie 3 to the same carver (Jacobsen and Moltke 1942, 934–935). It should be noted though, that this supposed carver name is due to an older interpretation of the inscription on Vestermarie 5, where the runic sequence **trebin : u:syni** was interpreted as Træbene-Sønne. However, this is now interpreted as 'shamefully killed' (Moltke 1985, 332). In *Danmarks Runeindskrifter* the Nyker stone is dated 1075–1125 (based on Bishop Egino's claim to have Christianised Bornholm), whereas Gräslund's typology of runic animals would set an earlier closing date, *c.* 1075–1100, Pr4 (Gräslund 2006). At the field runologists' meeting in 2015 the form *þænsa* in the inscription was held up as something unusual in southern Scandinavia. Once again it was noted (as by Moltke) that the carver uses a strange **t**-rune with the twig drawn as a single line. There was discussion as to whether the distinctive features of the Nyker stone are due to Swedish influence or to chronology.

Østermarie 2 (DR 391, DK Bh 52). Greyish, medium-grain granite. Partly the same names in the inscription as on Østermarie 3, but they look different.

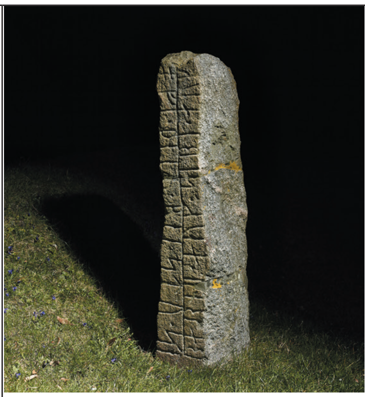
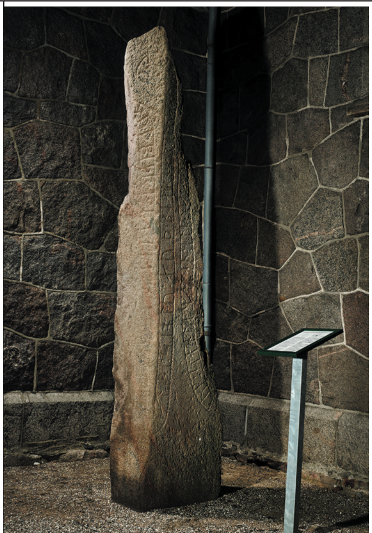
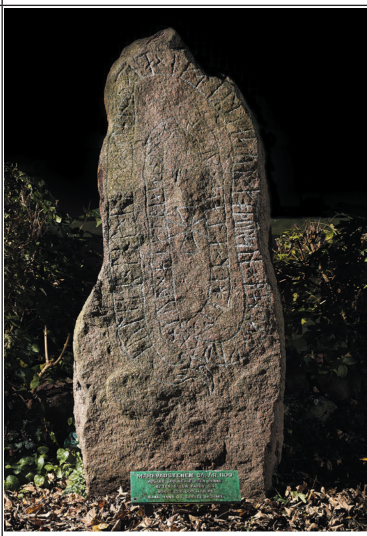
Østermarie 3 (DR 392, DK Bh 53). Greyish granite. This stone is said to have Swedish features (Jacobsen and Moltke 1942, 451-452). Moltke finds parallels to the propeller-shaped cross in Östergötland (e.g. Ög 87, Ög 203, Ög 244) and Södermanland (Moltke 1934, 18). Østermarie 3 is very likely to be younger than Østermarie 2, since yet another brother has been added and one brother has now died.

Klemensker 1 (DR 399, DK Bh 1), 'The Gunnhildr stone'. Reddish granite. The expression 'in light and paradise' occurs on Swedish stones (Jacobsen and Moltke 1942, 458; U 160, U 719 and possibly on Öl 51).

Klemensker 4 (DR 402, DK Bh 4). Reddish granite. Pr2, where the stone is dated to *c.* 1020-1050 according to Gräslund's chronology (Gräslund 2006).

Knudsker (DK Bh 69). This stone was first authenticated in 2017, thanks to the 3D-scanning

Name	Picture	English translation (from SRD)	Transliteration	Grouping according to Jacobsen and Moltke 1942 and Moltke 1985
Nylarsker 1 DR 379		Sassurr had the stone raised in memory of Hallvarðr, his father, (who) drowned abroad with all the seamen. May Christ ever (and) endlessly(?) help his soul. May this stone stand in memory.	**sasur : lit : resa : sten : eftiʀ : aluarþ : faþur : sin : truknaþi : han : uti : meþ : ala : skibara : etki : i : kristr : ha-b siolu has sten : þesi : stai : eftir**	Group 1
Nylarsker 2 DR 380		Svæinn (the Hooded? son of Kāpa?) raised this stone in memory of Bøsi, his son, a good *drængʀ*, who was killed in battle at Ūtlengia. May Lord God and Saint Michael help his spirit.	**kobu:suain : raisti : stain : þ(e)na : a(f)tir : bausa : sun : sin : tr(i)… …n : þan : is : tribin : ua(r)þ : i : (u)(r)ostu : at : ut: la(n)(k)iu : kuþ : tr(u)tin : hi(a)lbi : hans : ont : auk : sata : mikial :**	Group 1
Nyker DR 389		To... had this stone raised in memory of Svæinn, his son. A very good *drængʀ*, ... and (in memory of) his brother. May holy Christ help the souls of both these brothers.	**(t)o… [l](e)t : resa : sten (:) þensa : eftir : suen : sun : sin : trenkr al(g) oþar …una(u)i ok hans (:) (b)r(o)(þ) (u)r : krist : helgi hal(b)(i) siolu : þera :: bryþra : be(g)ia :**	Group 1

Østermarie 2 DR 391		Barni/Biarni and Sibbi and Tōfi they raised (the) stone in memory of Ketill, their father. May Christ help his soul.	**barni : auk : sibi : auk -ofi : þeiʀ : reistu : sd ei(n) (:) (e)ftiʀ : ke(t)(i)l : faþur sin : (k)ristr (:) (h)lbi hns siol :**	Group 2
Østermarie 3 DR 392		Barni/Biarni and Tōfi and Āsgautr had (the) stone raised in memory of Sibbi, their brother. May Christ help (his) soul.	**: (b)ar(n)i : auk : tofi : ok : askutr : letu : resa : sten : eftiʀ : siba : (b) roþor : sin : krist : sil : ia(l)bi**	Group 2
Klemensker 1 DR 399		Gunnhildr had this stone raised in memory of Auðbjǫrn, her husbandman. May Christ help Auðbjǫrn's soul into light and paradise. May Christ and Saint Michael help the souls of Auðbjǫrn and Gunnhildr into light and paradise.	**(k)(u)(n)iltr : l(e)t : r(e)isa : st(e)n : þ(e)n(s)(a) : eftir : auþbiarn : bonta : sin : kristr : hialbi : siolu : auþbiarnar : i lus : auk : bratis kristr : hialbi : siolu : (a)(u)(þ)biarnar : auk : ku(n)(i)(l)(t)(a)(r) : auk : santa mikel : i lius : auk : baratis**	
Klemensker 4 DR 402		Øylakʀ had this stone raised in memory of Sassurr, his father, a good husbandman. May God and Saint Michael help his soul.	**: aulakʀ : let : reisa : stein : þana : eftiʀ : sasur : foþur sin : bonta : kuþan : kuþ : hialbi : siol : hans : auk : sata : mihel :**	Group 2

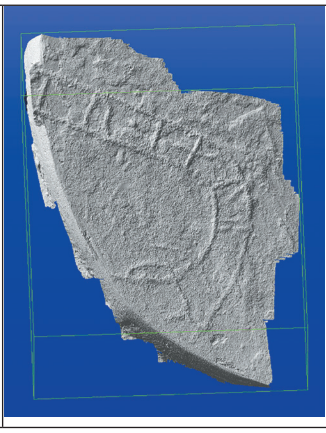
Knudsker		... May Christ help the soul (?)...	**...tr : ialb(i) (:) (s)...**	

Figure 1. Fact box: Runestones in the investigation. 3D-scanned in September 2017. Photo: Roberto Fortuna, National Museum of Denmark, CC-BY-SA. 3D-image: The new find in St. Knud. 3D-scanning by Teddy Larsson, S3Di; picture by Laila Kitzler Åhfeldt 2017.

(Figure 1; Eilsøe 2017; Kitzler Åhfeldt 2017; Imer & Kitzler Åhfeldt, forthcoming). The runestone fragment is incorporated in the wall above the door leading from the late medieval porch into the nave, in other words, over the original entrance to the church (Figure 3). In *Danmarks Kirker* the stone is said to be of yellowish granite (Danish 'gullig granit'), but it is not perceived by the editors as a runestone (Norn, Schultz, and Skov 1954, 184-185). The extant runes **...tr : ialb(i) (:) (s)...** are part of a Christian prayer, 'May Christ help (the soul)'.

Method

The eight runestones mentioned above have been analysed by a method for groove analysis on runestones that was first developed at the Archaeological Research Laboratory at Stockholm University (Kitzler Åhfeldt 2002) and has been used in several recent studies to examine different problems. From the high-resolution 3D-models, we have excerpted a number of variables (Figure 4), describing different properties of the grooves, with the aid of special software[2] designed for the purpose. These variables are employed to study similarities and differences between the grooves on different runestones, different parts of the same carving, and also to investigate relations between, for example, certain monument groups or geographical areas. That part of the analysis can be varied and it is under continuous development (e.g. Kitzler Åhfeldt 2012; 2015; 2016). Like many other laboratory methods, it functions best if the results are discussed in relation to previous studies and other indications, in an archaeological and runological discourse.

Figure 3. The runestone Knudsker above the door leading from the late medieval porch into the nave. Photo: Roberto Fortuna 2019, National Museum of Denmark CC-BY-SA.

On each runic inscription, we have selected a number of runes and parts of the ornamentation. From Bornholm there is a total of 253 samples, 151 of which are runes and 102 ornamental details (runic bands, crosses; Table 1). In further steps of this spe-

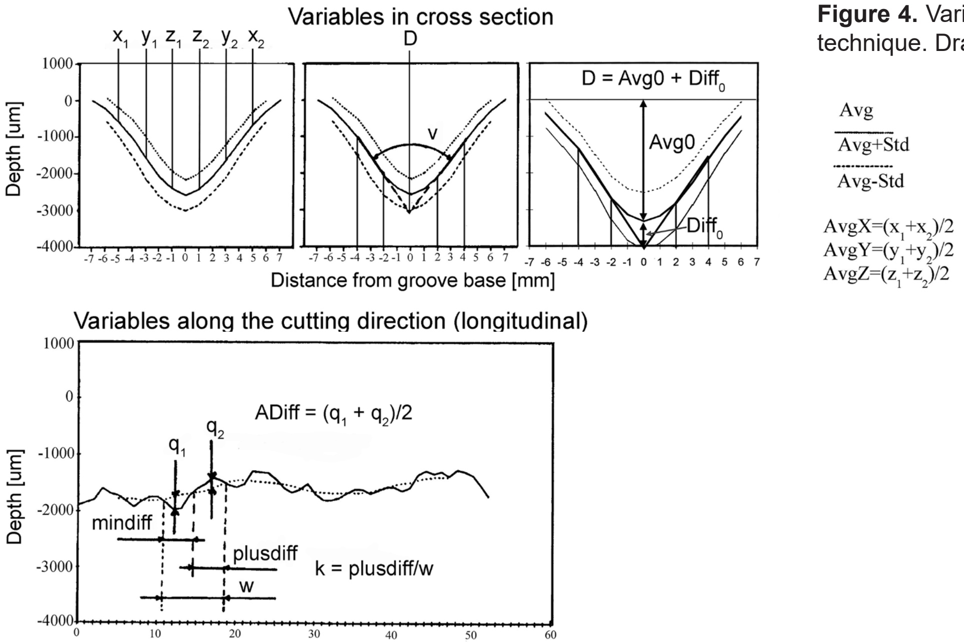


Figure 4. Variables for analysis of carving technique. Drawing: Laila Kitzler Åhfeldt.

cific analysis, each runestone is represented by two mean values, one for the runes and one for the ornament and the variables used are v, D, k, w (Figure 4).

The runestones were analysed with multivariate statistical methods in STATISTICA 9. Hierarchical cluster analysis (*Cluster Analysis*, CLU) is used here, with Ward's method and Euclidean distances. Cluster analysis is about detecting groups in data (in artificial intelligence this is also called *unsupervised pattern recognition*) (Everitt et al. 2011, 7). Cluster analysis can be performed according to different algorithms that have slightly different properties and thus can give different results; for a discussion of these see e.g. Michael Baxter (2016). The cluster analysis begins with standardisation of the variables, which gives them the same weight in the analysis even if they are in different units and of different size (Baxter 2016, 54).

Multivariate analyses in general look for patterns in data, but different choices can be made among the calculation algorithms and the material to be included, and the results will be affected by this. We may mention briefly that the choices made here are based on results obtained in previous methodological studies and grounded in empirical material. For the theoretical reasoning behind multivariate analyses and applied statistics, readers are referred to works on statistics concerning archaeological material (e.g. Baxter 2016).

Relations within Bornholm

As we saw above, some of the runestones in the sample were presumed to be made by the same carver on account of similar rune forms or ornamentation. The first group consists of Nylarsker 1 (DR 379), Nylarsker 2 (DR 380), and Nyker (DR 389). Due to similarities in rune forms and ornament, Moltke suggested that they belonged to the same carver or workshop (see above; Group 1 in Table 1 and Figure 1). The second group include Østermarie 2 (DR 391), Østermarie 3 (DR 392), and Klemensker 4 (DR 402; see above; Jacobsen and Moltke 1942; Group 2 in Table 1 and Figure 1). The two first partly mention the same names, while Klemensker 4 are connected to them by certain rune forms (Jacobsen and Moltke 1942, 935;). Klemensker 1 and Knudsker have no obvious connections to the other stones in the sample. Can this grouping be confirmed by similarities in carving technique or will other relations emerge?

The result of the cluster analysis falls out differently, as is shown in a tree diagram (Figure 5). The runestones appear to fall into three groups and they reveal something interesting. The result differed from what we expected because the runestones are not grouped according to the forms of the runes, nor the ornamentation, but according to the names of the individuals who raised the stones:

1) Sassurr is sponsor (DR 379) or father to the sponsor (DR 402). DR 399 is joined to this group (Figure 6).

Name	Signum in SRD	Entry in Danske Rune-indskrifter	Style[1]	Comment in SRD[2]	Grouping[3]	Rock art type	Analyzed runes/ sections of ornament
Nylarsker 1	DR 379	DK Bh 33	Pr3	Possibly the same carvers as in DR 372, 380, 387 and 389	Group 1	Sedimentary	25/23
Nylarkers 2	DR 380	DK Bh 34	RAK	Possibly the same carvers as in DR 372, 379, 387 and 389	Group 1	Sedimentary	21/10
Nyker	DR 389	DK Bh 31	Pr3	Possibly the same carvers as in DR 372, 379, 380 and 387	Group 1	Sedimentary	26/17
Østermarie 2	DR 391	DK Bh 52	RAK	Similar names as in DR 392, but looks different	Group 2	Metamorph	20/7
Østermarie 3	DR 392	DK Bh 53	RAK?	The same carver as in DR 401, 402, 406 and 408	Group 2	Metamorph	15/16
Klemensker 4	DR 402	DK Bh 4	Pr2	The same carver as in DR 392, 401, 406 and 408	Group 2	Metamorph	17/12
Klemensker 1	DR 399	DK Bh 1	RAK[4]			Metamorph	22/12
Knudsker		DK Bh 69				Metamorph	5/5
						Number of samples	151/102
						Total	254

[1] According to style groups in Gräslund 2006, here based on SRD.

[2] Based on Jacobsen & Molte 1942.

[3] Based on Jacobsen and Moltke 1942.

[4] This is not exactly RAK, as there are spiral ornaments.

Table 1. Analysed runestones.

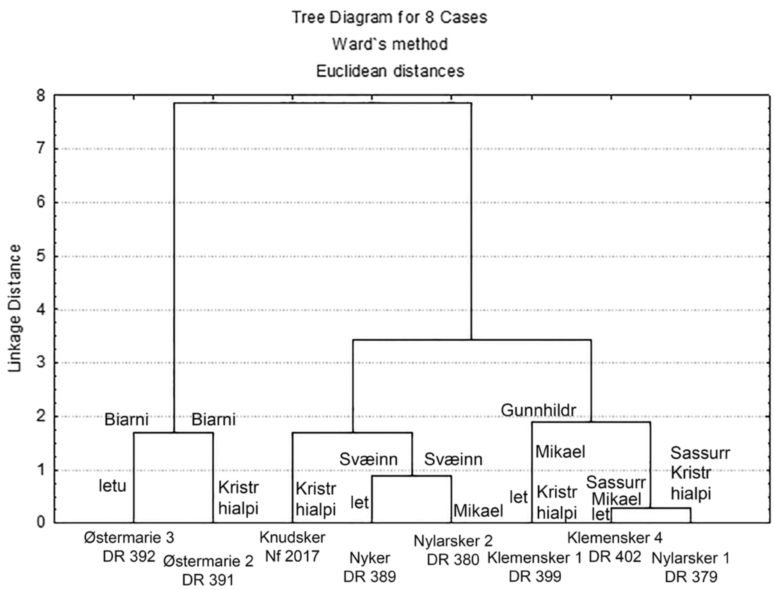


Figure 5. Tree Diagram. Result of Hierarchical Cluster Analysis, Ward's method, Euclidean distances. Drawing: Laila Kitzler Åhfeldt.

a) b) c)

Figure 6. Grouping according to result: Sassur's family. Not in scale. Photo: Roberto Fortuna, National Museum of Denmark CC-BY-SA.

a) Nylarsker 1 (DR 379). Sassurr had the stone raised in memory of Hallvarðr, his father, (who) drowned abroad with all the(?) seamen. May Christ ever(?) help his soul. May this stone stand in memory.

b) Klemensker 4 (DR 402). Øylakʀ had this stone raised in memory of Sassurr, his father, a good husbandman. May God and Saint Michael help his soul.

c) Klemensker 1 (DR 399). Gunnhildr had this stone raised in memory of Auðbjǫrn, her husbandman. May Christ help Auðbjǫrn's soul into light and paradise. May Christ and Saint Michael help the souls of Auðbjǫrn and Gunnhildr into light and paradise.

a) b) c)

Figure 7. Grouping according to result: Svæinn's family. Not in scale. Photo: Roberto Fortuna, National Museum of Denmark, CC-BY-SA. 3D-image: The new find in St. Knud. 3D-scanning by Teddy Larsson, S3Di; picture by Laila Kitzler Åhfeldt 2017.

a) Nylarsker 2 (DR 380). Svæinn (the Hooded? son of Kāpa?) raised this stone in memory of Bø̄si, his son, a good drængʀ, who was killed in battle at Ūtlengia. May Lord God and Saint Michael help his spirit.

b) Nyker (DR 389). ... had this stone raised in memory of Svæinn, his son. A very good drængʀ, ... and (in memory of) his brother. May holy Christ help the souls of both these brothers.

c) Knudsker (DK Bh 69). … May Christ help the soul (?).

a)

b)

Figure 8. Grouping according to result: Biarni's family. Not in scale. Photo: Roberto Fortuna, National Museum of Denmark, CC-BY-SA.
a) Østermarie 2 (DR 391). Barni/Biarni and Sibbi and Tōfi they raised (the) stone in memory of Ketill, their father, May Christ help his soul.
b) Østermarie 3 (DR 392). Barni/Biarni and Tōfi and Āsgautr had (the) stone raised in memory of Sibbi, their brother. May Christ help (his) soul.

a. DR 379: Sassurr had the stone raised in memory of Hallvarðr, his father …
b. DR 402: Øylakʀ had this stone raised in memory of Sassurr, his father...

2) Svæinn is sponsor (DR 380) or son of the sponsor (DR 389). The stone fragment Knudsker is joined to this group (Figure 7).
a. DR 380: Svæinn (OD: *Kåbe(?)-Svend*; of the hooded cloak? son of Kǭpa?) raised this stone in memory of Bøsi, his son...
b. DR 389: ... had this stone raised in memory of Svæinn, his son. A very good *drængʀ*, ... and (in memory of) his brother...

3) Biarni and Tōfi are sponsors, together with Sibbi (DR 391) and Āsgautr (DR 392) respectively (Figure 8).
a. DR 391: Barni/Biarni and Sibbi and Tōfi they raised (the) stone in memory of Ketill, their father...
b. DR 392: Barni/Biarni and Tōfi and Āsgautr had (the) stone raised in memory of Sibbi, their brother...

Our first observation is that the rune carvers have a connection to the sponsor family, here Sassurr's, Svæinn's, and Biarni's families (or families where these names are common). This is to say that the pairs of runestones that are most like each other in carving technique are also linked through the names Biarni, Svæinn, and Sassurr. The carving technique on the Gunnhildr stone, Klemensker 1, most resembles the stones of the Sassurr family, but it is hard to determine whether it is the same carver. Knudsker is most similar in its carving technique to the stones of the Svæinn family, but here too it is difficult to ascertain whether it is the same carver.

Nylarsker 1 (Pr 3) was raised by Sassurr, while Klemensker 4 (Pr 2) was erected in memory of a Sassurr, but the styles suggest that they were raised in the opposite order. The reason may be a large overlap between the style groups, as is known from elsewhere. It may also be the case that the name Sassurr was passed on from father to son or to the grandson. Although Nylarsker 1 and 2 were both found in Nylars church, and thus possibly were both erected at a nearby place, there is nothing in the carving technique to connect them. Moltke believed that Nylarsker 1, on account of runological, inscriptional, and ornamental similarities, belonged to the same workshop, master, or school as Nylarsker 2 and Nyker (Moltke 1934, 10). This was also discussed at the field runologists' meeting in 2015. Judging by the carving technique, however, Nylarsker 1 belongs to a different group.

On Østermarie 2 the brother Sibbi is one of those who raised the stone, while on Østermarie 3 he has died. Here too some time has elapsed, but we do not know how long.

For Svæinn too we see this time lapse: on Nylarsker 2 he raises the stone, on Nyker he is dead. Strictly speaking, we do not know that it is the same Svæinn, but the link between these stones as regards the rune carvers may be an argument for it. If so, Svæinn may possibly go under the name Kǭpu-Svæinn 'Svæinn the Hooded?/son of Kāpa(?)' on Nylarsker 2, while he is called simply Svæinn on Nyker.

Saint Michael is invoked three times, by Svæinn on Nylarsker 2, by Gunnhildr on Klemensker 1 and by Sassurr on Klemensker 4. Did Gunnhildr and Sassurr on the two Klemensker stones have the same carver? If so we may have a weak indication that this carver favoured Saint Michael. In the future it could be interesting to analyse Østerlarsker 2, the fourth runestone that mentions Saint Michael. This is one of several variants of runic prayers for the soul, which Per Beskow believes have their origin in the Christian missions. They have a wide distribution ranging from Denmark to the Mälar basin, even though they are most common in Uppland and on Bornholm (Beskow 1994, 19; see also Zilmer 2013, 134).

On the other hand, there is no link between rune carvers and the prayer *kristr hialpi*. The prayer that begins *kristr hialpi* occurs four times, distributed in all the groups. The sponsor formula with the auxiliary verb *lāta*, which has sometimes been considered a high-status marker (Højgaard Holm 2014, 269), occurs in all the groups and is thus not linked to the carver either. In each name group there are runestones both with and without an auxiliary verb in the sponsor formula.

What is interesting about the very fragmentary inscription on Knudsker is that the verb 'help' appears to be spelled *ialbi*, that is, without the initial *h*. This spelling is rather rare, but it does occur on two other runestones, erected on the other side of the island, namely on Østermarie 1 and Østermarie 3. Østermarie 1 was not 3D-scanned this time, so only future studies can determine whether the two runestones were made by the same carver. But Østermarie 3 was examined as part of this project, and the result shows that Knudsker and Østermarie 3 have some shared regional features but were probably not carved by the same person. On the Bornholm runestones there are also some other examples of loss of *h*, and this is usually regarded as a dialectal feature in the eastern Danish area, since it is also found in some of the Scanian runic inscriptions and manuscripts (Jacobsen and Moltke 1942, 788).

The scanning thus appears to support the interpretation that it is a question of a special dialectal feature, since Østermarie 3 and Knudsker belong to separate groups.

Limitations and Sources of Error

The tree diagram shows which runestones have the greatest similarities in the grooves. It is very difficult to say, however, whether the groups in the tree diagram from the cluster analysis definitely show different carvers. For cluster analysis there are no general rules for where to cut off the tree, and therefore the interpretation of how many groups there are is partly subjective (Baxter 2016, 63). It can also be a problem that different cluster methods give different results. If there is a real structure, however, different methods ought to give similar results, that is to say, stable clusters (Aldenderfer and Blashfield 1984; Baxter 2016, 68). A common difficulty in the application of cluster methods is the effect of what can be called 'noise', which can be anomalies, small deviant clusters, or cases where membership of a cluster is uncertain, for example, because something could be sorted in more than one cluster. The cluster methods give a sharp assignment to one group, even if there are close alternatives. Here we use Ward's method and Euclidean distances, since that has yielded good results in method studies (Kitzler Åhfeldt 2002). The same experience has been gained in other empirical studies in archaeology, where Ward's method is generally preferred (Baxter 1994). Euclidean distances are better than other distance-calculation methods at recognising non-spherical structures and are less sensitive to anomalies (Baxter 2016, 77).

The result differs slightly from Moltke's grouping according to rune forms and ornamentation. The consequence is that features which, according to Moltke, could belong to a special carver are shared by more than one carver. The new division, however, can be reasonably explained by the rune carvers being connected to the sponsor families. It is impor-

Figure 9. Distribution of runestones on Bornholm. Map: Rasmus Kruse Andreasen. With permission.

tant to note that both metamorphic and sedimentary rocks occur in the study, but the stratification follows the sponsors, not the rock types.

Discussion

Among the runestones included in the study we see several features that are often discussed in connection with Bornholm runestones, namely the prayer *kristr hialpi*, the auxiliary verb *lāta* in the sponsor formula, and the invocation of the archangel Michael. None of these is associated with any of the individual rune carvers, judging by the results of this analysis. These features appear instead to be shared features of Bornholm runestones, or perhaps rather chronological characteristics. The archangel Michael is also mentioned on the Tillitse stone (DR 212) from Lolland, which is dated to the mid eleventh century, and the formula *kristr hialpi* is used on the Vapnö stone (DR 352) from Halland, presumably with the same dating. The formulae could perhaps be interpreted as a fashion during the eleventh century, best expressed on the Bornholm stones because the runestone custom here was strongest during this period. On the other hand, the carvers appear to be linked to the families that raised the stones, here represented by Sassurr, Svæinn, Biarni, and Gunnhildr. One can therefore question the claim that the auxiliary verb *lāta* is a status marker. The Bornholm runestones were rather erected by particular families on their own farms, and there seems to have been a flat social structure without a special centre on Bornholm during the late Viking Age and early Middle Ages.

The rune carvers on Bornholm are clearly connected to the families, as is clear from the fact that similarities in carving techniques coincide with the name connections. This means that the technical analyses of the grooves on the runestones fit very well with societal and structural evidence that we have from Bornholm.

The organisational development from the Iron Age to the Viking Age on Bornholm is associated with Sorte Muld, which was the major centre for trade and power in the Iron Age, and one cannot help but wonder whether the king that Bornholm had, according to the merchant Wulfstan around 890, lived here. Late in the tenth century and at the start of the eleventh, Sorte Muld was reduced to a few individual farms (Aarsleff 2008, 119-120; Watt 2008, 26-27).

After this the settlement structure was different. Single farms popped up all over the island and have later been found by field surveys and metal detector searches. The settlements are characterised by features such as Baltic ware, weights, and coins, and they are often found adjacent to the present-day farm (Nielsen 1994, 125-129). As the settlement structure changed, the number of hoards deposited on the island increased, often close to the known settlement units. This suggests that no new powerful trading centre was established on Bornholm after Sorte Muld, and that the island was not ruled by one person. At the same time, the composition of objects and coins in the hoards suggests that Bornholm was an independent economic unit in the Baltic Sea in the eleventh century, which had closer links with Scania and the Slavic lands than with the rest of Denmark (Ingvardson 2010, 334-345).

It is against this societal background that one should view the growth of the runestone custom on Bornholm. Today a large share of Bornholm's runestones are gathered in and around the island's churches, but this current distribution bears little resemblance to where the runestones originally stood. It is characteristic of Bornholm's runestones that there is no sure evidence of their original places. More than half have been found at the churches, where they have either been discovered in the churchyard or are walled into the churches. Some of them might possibly have stood at the churches from the beginning, if the churches were built at the site of larger farms or earlier burial grounds. But almost half have been found as parts of bridges over rivers or at fords, or associated with the single farms that appeared on the island in the course of the late Viking Age or early Middle Ages. This sketch of the distribution of runestones shows a picture of the finds which is as scattered as a map of the island's hoards and the late Viking-Age and early medieval settlement (Figure 9). It is possible that some of the runestones can be linked to the documented settlement remains, for example, Åker 1, also called the Grødby stone, with a find history going back to Ole Worm's time, when according to the priest's report it was 'In Grødby at Jørgen Vdi's farm', and Worm informs us that it was placed in a bridge that was called 'Runebroe' or Rune Bridge. Later the stone fell into oblivion, but it was found again in 1819, then in Grødby bridge south of Åkirkeby and west of Pedersker (Jacobsen and Moltke 1942, 423). Grødbygård is one of the farms in Åker parish with roots going all the way back to the late Viking Age and early Middle Ages (Nielsen 1994, 127). The same pattern applies to Klemensker 1 and 4, which are dealt with in this article. Klemensker 1 was laid over a stream close to Brogård (Jacobsen and Moltke 1942, 457–458). Brogård likewise goes back to the late Viking Age and early Middle Ages (Nielsen 1994, 127). And Klemensker 4, which is also called the Marevad stone, was built into the bridge over a stream between the lands of Marevad and Pilegaard (Jacobsen and Moltke 1942, 461). Pilegaard too has roots in the late Viking Age and early Middle Ages. It is therefore not unreasonable to assume that many runestones originally had a central location at the single farms that popped up during the eleventh century.

When one follows this line of thought it is natural that the rune carvers are linked to the individual families and perhaps can even be found as members of the families. This strengthens an earlier proposal that the carvers can be seen as representatives of their households and their connections may reflect the social networks of their families (Kitzler Åhfeldt 2015). We have here a decentralised society, where power was in the hands of the separate families. Trade was pursued on the individual farms, and wealth was amassed within the individual family. This also accords well with the fact that we rarely find titles like retainers or estate-stewards among the runestones on Bornholm, because such professions were unnecessary in a family-based society. The many hoards may indicate that Bornholm was especially vulnerable to plundering (Ingvardson 2010), which presumably is also a sign that power was divided between many people, each seeking their own protection.

On Bornholm, then, there was no professional rune carver who travelled around with commissions to carve runestones. Although there was a certain consensus about form and style in eleventh-century runestones, the runestones are also expressions of the decentralised structure. This suggests some exciting perspectives concerning who could carve runes at the end of the Viking Age and the start of the Early Middle Ages.

Conclusion

The above studies suggest that the carvers of the runestones should be sought within the individual families. We do not know how many wealthy families there were on Bornholm during this period, but the many single farms, the hoards, and the relatively large number of runestones distributed over the whole island indicate that there were quite a few. If we reckon, as the analyses suggest, that there was at least one rune carver in every family, we have indirect evidence that the culture of runic writing was more widespread at the start of the Middle Ages than we have hitherto assumed – regardless of the fact that the inscriptions are primarily preserved on stone. One can also discuss, further, whether the rune carvers were the only individuals in each family who knew runes, or if it was a part of a person's cultural education to learn to read and write runes. In any case, the analyses suggest that there was no need for help from outside to carve runes, neither in the Viking Age nor later.

The analyses have shown that the Bornholm rune carvers were linked to particular families, and that the individual rune carvers were following the different fashion currents of the time. One can possibly envisage contacts on a personal level with rune carvers from central Sweden, through reciprocal visits and travels, in view of the fact that comparisons between carving techniques on Bornholm's runestones and areas such as Öland, Gotland, and mainland Sweden appear to indicate Södermanland as particularly interesting (Kitzler Åhfeldt 2019). In our opinion, however, cooperation between rune carvers need not have any connection whatever to either royal power or the unification of kingdoms. We have also shown that the individual families can perhaps be linked to some of the single farms that grew up on Bornholm in the late Viking Age and early Middle Ages, replacing the previous highly centralised societal structure. Perhaps Gunnhildr, Auðbjǫrn, and their family, known from Klemensker 1, lived at Brogård, while Sassurr and his family lived at Pilegård in Klemensker parish. Future studies may show whether the same pattern can be seen for other Bornholm runestones which can be grouped together by virtue of associated names. If so, we see a Bornholm society that differed noticeably from the results we know from studies of Swedish runestones.

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Notes

1. This workshop, named *Relations and Runes: The Baltic Islands and their interactions during the Late Iron Age and Early Middle Ages*, was a joint venture between the research projects 'Everlasting Runes: A digital research platform for Sweden's runic inscriptions' and 'The Viking Phenomenon'.
2. The Groove Measure function in DeskArtes Design Expert, along with special calculation templates.

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The DIME project - Background, status and future perspectives of a user driven recording scheme for metal detector finds as an example of participatory heritage

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ABSTRACT
In September 2018, the DIME portal was officially launched to facilitate the user driven recording of metal detector finds produced by members of the public. The concrete and operational aim of DIME is to provide a portal for the registering and hence safeguarding of the increasing number of metal detector finds and to make them accessible for the general public and for research. The more overarching vision behind the DIME project is to realise the potential of recreational metal detecting as a medium to implement an inclusive and democratic approach to heritage management in Denmark and to advance the incorporation of principles of citizen science and crowdsourcing in museum practice. This article intends to present the background of the DIME portal's development, its basic functionalities and their technological underpinning as well as the overarching vision behind DIME.

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Background of DIME

Over the last decades, recreational metal detecting practiced by amateur archaeologists has produced some of the most significant archaeological discoveries in Denmark. The formal heritage sector, from the very beginning of metal detector archaeology in the late 1970s and early 1980s pursued a liberal model based on cooperation and inclusion rather than confrontation and criminalization. Since then recreational metal detecting has developed into an increasingly popular hobby, and the number of trea-

Figure 1. Two situations symptomatic for the cooperative nature of recreational metal detector archaeology in Denmark. Top: museum curator and amateur finder during one of the recurring 'find-evenings' arranged by the Funen based amateur archaeologist association Harja and the five archaeological museums in the Funen area (Photo: Bo Grønhøj). Bottom: Large scale metal detector surveying at Hindsholm, Funen on the occasion of the annual 'Bifrost rally' in 2013, arranged by Harja in cooperation with Østfyn's Museer (Photo: Claus Feveile).

sure trove ('Danefæ') finds has skyrocketed; a trend that looks as though it will continue in the years to come. (Figure 1)

Recreational metal detector archaeology is a subject of great controversy and official stakeholders' attitudes and practical approaches towards the phenomenon differ across Europe and within individual countries.[1] In Denmark, both the general public and the official heritage sector generally consider recreational metal detecting a positive contribution to Danish archaeology. Not only has it radically altered the understanding of central aspects of Scandinavian societies during the metal-rich periods, it has also opened new research perspectives. Furthermore, as an integrated tool of heritage practice, metal detecting has secured an important part of cultural heritage and ensured the identification of countless archaeological sites which otherwise would have been in danger of irreversible destruction (Henriksen 2005; Andersen & Nielsen 2010; Baastrup & Feveile 2013). The success of the liberal Danish model, where everyone is free to use metal detectors with the landowners' permission, except protected sites and monuments, is based on a complex interplay of legislative, historical, cultural and social parameters, which to a large extent are specific if not even unique for the cultural context of Denmark (Dobat 2013).

Although also internationally acknowledged as a success story of Danish Archaeology, the rising popularity of recreational metal detecting has led to a number of problems, both for the growing community of detector users and the heritage sector (Ulriksen 2012; 2014; Feveile 2015; Dobat 2016). The lack of a national strategy and an appropriate infrastructure to support the central recording of finds has led to a situation where the enormous research potential of detector finds across local museum collections is difficult to exploit. In Denmark, a comparably large number of local museums have the archaeological responsibility in a given area (including conducting all development driven archaeology). This entails the collecting and recording of metal detector finds from the museum's area of responsibility and forwarding them to the National Museum for evaluation under the treasure trove 'Danefæ' scheme ('Danefæ' legislation under part 9 of the 'Consolidated Act on Museums'). However, only a small fraction of the many old and new finds is accessible to the broader public today. The enormous number of finds handed over to local museums and the Danish National museum have developed into an administrative burden at the affected institutions; and have in fact resulted in a collapse of the load capacity within the system.[2] (Table 1)

Representatives of the heritage sector have long called for a central infrastructure facilitating the recording of detector finds and the administrative workflow under the treasure trove (Danefæ) scheme. Detector users have expressed similar attitudes or started on the development of digital tools for find recording and display.[3]

Until now, different recording practices and formats have been applied in the recording of metal detector finds at the Danish museums, ranging from traditional analogue recording in handwritten journals over standard and partly user-generated excel spreadsheets to existing central recording portals used by museums and the Danish heritage agency (Slots- og kulturstyrelsen). However, the various systems used until now were designed to primarily support administrative processes but do not support the use of metal detector finds for research or public dissemination. The best place for the public, detector users and heritage professionals alike to keep track of new finds and gather research data have been user driven Internet platforms and social media fora (detectingpeople.dk; Facebook Group 'Detector Danmark'). Hence, in their treatment of the growing number of detector finds, the Danish museum sector has until now hardly complied with the ideals of public accessibility, usage, research and enlightenment which underline current international and national heritage legislation, and which often are emphasized by policy and decision makers.

Building bridges – goals and principles of the DIME project

In 2016, and thanks to a generous donation by the KROGAGER FOUNDATION, Aarhus University (Andres Dobat) initiated the development of a user driven recording platform for metal detector finds. A first version of the DIME platform was designed by Peter Jensen and the Unit of Archaeologi-

Year	Σ Unique finds(sent to the NM for Danefæ evaluation)	Σ Unique finders*** (who received Danefæ compensation)	Σ treasure finds*	Σ Danefæ compensation (DKK)	Σ members FB group 'Detektor Danmark'	Σ members FB group 'Detektor Danmark' (with detectors)****
2011	?	202	3,001	?	?	?
2012	3,061	?	3,412	856,600	100	?
2013	4,333	?	4,367	1,184,373	?	?
2014	7,176	?	5,312	3,044,100	1,000	?
2015	9,756	?	3,516	4,231,775	2,000	?
2016**	17,055	251	5,004	3,661,950	3,000	652
2017**	14,364	379 (?)	9,634	3,160,000	4,000	653
2018**	17,385	447 (?)	21,971	7,680,000	5,066	655

Table 1. Recent developments in annual numbers of finds and finders as well as total amount of Danefæ (treasure trove) compensation, in Denmark (data: Danish National Museum). For a statistic over annual find numbers before 2011 see Dobat 2013.

*Σ treasure finds does not necessarily reflect Σ of incoming finds per year but more institutional priorities and level of investment in Danefæ processing at the National Museum in given time interval.
** All numbers are subject to change due to the backlog of the Danefæ processing at the NM, i.e. the many Danefæ cases still in process.
*** As Danefæ legislation also applies to non-metal finds, an unknown (though very small) part of unique finders are not metal detectorists.
**** according to polls conducted among group members.

cal IT at Aarhus University and Moesgaard Museum, and was launched on 20th September 2018.

The initial development of DIME was part of a research project, based at Aarhus University and was overseen by a larger project consortium, which also involved Moesgaard Museum (Mads Holst & Stine V. Laursen), Nordjyllands Historiske Museer (Torben Trier Christiansen) and Odense Bys Museer (Mogens Bo Henriksen). Throughout the development process, the project group cooperated intensely with future users, in particular Danish detectorists and museum professionals.

From its inception the project consortium behind the DIME portal have worked towards a user-driven platform that would build a digital bridge between different user-groups: Danish metal detectorists, curators at the Danish museums, the general public, and researchers. The more specific goals guiding the design and development of the scheme were:

- To ease and expedite the recording workflow and **administrative processing** of detector finds at Danish Museums.
- To make detector finds and contextual data and information accessible to the **broader public and researchers**
- To provide a recording tool for amateur detectorists, functioning as a **digital find-diary** enabling them to keep track of finds and sites
- To provide a technological foundation that **stimulates and enhances cooperation and exchange** between amateur practitioners, curators and researchers
- To provide a central forum for **disseminating and promoting best archaeological practice** in the field when searching for and recording public finds
- To support **migration and sharing of data by other central databases** both on a national level (The Sites and Monuments Record, MUD, the SARA system) and on an international level (e.g. ARIADNE)

As prerequisite to achieve these goals, the design and development of DIME was governed by a number of basic principles:

- **User engagement**: DIME would encourage metal detector users to record their own finds, i.e. to upload basic data (GPS coordinates and images) and to at least attempt to provide data (dating frame, classification, description, etc.) for finds. In addition, DIME would facilitate knowledge exchange between finders and allowing users to provide feedback on each other's finds.

- **'Simple is beautiful'**: Given the very heterogeneous composition of the Danish detector community, the ambition of user engagement required a broadly accessible and 'intuitive to use' user interface and data structure that would both enable the less experienced user to fulfil minimum requirements, while at the same time allowing the more experienced user to provide additional data and information.
- **Interoperable data**: In light of the current development towards digital infrastructures and increased data exchange across dispersed datasets and repositories DIME was to be designed as a portal facilitating direct migration of data into other data repositories and collection management tools, both on a national and an international scale (e.g. MUD, SARA, ARIADNE, etc.)
- **All finds are valuable**: As the legally based differentiation of treasure-trove and non-treasure-trove has resulted in different registration standards and an unfortunate division of institutional responsibility (local museums versus Danish National Museum) DIME was to be designed to accommodate the recording of all finds, disregarding their potential status under the treasure trove scheme or their chronological context.
- **Open source**: To enable other metal detecting, heritage management and research communities to re-use elements of the DIME portal in the development of comparable portals for other contexts, the system should be built using exclusively open source technology.

During the first two months after the portal's official launch (as of May 2019), more than 1330 detector users have joined the community and uploaded all together more than 26700 individual finds. In addition, employees from 28 museums have been granted 'museum-user access' rights and the respective institutions have begun to incorporate DIME into their administrative practice.

Participatory heritage – the vision behind DIME

Danish metal detector archaeology embodies some of the celebrated hallmarks of Danish Archaeology with its long tradition for broad public appeal, inclusive discourse, citizen involvement and decentralized structure of the formal heritage sector (Kristiansen 1981; Lyngbak 1993; Hansen & Henriksen 2012). For the practitioners it is a recreational hobby, but it is also a legitimate way of entering into a dialogue with the past. In the case of the latter, it is genuinely democratic in character as it provides a means for members of the public to directly and actively engage with tangible elements of cultural heritage, disregarding educational, cultural or social preconditions. Instead of passively consuming expert knowledge and narratives, detector users cherish the idea of actively contributing to the writing of history with their findings – a claim that both detector associations and individual practitioners actively promote as being their most central incentive (Dobat 2013; Dobat & Jensen 2016).[4]

In this light, the Danish case of recreational metal detecting and the DIME project resonate well with internationally recognised visions for the social relevance of archaeology and heritage; not least the ambitions of the European Faro Convention (Faro 2005), which in Article 12: access to cultural heritage and democratic participation, promotes the idea that human values should be at the centre of cultural heritage, and that everyone should be able "*to participate in the process of identification, study, interpretation, protection, conservation and presentation of the cultural heritage*".

The DIME project presumed that the individual members of the Danish metal detector community should (and are willing to) be integrated into the workflow of find recording. It therefore was one of the most noteworthy results of the '2015 Danish detectorists survey' (Dobat & Jensen 2016), that 83 % of the respondents expressed the wish to participate in the find registration process at museums (5 % replied not be willing to upload data).

The embracing of the principle of 'user engagement' was partly based on plain economical reasoning, as the growing numbers of finds is increasingly difficult to manage by professional staff at museums. Hence, user engagement in the sense of basic voluntary support of the public sector, was chosen as a means to ensure the economic sustainability of future find registration, and to establish a functional model for the future management of incoming metal-detector finds in Denmark.

The main reason, however, why the DIME project aimed to develop a user driven recording portal was the ambition to stimulate and advance an inclusive and democratic approach to heritage management in Denmark. It was the vision of the project group that the DIME portal should function as a best practice example for the incorporation of principles of citizen science and crowdsourcing in museum practice.[5]

Engaging members of the public to contribute to the registration of their finds can be considered not only a more sustainable, but also a more rewarding path towards a solution of the capacity overload at many Danish museums. It at least holds the potential to not only lessen the administrative burden presently on the shoulders of professionals, but also to add additional value to metal detector finds as a forum and medium of public engagement with cultural heritage. (Figure 2)

Already the initial design and development of the DIME platform took form of a citizen science project, as the mapping of detector user's attitudes and practices as well as practitioners' ideas and suggestions were included as guiding principles for the design and implementation of DIME. The principles of 'citizen science' and 'crowdsourcing', i.e. Public Participation in Scientific Research (PPSR) (Bonney et al. 2009) have become increasingly relevant in very different branches of science over the past decades. Danish recreational metal detector archaeology typically falls into the basic level of PPSR as developed by Bonney et al. (2009):

'Contributory projects - initiated and designed by professional scientists for which members of the public contribute data'.

With few notable exceptions, the role of Danish detector users is limited to that of 'finders', as the majority of practitioners are rarely involved in the museum's analysis of finds and/or sites, or the development of guiding research questions and methodological frameworks for the further investigations of specific assemblages.

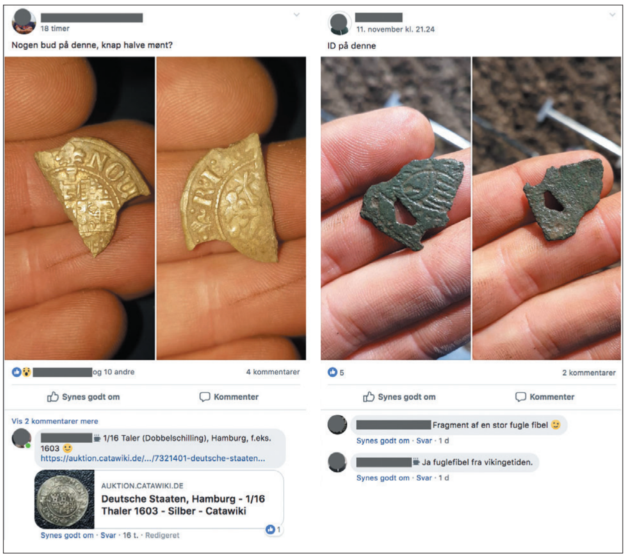

Figure 2. Typical examples for 'find posts' by detector users requesting ID (meaning classification and dating) in the Facebook group 'Detektor Danmark'. It is this existing practice for knowledge sharing the DIME portal taps into (picture: Facebook).

At the same time, however, many representatives of the Danish metal detector scene engage with not only 'their' finds and sites, but also with analytical aspects to a level that would justify their work as falling under a higher level of Public Participation in Scientific Research as developed by Bonney et al. (ibid): 2)

'Collaborative projects (initiated and designed by professional scientists in which members of the public contribute data and help to refine project design, analyse data and communicate results)'

And:

'Co-created projects (initiated and designed by professionals together with members of the public crowd, in which both parts are actively involved in most steps of the research process).[6]'

Recreational metal detecting in Denmark has challenged the classic division of roles in archaeology and heritage management, with amateur collectors producing finds but otherwise being more or less passive recipients of professional authorities' expert knowledge. At least a large part of the Danish detector community can be characterized as not only very committed to their hobby but also highly competent, both with respect to the recording of relevant contextual data in the field and the identification and dating of finds.

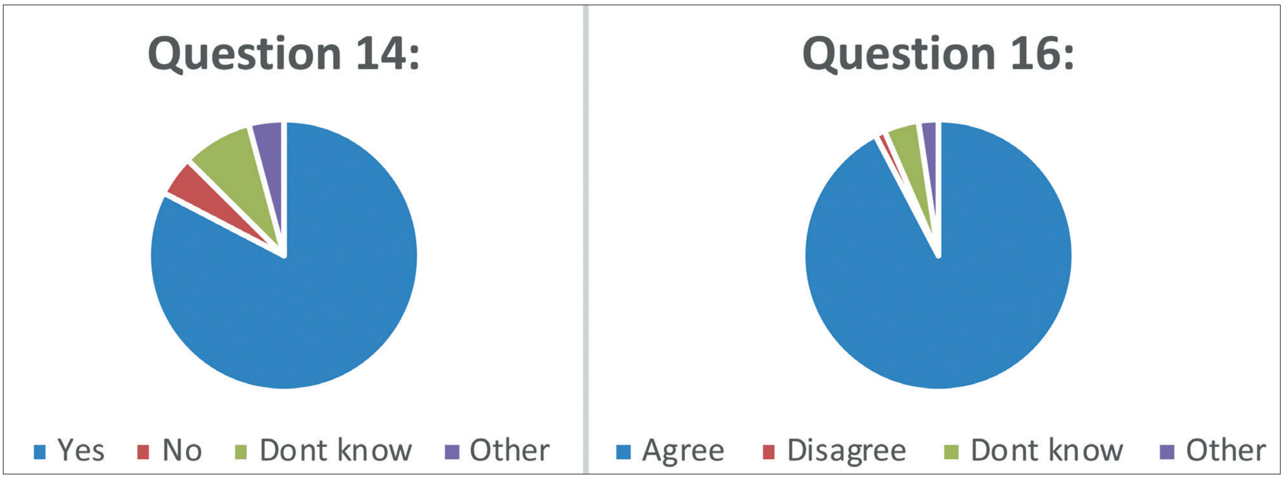

Table 2. Results of the ‘2015 Danish detectorists survey’. Question 14: Would you be willing to upload finds in a publicly accessible online scheme (provided that find-spots were hidden for members of the public and only accessible for archaeologists and researchers)? Question 16: Disagree or disagree to the following statement: I consider it important that finds and contextual data are accessible for archaeologists and researchers! (Data: ‘2015 Danish detectorists survey’, Dobat and Jensen 2016).

The digital social media have played a crucial role in the building of know-how and competence within the Danish detector community. Especially the various Facebook groups (e.g. Detektor Danmark, CPE International ID Group, etc.) have proven to provide forums for exchange on the possible identification and dating of finds and even professionals are beginning to draw on the joint expertise and knowledge of these groups. In this way, the World Wide Web and digital media have facilitated public engagement and access to detector finds and in fact improved standards of archaeological work done by members of the public.

User-centred-design

To ensure that the DIME portal would be geared towards the needs of the stakeholders, the system has been developed on the basis on a mapping of existing practices and requirements for a digital recording portal among the different stakeholder groups, notably Danish metal detector users and Danish museum curators. As for the metal detector community, an online questionnaire was spread via Facebook (group ‘Detektor Danmark’) and the various detectorists associations, resulting in a total of 168 individual responses. The survey combined quantitative and qualitative data on detectorists’ surveying and recording practices and attitudes towards find recording (for detailed presentation of survey results see: Dobat & Jensen 2016). More importantly, the survey and the following focus group interviews conducted with selected representatives of the user group provided constructive ideas and suggestions for the design and functionality of DIME. In order to map practices and requirements at Danish museums, interviews were conducted with curators with a special interest in detector finds from 27 local museums.[7] While different attitudes and conflicts of interest did emerge in the two surveys, the two user groups in fact concurred on the majority of issues, such as data formats and other implementation details or the strategic goal of the platform as a tool facilitating research, management (Danefæ workflow) and dissemination. (Figure 3)

DIME functionalities and specifications

In essence, the DIME portal supports the digital recording of artefacts (primarily metal detector finds), querying and geographical mapping of specific artefact types, and the further processing and export of find data and administrative data to other digital formats. Beyond that it allows other users to provide feedback to finders on the classification and dating of finds and supports communication between finders and responsible museum institutions.

As DIME is openly accessible, there is little reason to present its functionality in detail. Instead, the curious reader is encouraged to visit DIME and take a tour, or see the short instruction movies, which are streamed via the DIME homepage (dime.au.dk). However, as certain modules are the restricted domains of certain user groups (e.g. the find administration module for museum users or researcher's access), an overview of the DIME system's functionality shall be given in the following.

User groups: The DIME system differentiates four main user groups with varying access- and editing rights in DIME: 1: 'public users' (members of the public without login), 2: 'finders/recorders' (typically amateur finders), 3: 'museum users' (curators employed at a Danish local museum), 4: 'researchers' (researchers affiliated with institutions in the heritage sector or university).[8]

Figure 3. DIME was designed, developed and tested in close dialogue with both of the two important user groups, the Danish museums and the Danish metal detector user community. Here one of several test events arranged in cooperation with Odense Bys Museer and Harja (picture: Harja).

Find recording module: After registration, anyone can enter data in the DIME system's find recording module. Registration of a find includes the obligatory upload of 1) GPS data and 2) at least one photograph and 3) entering of basic information on artefact type and material. In addition, users have the option to provide more detailed information, such as museum case number, the object's weight, dimension and secondary material as well as a free-text description etc. A number of mainly administrative information is generated per default, such as a unique DIME ID, finders ID. Via the GPS data, the find is per default linked with a municipality and the responsible local museum. Another important feature is the automated rejection of GPS values outside Denmark and beyond the low-water mark.

Crowdsourcing and citizen science: It's the explicit goal of the DIME project to facilitate the existing practice of peer-feedback and exchange among the practitioners and to enable DIME users to both receive and provide help in the classification and dating of finds. DIME attempts to realize this ambition by tapping into the already established channels of communication among Danish Detectorists and allowing finders to share finds directly on Facebook – preferably the purpose dedicated DIME ID group. The latter is partly administered and monitored by members of the detectorist community, highlighting the inclusive approach of the DIME project. Beyond the 'Facebook share option' DIME encourages user interaction by allowing all registered users to provide feedback on finds directly within DIME, for example an alternative classification or dating. Through this, DIME activates and uses the high level of competence and knowledge among the Danish detector users and allows the detector community to actively contribute to and participate in the enrichment of metal detector find data.

Find administration module and workflow: On recording finds are stored in DIME and become visible in the public view module. In a second step, a finder/recorder has the option to report a find to the responsible museum. Vice-versa the museum can also request a find to be reported. Finds can be accessed in the find recording module by 1) the finder/recorder and 2) the registered museum user for the given museum area. The later can edit the data provided by the finder (except GPS data) and/or add further information. Via the notification system, he or she can also request further information to be added in the find recording module.

In the find administration module both finder/recorder and museum users can see and query 'their' finds (for the finder/recorder only her or his own finds; for the museum user all finds reported to the respective museum). The module allows querying and selection of finds after specific criteria (finders ID, find spot, find metadata, etc.) and the migration of a data selection to other data formats.

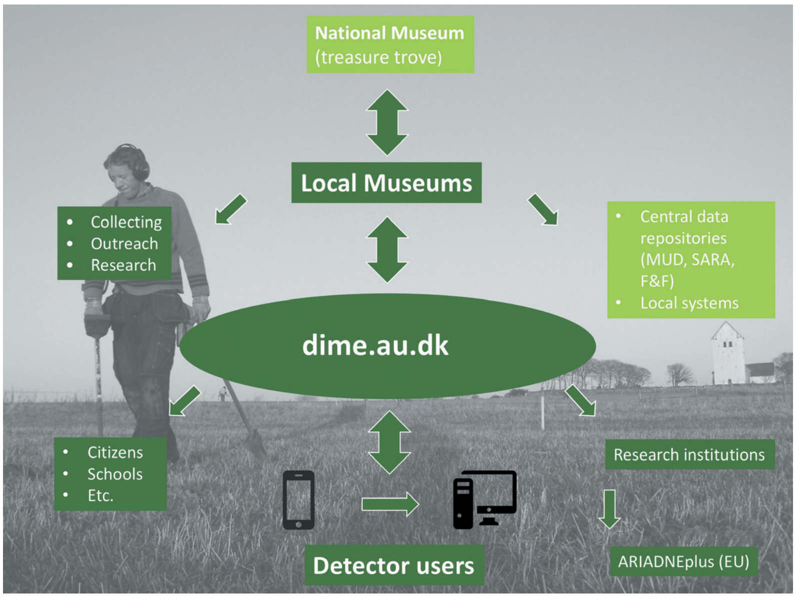

Figure 4. DIME and its relation and applicability in the wider landscape of archaeological heritage institutions, digital systems and stakeholders. Dark green: already established links. Light green: links under development or in design (picture: DIME).

Public and researchers access to the search module: On initial recording on DIME a find (and a selection of the attached metadata) is searchable by all user groups. Data are freely available, under a creative commons license (CC BY-NC-SA 4.0) for the academic and wider communities to use for their research. Public users and other users than the actual finder only can search and view selected information for all finds (personal information on the finder and the find spot remain hidden).[9] The mapping tool in the public search module allows mapping of single or combined search options (find types or find types & Period) as 'heat-map' on municipality level. Only the researcher's access provides near full data coverage for all finds (including GPS data) and allows the user to generate high-resolution maps over selected find categories or specific assemblages.

Support for mobile devices: The initial user requirement surveys and the various test-runs made apparent the need for an 'on site recording option', i.e. the possibility for an easy and direct recording of GPS coordinates and other data in the field, via a mobile device. To facilitate this user requirement, a DIME Mobile device version was developed, allowing GPS coordinates to be stored on the find spot and uploaded to DIME together with default updates of the find date, a unique DIME ID. DIME Mobile device version, however, only facilitates rudimentary recording of the object itself, and users are encouraged to complete a record on return to a stationary/desktop device. (Figure 4)

DIME user data are aligned with the current tendency towards an increasing usage of mobile devices away from stationary/desktop devices. More than 50 % of all finds records in DIME are at least initiated via the mobile phone user face. The developers focus on an 'on site recording option' thus helped acceptance of DIME within the detectorist community. Its downside, however, is evident in the many incomplete finds records, containing limited information and poor-quality photographs (as most detectorists are reluctant to spend much time on recording whilst detecting).

Data exchange and export: In order to ensure interoperability of data, the find database and the administration workflow uses the CIDOC Conceptual Reference Model (Crofts et al. 2011) ontology. Registration is based on the same chronological and classification system as it is used in existing national databases and collection management tools (MUD, REGIN). DIME data are thus interoperable with archaeological data from other sources and DIME (in principle) facilitates direct export and sharing of data with these existing data repositories. Various factors beyond the influence of the DIME board have until now prevented the establishing of direct links between DIME and the above-mentioned systems. Until then, DIME data can be exported via EXCEL documents in the find administration module.[10]

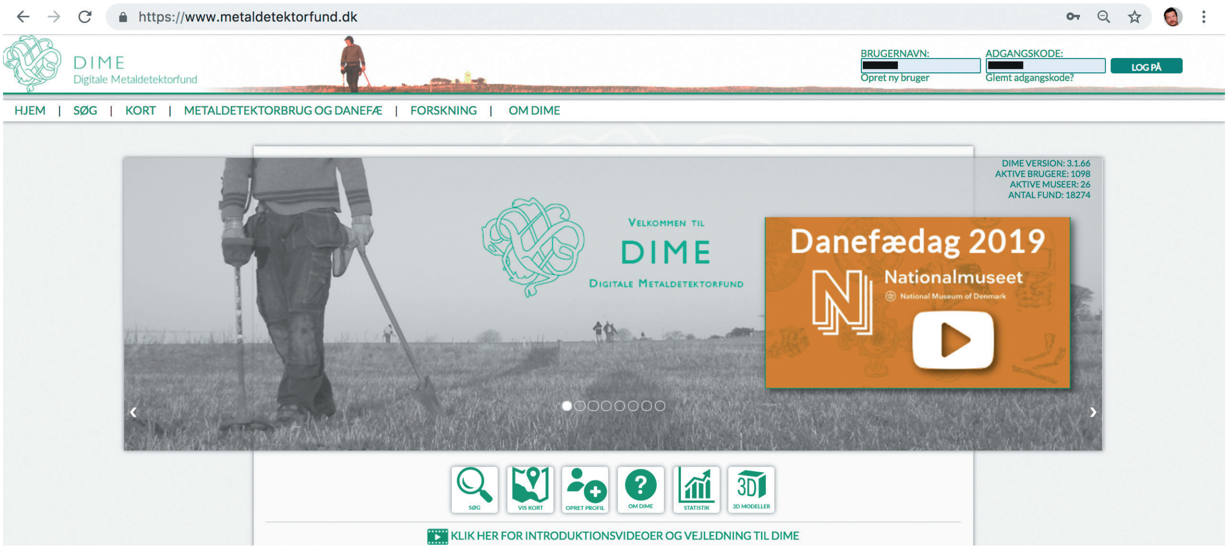

Figure 5. The DIME-portal's front-screen interface in PC-version for registered/logged-on users (picture: DIME).

It's all about the finder

In principle, all archaeological single finds, disregarding their chronological framework and material, can be recorded in DIME (also stone artefacts and ceramics!). However, DIME is anything but an all-purpose recording tool, and a specialized collector of stone age artefacts will find the DIME portal inappropriate for the recording of her/his finds.

One could argue that this strategy carries the danger of inevitably leading to a fragmentation and dispersal of the archaeological record. However, with the conscious decision in favour of a specialized portal for detector finds (and metal detector finders!), the working group acknowledged the need for a paradigm shift in the heritage sector's approach to find registration; a shift away from a traditional 'find-centred' to a 'user-centred' approach. In the development of DIME the group of people producing a particular type of archaeological finds was given priority as the governing parameter over the character and properties of the archaeological material (a find's dating frame, material, type, provenance, etc. or its legal status under the treasure trove system).

The focus on metal detected finds and 'detectorists' is rooted in the recognition of this particular stakeholder community as a potential resource. Despite being a highly heterogeneous group with enormous variations in levels of experience, knowledge, and willingness to cooperate with the official heritage sector, the general impression is that of a highly competent, skilled and well-connected community with a pronounced sense of group identity.
The decision to focus on metal finds, however, was also grounded in the progress of technological possibilities and attitudes within digital infrastructure development, away from all-encompassing and monolithic data repositories and towards smaller and flexible tools and solutions, linked by web-based services using common interfaces.

The success of a specialized data recording portal is dependent on the development of an infrastructure providing access to data and facilitating the exchange of data across repositories. Provided these conditions are in place, the same strategy that governed the design of DIME can be transferred to other interfaces between the official archaeological heritage sector and public stakeholders; e.g. amateur driven maritime archaeology. The growing community of recreational divers in Denmark who survey the seabed for submerged relics of the rich maritime pasts is characterized by similar challenges (and opportunities) as Danish recreational metal detecting archaeology (Jessen 2017).

Dissemination and user education

In order to promote not only the general acceptance of DIME, but also to advance and improve standards and best practice in find recording, emphasis has been put on the development of educational resources in DIME. Instead of a written manual, seve-

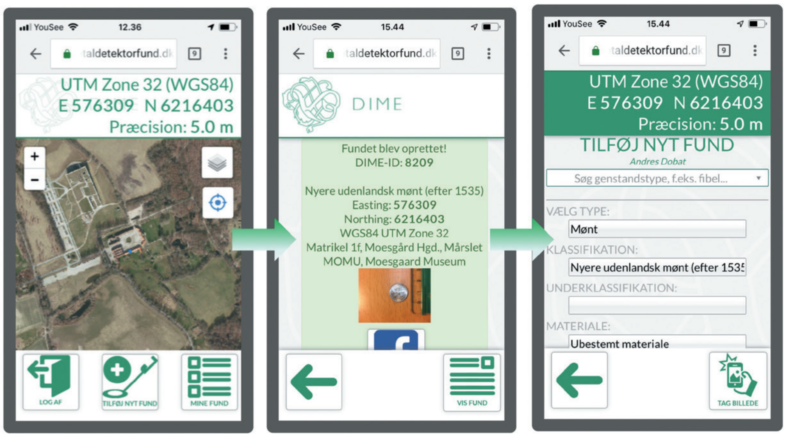

Figure 6. The DIME-portal user-face in the find recording module in mobile-version (accessible for registered/logged-on users). Left: prior to find registration, Middle: classification module; Right: Datasheet after successful find registration with DIME-ID Nr., basic location data and Facebook link (picture: DIME).

ral short videos, some featuring and even produced by well-known detectorists, introduce novices to the DIME portal, its basic functionalities and best recording practice. In addition, movie clips provide guidance on artefact photography and basic dos and don'ts of artefact treatment and storage are provided by a conservation expert. A number of additional help-features are under development, in many cases initiated and accomplished by members of the detector community. (Figure 5 and 6)

In our communication with the detector community, the DIME project group relies heavily on the existing exchange forums on Facebook, which currently is the most widely used channel for exchange among Danish detectorists. Also, the majority of detectorists who were included as experts and/or test-users in the development and testing phase were recruited via social media.

Experience gained during the first months following the launch of DIME indicate, that the high level of user inclusion both in the development and the production of educational resources was a crucial factor for the initial acceptance of DIME by the primary users. Several of the practitioners which had been drawn on earlier, took on a role as ambassadors for the DIME portal in the context of social media and acted as 'influencers' within the detector milieu. The commitment of certain 'super-users' of the DIME system eventually lead to the user-initiated establishing of a 'DIME support group' on Facebook, in which proficient users offer help to less experienced users of the DIME portal. In light of these developments, the vision of 'user engagement' has already begun to take very concrete form, beyond the original goal of data and knowledge sharing.

One important element of dissemination of best practice and user education is the flow of scientific results and knowledge back to the detectorist community. Researchers are only granted privileged access rights to DIME data for research projects on the condition that they provide a short summary of their projects results and allow DIME to post or link to relevant publications. We hope to create an awareness of the scientific value of metal detector finds and their contextual data in general. Particularly, we aim at creating an understanding of the scientific value of those less prominent find categories (scrap metal, production waste, etc.) which are often overlooked or considered meaningless by detectorists, but which can be of enormous value to researchers.

DIME and international trends and developments

Internationally, on one hand, Denmark is often seen as a positive example of the liberal model in European detector archaeology. On the other hand, when it comes to the registration, and hence the exploitation of detector finds in research and dissemination, the Danish case can be viewed as a tale of missed opportunities.

Danish metal detector archaeology has undoubtedly paved the way for research into new, previously unknown aspects of prehistoric societies (see for example: Henriksen 2000; Horsnæs 2010; Baastrup 2013; Ulriksen 2012; Feveile 2017; for additional examples see Dobat 2016, 57). However, the many old and new finds have yet to be fully appreciated as a primary object of archaeological research and detailed analytical studies across individual sites and regions.

Denmark has for a long time been lagging behind the developments in other European countries; not only when it comes to the handling of archaeological finds, but also with respect to more general approaches and trends within public management and the use of digital media in the humanities. In England and Wales, the Portable Antiquities Scheme (PAS) was established as early as 1996, serving as a tool for the central recording of archaeological objects found by members of the public (mainly detector finds), and making these finds publicly accessible to researchers and the general public alike (Lewis 2013).[11]

In the wider trend towards inclusive approaches in public management, the ideals of citizen science as well as the paradigm of digital humanities and Big Data, similar schemes have been or are being developed. Already in 2016, the MEDEA portal was launched in Flandern (Belgium). In contrast to the portable Antiquities Scheme, which is based on a regional network of Finds Liaison Officers, MEDEA is designed as a user-driven platform. As in the case of the DIME project, MEDEA encourages detector users to upload basic information and raw data directly (Deckers et al. 2016). In the Netherlands, the PAN (Portable Antiquities of the Netherlands) has been under development since 2016 and will facilitate recording of finds by members of the public (Kars & Heeren 2018). Most recently, a project consortium consisting of University of Helsinki, Aalto University and the National Board of Antiquities have joined forces under the project 'Finnish Archaeological Finds Recording Linked Open Database' (SuALT), which will provide a solution to the increasing numbers of detector finds in Finland (Wessman et. al 2019).

Organization and sustainability

As of September 2018, DIME has gone through the transformation from a grass-roots driven development project to an element of core operational practice at a growing number of museums. The DIME portal's future will be shaped by the DIME board, comprising representatives of the institutions belonging to the initial project consortium (Aarhus University, Moesgaard Museum, Odense Bys Museer, Nordjyllands Historiske Museer), plus representatives of the Association of Danish Amateur Archaeologists (SDA) and The Danish National Museum.

As the financial support received by the KROGAGER FOUNDATION only covered development costs, the future maintenance and further development of DIME is dependent on user contribution. The use of DIME as a recording tool will always remain free of any charges for the individual detector user, nor will public users or researchers have to pay for access to DIME data. However, DIME will ask participating museums (DIME partners) to contribute financially after a period of free use, when the system has hopefully proven to constitute a valuable tool for improving registration efficiency and quality at participating museums.

Unresolved issues and future challenges

In its current state, the DIME system provides a solution for the most pressing issues relating to Danish recreational metal detector archaeology, allowing basic recording and processing of the growing number of finds. However, there are several functionalities that are not yet supported by the system, or which until now have been impossible to be implement, either due to external factors or simple lack of time and sufficient funding. The success of DIME will depend on its ability to meet future challenges, to incorporate ideas and suggestions from users and to develop further. Some of the functions that either are in development or will need to be designed in the near future are:

- Site module: Option to upload information and data linked to a certain find spot (e.g. settlement, battle field, treasure find, GPS tracks, etc.) covering continuous surveying and several surveying campaigns and the possibility to link single finds to an overarching find category and provide a unique ID for e.g. a treasure hoard, a settlement site or fragments of one and the same objects.
- Flexible data sharing among users: Option facilitating the sharing of find data among a trusted group of detector users (in its current state, DIME does not reflect the social com-

plexity and dynamics characterizing parts of the detector community, where groups of detectorists or associations often share 'surveying rights' for a certain find spot – and hence also wish to share data).
- User's exhibition space: Option facilitating the user driven selection of certain finds and the curating of digital exhibitions around common themes or find assemblages from certain sites.

The two most central fields of future development are:

1. the implementation of migration and share of data with other databases, not least MUD, F&F and SARA
2. the role of DIME as a tool in the central processing of treasure trove (Danefæ) at the Danish National Museum.

The project group behind DIME is currently worked on both fields in cooperation with relevant partners. From the very beginning of development work, high priority was given to the integration of DIME with the new SARA system, hosted by the Danish Agency for Culture and Palaces. This dimension of the DIME portal, however, could not be achieved, for reasons beyond the control of the DIME working group. The SARA system until now has not materialized as a functional alternative to the existing systems.

One of the unknown factors influencing the future of the DIME portal is its acceptance by the metal detecting community. Experienced detectorists generally seem to agree on the basic necessity of a standardized recording of their finds and in the '2015 Danish detectorists survey' more than 83 % of the respondents confirmed to be willing to upload finds in a publicly accessible online portal (Dobat & Jensen 2016). From the start, DIME has been received very positively among the Danish detectorists. The fact that more than 800 detector users joined the DIME community during the first three months of its existence can be taken as indicative of that the constructive attitudes expressed in the '2015 Danish detectorists survey' are in fact followed up on through concrete action. However, it remains to be seen whether also the Danish Museum community will be willing and able to embrace the DIME system in the long run, and whether users will be sufficiently motivated and capable of providing data of sufficient quality to be used directly in the further processing by museum professionals.

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Digital systems mentioned in the text:

- **DIME**: Digitale Metaldetektorfund: dime.au.dk
- **MUD**: Museernes Udgravningsdata: http://www.udgravningsdata.dk/
- **SARA**: Fælles system til registrering og administration af museernes samlinger: https://slks.dk/museer/museernes-arbejdsopgaver/registrering/sara/
- **F&F**: Fund og Fortidsminder: http://www.kulturarv.dk/fundogfortidsminder/
- **REGIN**: https://www.kulturarv.dk/regin/index.do
- **PAS**: Portable Antiquities Scheme: https://finds.org.uk/
- **PAN**: Portable Antiquities of the Netherlands: https://www.portable-antiquities.nl/
- **MEDEA**: https://vondsten.be/
- **SuALT**: The Finnish Archaeological Finds Recording Linked Open Database

Notes

1. For an overview see the Open Archaeology (2016): Topical Issue on Aspects of non-professional metal detecting in Europe.
2. In 2016, Danish local museums spent 316 weeks (equivalent to 8 full-time positions) on the local registration and further administration of detector finds produced by members of the public (Pedersen et al. 2018, 11). This development has left not least the Danish National Museum's treasure trove administration struggling with a backlog of several years for certain artefact categories.
3. In 2015, a large proportion of Danish detector users 'samarbejdende detektorfolk' ('cooperating detectorists') came together for a workshop on challenges and possible solution of Danish detector archaeology. The lack of a central find recording database was unanimously identified as one of the most crucial deficiencies of Danish detector archaeology (Krause-Kjær 2015).
4. It has to be emphasised that also the Danish metal detector community is characterised by enormous heterogeneity in terms of motivations and incentives. According to museum curators working closely with detectorists, not all

are solely driven by the desire to contribute to historical knowledge and research. And when practitioners emphasise this particular aspect of recreational metal detecting towards heritage officials, the media or in surveys, it is also a direct response to the presumed expectations; i.e. detectorists may have other and less idealistic motivations (not least the monetary gain that comes along with treasure trove finds) but they provide the answers they know the public and professionals want them to give. Furthermore, the enormous media focus on gold artefacts and treasure finds has attracted participants with less idealistic and more pecuniary incentives to the hobby.

5. In this way, the DIME project resonates with current political and ideological ambitions towards civic empowerment and democratization of heritage management. The authors are well aware of the potential pitfalls of such an approach. Under different headings (e.g. 'Big Society'), governments across Europe are promoting the idea of increased civil contribution to public services like public health sector or eldercare, stirring debates across political positions and ideologies. The idea of involving metal detectorists in registration process of their finds thus carries the potential risk of being misused under a neoliberal agenda for legitimizing funding cuts.
6. Level 1 in Bonney et al. (2009) analytical hierarchy of Public Participation in Scientific Research can be dismissed here:http://www.birds.cornell.edu/citscitoolkit/publications/CAISE-PPSR-report-2009.pdf.
7. During the entire project period, presentations of the DIME portal in various contexts were used to encourage in particular museum curators to contribute to the development work with ideas on design and functionality of the DIME portal.
8. For detailed information on the registration process for the different user groups with editing rights in DIME and the requirements for DIME research access see the DIME homepage dime.au.dk.
9. The background of this is the somewhat competitive nature of recreational metal detecting and the increasing pressure on find producing surveying areas. While the majority of Danish detector users are willing to provide the exact location (GPS data) of finds and productive find spots to heritage officials, many are reluctant to make these data publicly available – and hence allow potential competitors to 'seize' the same search areas (Dobat & Jensen 2016). The DIME portal recognizes this particular user requirement of 'disclosed find spots' and limited data availability. This is despite the fact that the system's functionality thus contrasts with the ideal of open data access.

   The potential and limitations of the DIME portal as a tool facilitating Public Participation in Scientific Research are thus closely interrelated with the social dynamics and attitudes of the main stakeholders. Even though the restrictive policy with regard to research accesses is a compromise without alternatives, the future development of DIME will also have to focus on the systems further adjustment and alignment to the social dimension of recreational detector archaeology. In many cases, two or more detectorists share one or several search grounds (find localities) and thus have a vested interest to view each other's finds and data.
10. A direct data migration option from DIME to the central Danish heritage data repositories (Fund & Fortidsminder; SARA; MUD) is a priority in the future development of DIME.
11. Especially the Portable Antiquities Scheme for England and Wales can be drawn upon as an example of the enormous potential of a central recording of detector finds. As of January 2018, and according to the PAS' own assessment (https://finds.org.uk/research), the PAS has provided data for more than 600 research projects, among these 126 PhD projects, and single finds or distribution maps over particular artefact categories have been included in countless publications.

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