The use of axe- and ring-metal as a raw material source in the Late Neolithic and Early Bronze Age in Southern Scandinavia

Heide Wrobel Nørgaard

Zusammenfassung

Die Verwendung von Beil- und Ringmetall als Rohmaterialquelle im spätneolithischen und frühbronzezeitlichen Südskandinavien

Ein kontinuierlicher Anstieg des Metallflusses nach Südskandinavien beginnt um 2100–2000 v. Chr. Die ersten Netzwerke gewährleisteten die Versorgung mit Metallen aus dem österreichischen Inntal und der Slowakei, ergänzt durch zinnreiches britisches Metall. Diese Netzwerke veränderten sich im Laufe der nächsten 700 Jahre, verblassten und wurden teilweise durch neue Kontakte ersetzt. Einer dieser neuen Kontakte versorgte den Norden mit ostalpinem Metall vom Mitterberg und später mit Metall aus den südlichen Alpen, das ab der entwickelten nordischen Bronzezeit zur dominierenden Quelle wurde. Spuren eines Rohstoffhandels, sind hier in der frühen Bronzezeit Südskandinaviens nicht erkennbar. Auch Barren, wie man sie aus Süddeutschland kennt, sind in der frühen Bronzezeit selten Teil von Funden. Im Gegenteil scheint der gezielte Import von Artefakten mit bestimmten Materialeigenschaften die Grundlage für die lokale Materialproduktion zu sein. Axt- und Ringmetall wurden als Rohstoffquelle für die weitere Produktion nach Skandinavien gehandelt. Neben der eigentlichen Nutzung der Artefakte wurden große Mengen der Nutzung entzogen, um sie gezielt wiederzuverwenden. Die hochzinnhaltigen Bronzeäxte von den Britischen Inseln trugen wesentlich zur frühen Bronzeproduktion im Spätneolithikum in Südskandinavien bei. Zusammen mit großen Mengen an Äxten aus nickelreichem Fahlerz, die aus dem Aunjetitzer Gebiet importiert wurden, und Ringmetall aus nickelarmem Fahlerz aus den Zentralalpen bildeten sie die Materialbasis für die lokale Metallverarbeitung in den ersten 200 bis 300 Jahren der Nordischen Bronzezeit. Darüber hinaus könnte auch das Erscheinen der Speerspitzen in einer frühen Phase (BZ Periode IA; 1750/1700–1600 v. Chr.) ein Nebenprodukt des sich verändernden Metallhandels und des Zuflusses neuen Metalls in einen bestimmten Axttyp sein. Der metallurgische Fingerabdruck von Äxten des Virring-Typs und der frühesten Speerspitzen kann mit der lokalen Produktion mehrerer Artefakte mit ähnlichen südosteuropäischen Signaturen in Verbindung gebracht werden.

Schlagwörter Frühbronzezeit, Metallhandel, Artefakt-Währung, Archäometallurgie, Speerspitzen

Summary

A continuous rise in the flow of metals to Southern Scandinavia begins around 2100–2000 BC. The first networks established guaranteed a supply of metals from the Austrian Inn Valley and Slovakia, complemented by high-tin British metal. These networks shifted during the next 700 years: They faded out and were partially replaced by new contacts supplying the north with metal from the Eastern Alpine Mitterberg and, later, from the Southern Alpine region, which became the predominate source from the established Nordic Bronze Age onwards. No traces of a raw-material trade have been visible in Southern Scandinavia's Early Bronze Age periods, nor have deposits of ingots, as they are known from southern Germany, been discovered. On the contrary: The targeted import of artefacts with certain material properties seems to have been the basis for local material production. Axe- and ring-metal were traded to Scandinavia as a raw material source for further production. In addition to the actual use of the artefacts, large quantities had been withdrawn from use in order to be reused in a targeted manner. The high-tin bronze axes from the British Isles contributed significantly to the early production of bronze in the Late Neolithic in Southern Scandinavia. Together with the large quantities of axes made of Ni-fahlore imported from the Únětician region and the ring-metal of low-Ni-fahlore from the Central Alps, they form the material base for the local metalwork in the first 200 to 300 years of the Nordic Bronze Age. Additionally, the appearance of the spearheads in an early period of the Nordic Bronze Age (NBA IA 1750/1700–1600 BC) might also be the result of an influx of new metal in a specific axe type. The metallurgical fingerprint of Virring-type axes and the earliest spearheads can be related to the local production of several artefacts with similar South-Eastern European signatures.

Keywords Early Bronze Age, trade networks, artefact ingots, archaeometallurgy, spearheads

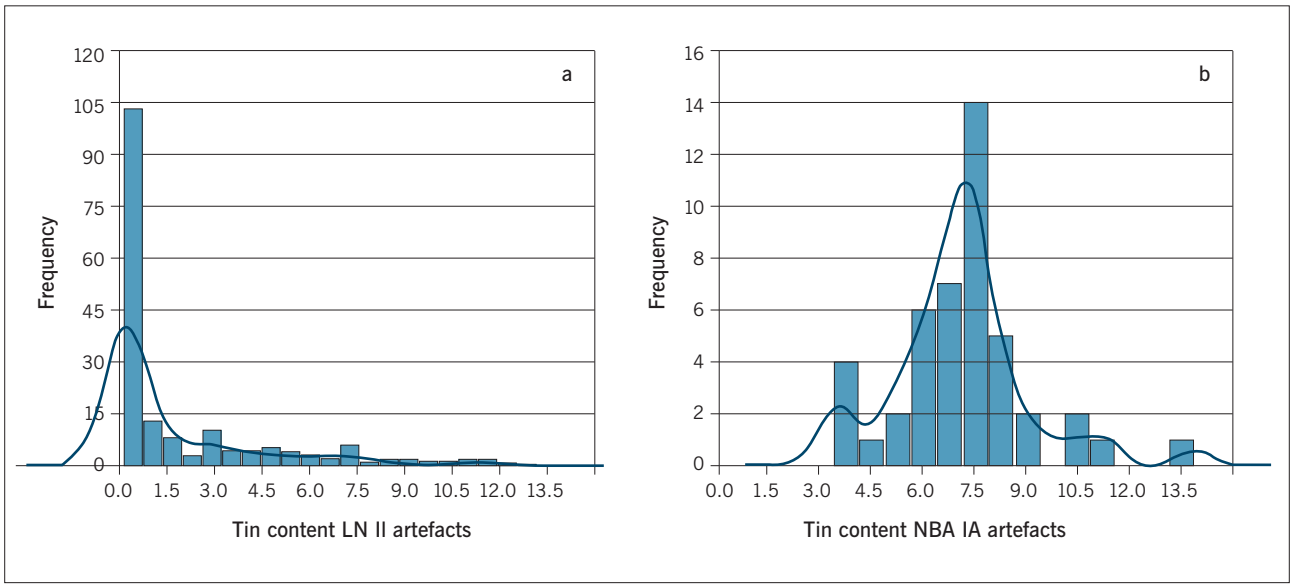

Fig. 1a–b Histogram of the tin percentage within LN II (a) and NBA IA (b) artefacts found in Denmark.

Abb. 1a–b *Histogramm des prozentualen Zinngehalts von Artefakten der Stufe II des Spätneolithikums (a) und Periode IA der Nordischen Bronzezeit (b) aus Dänemark.*

Introduction

Our knowledge concerning the metal trade networks that supplied the Scandinavian Bronze Age with the most needed raw material has grown immensely in the last decade. Several projects aimed to define possible supply centres, networks, routes, and shifts in time, by analysing artefacts regarding their archaeometallurgical fingerprint[1]. The number of analysed artefacts corresponds to around 50 % of the known metal artefacts from the establishment of the Nordic Bronze Age to its decline. Thus, the state-of-the-art knowledge provides an excellent base, allowing estimations on the extension of the defined networks and how this metal trade might have been organised. This article will focus on defining the kind of metal used within the trade to the outskirts of the metal-producing areas in the Bronze Age in Europe.

Today we know that the first 700 years of the Nordic Bronze Age (Fig. 1) have been characterised by a continuous rise in the flow of metals to Southern Scandinavia that began around 2100–2000 BC, with the hoard from Pile, Scania (Sweden), as one of the most characteristic finds

APPROX ^{14}C RANGE *	MAJOR DIVISION	AEGEAN	EUROPE NORTH OF ALPS	SOUTHERN SCANDINAVIA
3800–2900 BC			Neolithic Farmers	Earlier Neolithic
2900–2350 BC			Corded Ware	Younger Neolithic
2350–2100 BC			Bell Beaker	Late Neolithic I (LN I)
2100/2000–1700 BC	EBA	MH III	EBA (Br A1–2b)	Late Neolithic II (LN II)
1700–1600 BC		LH IA-B	Final EBA (Br A2c/A3)	NBA IA
1600–1500 BC		LH II	Early MBA (Br B1)	NBA IB
1500–1300 BC	MBA	LH IIIA-B	Late MBA (Br B2/C)	NBA II
1300–1200/1100 BC		LH IIIC	Final MBA/Early LBA (Br D–HA A)	NBA III

Tab. 1 State-of-the-art chronology of Southern Scandinavia and European-scale. * The ^{14}C ranges are based on a combination of radiocarbon and dendrochronological determinations.

Tab. 1 *Neueste chronologische Daten und Vergleich von Südskandinavien mit anderen Teilen Europas. * Die ^{14}C-Spannen beruhen auf einer Kombination von Radiokohlenstoff- und dendrochronologischen Bestimmungen.*

1 Nørgaard et al. 2019; Nørgaard et al. 2021; Nørgaard et al. 2022; Ling et al. 2014; Ling et al. 2019; Melheim 2015; Melheim et al. 2018; Melheim/Sand-Eriksen 2020; Vandkilde 2017.

(Vandkilde 2017). High impurity (fahlore) metal from the Austrian Inn Valley and Slovakia was among the first metals to arrive in Scandinavia, probably via the central German Únětician hubs. This fahlore metal was differentiated by low or high nickel (Ni) content, it originated in central Europe, and it is associated with a specific type of artefact: axes and loop neck-rings (Nørgaard et al. 2021). Complemented by high-tin British metal, these three sources represent the major metal suppliers in the Southern Scandinavian Late Neolithic (LN II), between 2000 and 1700/1750 BC (Tab. 1). During the first phase of the establishment of the Nordic Bronze Age (NBA IA, 1750/1700–1600 BC), instabilities that end in the Únětice downfall in c. 1600 BC might be responsible for a period of raw material shortage, visible in the reuse of existing stocks. The direct reaction to these changes is visible from 1600 to 1500 BC, i.e., within the NBA IB period, when the metal-supplying networks extended to the south. The material testifies that there was a continuing supply of low-impurity copper from the Slovakian area and Central Alpine metal was used in the creation of status symbols, such as the shaft-hole axes (Nørgaard et al. 2022). Additionally, an initial use of Northern Italian copper can be documented in NBA IB (1600–1500 BC), an extension of the network to the south which will dominate the metal trade in the following periods. English and Welsh metal played a central role during this period. Finally, from around 1500 BC, when British copper imports declined, the predominance of novel Northern Italian copper coincides with the full establishment of the NBA and highlights a western in-land route (Nørgaard et al. 2019; Nørgaard et al. 2021; Nørgaard et al. 2022) connecting the NBA with the Southern German ›Tumulus Culture‹ and the first transalpine amber traffic (Vandkilde et al. 2024).

As the metal networks providing the NBA's most-needed raw material were subject to change, the material culture was likewise changing with the development of the Nordic Bronze Age. While the Late Neolithic (LN) II period was characterised by a predominance of flat and, later, flanged axes and ring metal, the beginning of NBA IA can be connected to the appearance of a new artefact type: the spearhead (Vandkilde 1996). In the following period, NBA IB, the sword also gained its place in the material culture repertoire (Berger et al. 2022), showing undoubted connections to South-Eastern Europe.

The above-mentioned studies of H. W. Nørgaard and colleagues suggested that certain artefacts function as ingots within the metal trade (Nørgaard et al. 2019; Nørgaard et al. 2021). Despite earlier assumptions of a raw material trade, no trace of it has been visible in Southern Scandinavia's Early Bronze Age periods. Additionally, the deposition of ingots in a manner comparable to the deposition of rib- or ring-ingots during the Early Bronze Age in Central and Southern Germany is unknown in Southern Scandinavia. Ingots appear in Scandinavia in hoards first in the Late Bronze Age, around 1000 BC. Here, casting cakes, metallurgical debris, and partly broken pieces of bun ingots of bronze and tin (see Boddum et al. 2011; Boddum et al. 2015) testify to an emerging hoarding tradition connected to metallurgical activities. However, the targeted import of artefacts with certain material properties seems to be the basis for local material production in the Early Nordic Bronze Age.

Early tin bronze in Southern Scandinavia

From a bird's-eye view, it is astonishing that Southern Scandinavia fully joined the group of metal-using societies only at the dawn of the 2nd millennium BC (Nørgaard et al. 2019; Vandkilde 2017). What is particularly interesting here is the way in which it was done. Imported metal artefacts have been known since the 5th millennium BC in Southern Scandinavia (Klassen 2000; Klassen 2004), and, already at this stage, different metal sources were used (Nørgaard et al. 2021, 9; Brozio et al. 2023). Denmark might have had an independent metal production already in the 3rd millennium BC (Gebauer et al. 2020), but the earliest clear evidence for local metal production in Southern Scandinavia dates to the beginning of the 2nd millennium BC (i.e., Vandkilde 2017). In contrast to many metal-using societies, this change in material culture did not take place in stages of development – as observed in the south (from pure copper to fahlore to bronze) – but rather in a rapid development from the import of artefacts to the parallel local production of copper and tin-bronze and the exclusive production of tin-bronze objects.

This rapid introduction of tin-bronze (Fig. 1) is likely connected to the way in which metal as raw material was imported.

The Southern Scandinavian Late Neolithic material culture is characterised by a variety of imported artefact types, predominately axes and ring-shaped items (see Vandkilde 1996). Moreover, Southern Scandinavia is the continental region with the largest number of Anglo-Irish axe-heads outside of the British Isles, followed by the Rhine estuary and the middle Elbe region (Fig. 2). Anglo-Irish axes[2] appear first in Scandinavia in the early LN II with single specimens of the Killaha-type (i.e., Harbison 1969). The numbers increased in the second part of LN II, and developed flat axes appeared in single depositions in bogs, burials, and hoards (i.e., Burgess/Schmidt 1981; Harbison 1969). The distribution of these axes outside the British Isles suggests a transport route along the coast (Butler 1996; Needham 2009) with further inland travel through river systems. Evidence of axe-hack metal[3] and amber axe-pendants imitating decorated flat axes in the Limfjord region in Northern Jutland (see Vandkilde et al. 2024), in addition to hot spot centres for Baltic Amber in Únětician hubs (Vandkilde 2017), support the importance of this route.

However, the preserved axes of Southern Scandinavia are of extraordinary shape and size (see Butler 1955). As

2 See Harbison 1968; Harbison 1969; Megaw/Hardy 1938; Needham 1983; Vandkilde 1996; Burgess/Schmidt 1981.

3 Two halves of developed undecorated flat axes similar to the Ballyvalley-type from the find location Limfjord, North Jutland (Denmark), are known from the collections of the British Museum (<https://www.britishmuseum.org/collection/object/H_1869-0724-1> [08.04.2024]), indicating the presence of broken axe metal.

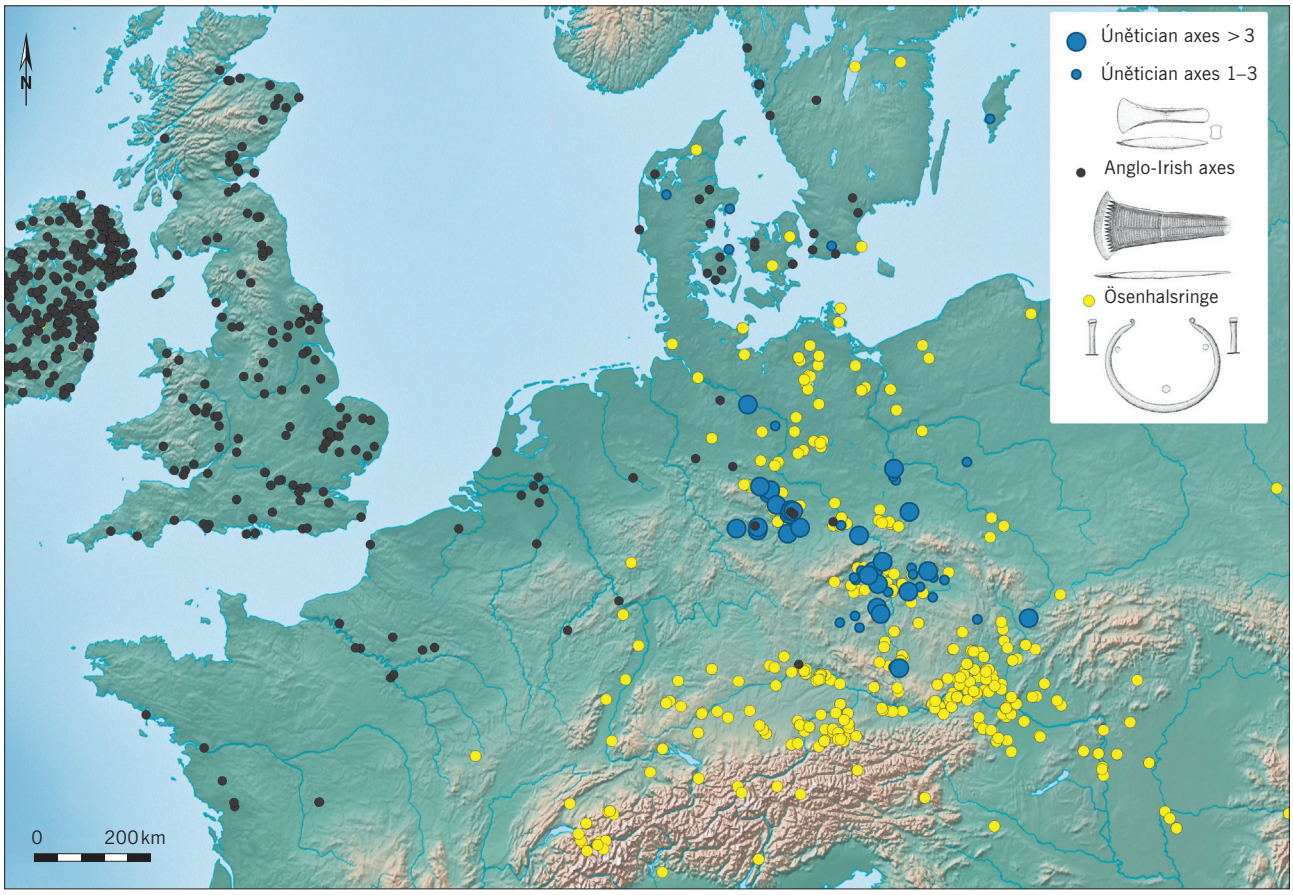

Fig. 2 Distribution of the artefacts that are considered the major sources of metal for the Southern Scandinavian Late Neolithic (LN II) and earliest Bronze Age (NBA IA): the Anglo-Irish axes, Úněticiaan flange axes, and looped neck-rings *(Ösenhalsringe)* in Central and Northern Europe. The distribution of Anglo-Irish axes in France and Belgium is still an ongoing task and the present map does not consider the latest publications by H. Gandois.

Abb. 2 *Verbreitungskarte der Artefakte, die als wichtigste Metallquellen für Südskandinavien während des Spätneolithikums Stufe II und der Nordischen Bronzezeit Periode IA gelten: anglo-irische Beile, Randleistenbeile der Aunjetitzer Kultur und Ösenhalsringe in Mittel- und Nordeuropa. Die Kartierung der anglo-irischen Beile in Frankreich und Belgien ist noch nicht abgeschlossen; ebenso sind die jüngsten Veröffentlichungen von H. Gandois unberücksichtigt.*

such, it seems that besides the preserved high-quality axes, British artefacts were reused within the Southern Scandinavian metal production. An intensive typological examination of the 150 analysed LN II axes (i.e., Nørgaard et al. 2019; Nørgaard et al. 2019a; Nørgaard et al. 2021) illuminates the origin of the tin detected in the Scandinavian artefacts (Fig. 3).

Especially the larger local axe types (A3 and A4 in Vandkilde 1996, 66–91) show tin contents far over the 2 % hurdle that was considered the minimum required for an alloy to be called bronze, as determined in the 1990s through extensive studies of early copper alloys (i.e., Muhly 1993, 240)[4]. The axes with the highest tin content – above 7 wt % and up to 14 wt % – are classified as of Anglo-Irish origin and show the expected high-tin bronze. This uneven distribution of the tin content in these early bronzes indicates an intentional reuse of foreign artefacts to create local objects.

It seems that especially British metal has been of interest for the production of local axe types. Some axes indicate a direct recast of Anglo-Irish axes to local forms such as the large Storre-Heddinge-type axe from Ørnbølle Hede (NM 26062; Vandkilde 1996, 422) and the nearly 12-cm-long Gallemose-type axe from Northern Jutland (ÅHM 3384, Vandkilde 1996, 416.) with 10.4 and 11.3 % tin (see Fig. 3). Other artefacts point towards a potential mixing of high-tin bronze with low-tin copper artefacts.

The well-known hoard from Store-Heddinge near Præstø on Zealand (Denmark) can shed light on this reuse of British axe metal in local Southern Scandinavian metal production. First and foremost, a detailed isotopic investigation revealed that the Anglo-Irish axe types were imported to Southern Scandinavia and that the metal assumed to be reused in local production had been made solely from English and Welsh metal deposits (see Nørgaard et al. 2019; Nørgaard et

4 Copper ore can have varying concentrations of tin as a trace element, mostly in the ppm range. However, occasionally deposits can contain copper and tin in the ore mineral, as the example of the Mushiston mine, Sughd Region, in Tajikistan shows (see Berger et al. 2023). The metal smelted from this kind of ore will have varying concentrations of tin. The 2 % hurdle that Muhly mentions is based on the distribution of tin contents in Early Bronze Age archaeological objects (see here also data from the Stuttgarter Metallanalysendatenbank, Junghans et al. 1960; Junghans et al. 1968; Junghans et al. 1974; Krause 2003). Nevertheless, new experiments on the impact of trace elements in copper alloys have shown that significant visual changes of the alloy first occur at a proportion of at least 2 % (Mödlinger et al. 2017).

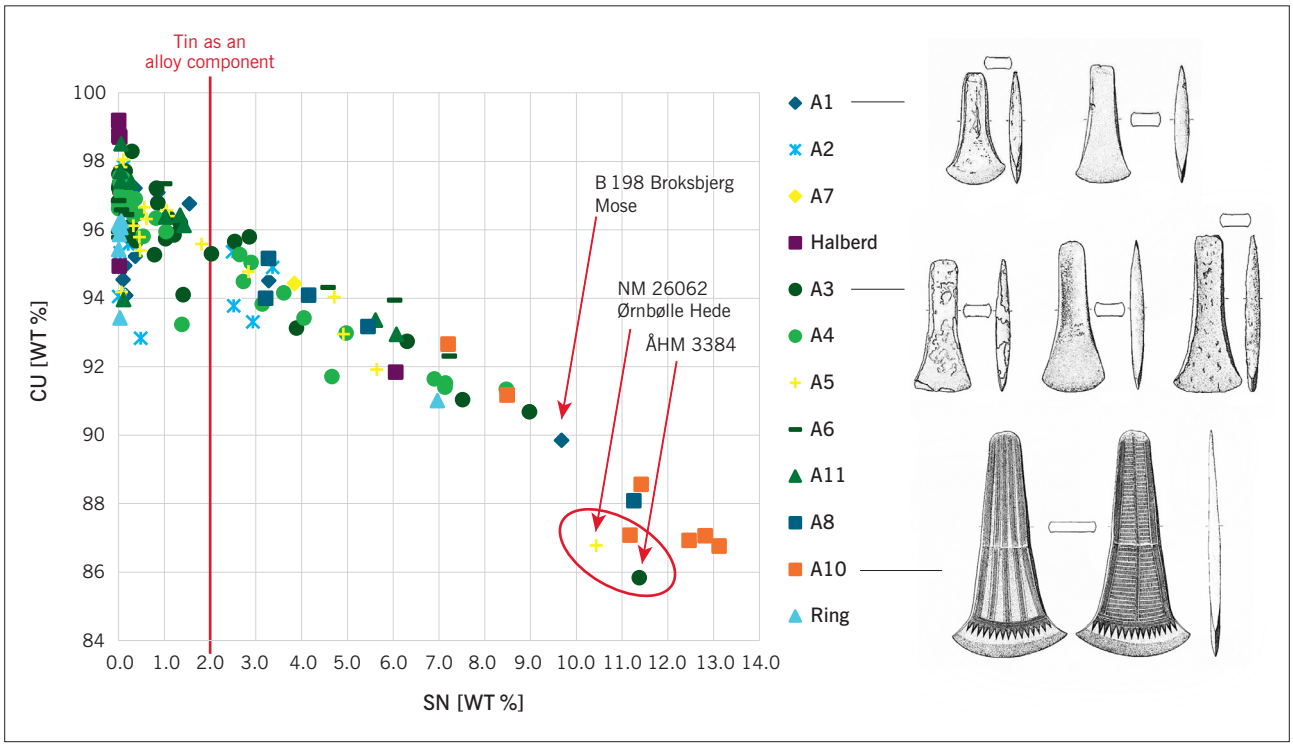

Fig. 3 Tin concentrations in LN II artefacts, taking into account the identified stylistic types. The typological classification is based on H. Vandkilde 1996.

Abb. 3 *Zinngehalt von Artefakten der spätneolithischen Periode II unter Berücksichtigung der typologischen Einteilung nach H. Vandkilde 1996.*

al. 2021). It follows that the axes should be referred to as Anglo-type axes. Second, a typologically identified Anglo-type axe is not *per se* of English or Welsh metal. For example, the large axe with narrow waist and ›English‹ bevelled decoration from Tolne Hjorring in Northern Jutland (NM3887; Tab. 2) cannot be isotopically associated with British ores even if the chemical composition is comparable with the low impurity copper known to be from English and Welsh sources (see Nørgaard et al. 2019, 21).

The Store-Heddinge hoard contains four axes: one decorated Anglo-flanged-axe (MLXIX), two primitive flanged axes with strong typological characteristics of Anglo-axes (MLXXa–b), and a local-style flanged axe of the Store-Heddinge-type MLXXc (Fig. 4; Tab. 2; according to Vandkilde 1996, 80). The isotopic ratios of the axes reveal that the large decorated piece MLXIX was made of Welsh or English metal. The same is valid for the local-style axe MLXXc, which has a tin content of 6.9 wt % (Fig. 5). The two primitive flanged axes MLXXa and MLXXb are stylistically very similar. While MLXXa is very likely made of metal from the Alderly Edge mine in England; the other axe seems to be a product of mixing British and Slovakian artefact metal in an attempt to copy foreign styles. Table 2 presents several artefacts that can be typologically considered as hybrid forms, stylistically between the characteristic long narrow shape and flattened flanges of Anglo-type axes and the partly high-flanged curved axes of local style (typology based on Vandkilde 1996). They provide the basis for the isotopic investigation visualised in Fig. 5. Interestingly, the large decorated local-style axes are frequently produced with metal from Welsh or English sources[5].

In addition to the tin values and isotope ratios of Anglo-type axes presented above, further evidence of possible mixing of artefact metal in local production can be referred to. As suggested by the examined imported artefact types (see Fig. 2) and the concentration of Baltic amber finds in the circum-Harz region, an intensive exchange of goods is to be expected between the Southern Scandinavian and the Únětice region. The studies by Nørgaard and colleagues (2019; 2021), which include around 600 artefacts from the first 600 years of the Nordic Bronze Age, revealed that two dominant fahlore types supplied the Late Neolithic and Early Bronze communities in Denmark with copper. The nickel-rich fahlore probably had its origin in the Slovakian Ore Mountains (Nørgaard et al. 2019) and was used for making a variety of Únětician axe types. According to H. Vandkilde, Únětician axes provide a large proportion of the imported items (Vandkilde 2017, 147). The low-Ni fahlore could be linked to the mineral deposits in the Inn Valley (Nørgaard et al. 2021). This metal is also known as *Ösenring*-metal, as it is most widely used in looped neck-rings and only occasionally appears in the material culture of the Late Neolithic in Southern Scandinavia as complete items (see Fig. 2; cf. Vandkilde 2005).

5 Fig. 6 shows that especially the Gallemose axes (CM 142, B294), but also axes of type Store-Heddinge (MLXXc), Vaerslev (VMÅ139), and Æbelnæs (B10789 and B494), are predominately of Welsh metal. It shall be the task of future studies to clarify whether the Anglo-style axes ML6573 and ML6574 may also be local imitations of a popular form as they are probably made from Mitterberg copper.

Original no. A-number	Object	Date	Site	Context	Additional finds	Reference	Analyses
ML6574 MA-181036	flanged axe, type Anglo-Irisch A10	LN II	Beddinge, Vermenhögs, Scania	one-type hoard	similar flanged axe	Oldeberg 1974, 66	Nørgaard et al. 2019, S2
ML6573 MA-181035	flanged axe, type Anglo-Irisch A10		Beddinge, Vermenhögs, Scania	one-type hoard	similar flanged axe		
NM B294 MA-171110	flanged axe, type Gallemose		Brandslund, Skovby, Odense	single find, field	none	Vandkilde 1996, 414	
NM B198 MA-166631	flanged axe, type Emmen		Brokbjerg Mose, Hellum, Ålborg	single find, bog	none	Vandkilde 1996, 410	
ÅHM 3384 MA-171125	flanged axe, type Gallemose		Denmark	unknown	unknown	Vandkilde 1996, 416	
NM MA-170414	flanged axe, type Virring		Denmark	unknown	unknown		
VMÅ139 MA-171127	flanged axe, type Vaerslev		Dybvad Mølle, Års, Ålborg	single find, gravel	none	Vandkilde 1996, 418	
NM B1335 MA-166635	flanged axe, type Torsted-Tinsdahl		Flemløse, Baag, Odense	single find, gravel	none	Vandkilde 1996, 427	
NM 26063 MA-180953	flanged axe, type Anglo-Irisch A8		Flenstofte, Baag, Odense	single find, bog	none	Vandkilde 1996, 424	
NM B3888a MA-171133	flanged axe, type Anglo-Irisch A8		Gallemose, Støvring, Randers	multi-type hoard, bog	6 local flanged axes, 1 Únětician type axe, 7 solid rings, 2 ›Blutegel‹ rings, 3 hooks	Vandkilde 1996, 416	
NM3887 MA-170358	flanged axe		Hjørring, Tolne, Horns	burial in barrow	unknown	Vandkilde 1996, 421	
ML11056 MA-181037	flanged axe, type Anglo-Irisch A10		Löddeköpinge, Harjagers, Scania	single find	none	Oldeberg 1974, 72	
NM B10789 MA-170385	flanged axe, type Aebelnaes		Odsherred, Holbæk	one-type hoard	2 European-type flanged axes	Vandkilde 1996, 409	
NM B9819 MA-166625	flanged axe, type Store-Heddinge		Rye, Volborg, København	single find, meadow	none	Vandkilde 1996, 421	
NM B5310 MA-180951	flanged axe, type Anglo-Irisch A10		Selchausdal, Løve, Holbæk	single find, bog	none	Vandkilde 1996, 425	Nørgaard et al. 2021, S2
NM 4558 MA-180952	flanged axe, type Anglo-Irisch A8		Selchausdal, Løve, Holbæk	single find, meadow	none	Vandkilde 1996, 424	
CM 142 MA-171107	flanged axe, type Gallemose		Skibby, Horns, Frederiksborg	single find	none	Vandkilde 1996, 412	Nørgaard et al. 2019, S2
SØM3197 MA-171115	flanged axe, type Gallemose		Skodsbøl, Nybøl, Sønderborg	one-type hoard, near settlement	1 local-type flanged axe	Vandkilde 1996, 414	
MLXIX MA-180954	flanged axe, type Anglo-Irisch A10		Store-Heddinge, Stevens, Præstø	one-type hoard	1 local-type flanged axe, 2 Anglo flanged axes	Vandkilde 1996, 421	Nørgaard et al. 2021, S2
MLXXa MA-180955	flanged axe, type Anglo-Irisch A8		Store-Heddinge, Stevens, Præstø	one-type hoard			
MLXXb MA-180956	flanged axe, type Anglo-Irisch A8		Store-Heddinge, Stevens, Præstø	one-type hoard			
MLXXc MA-180957	flanged axe, type Store-Heddinge		Store-Heddinge, Stevens, Præstø	one-type hoard			
VHM 5384 MA-171122	flanged axe, type Aebelnaes		Tolne Parish, Horns, Hjørring	single find	none	Vandkilde 1996, 425	Nørgaard et al. 2019, S2
NM B3370 MA-170348	flanged axe, type Værslev		Valore, Ramsø, København	single find, field	none	Vandkilde 1996, 418	Nørgaard et al. 2021, S2
NM B494 MA-171063	flanged axe, type Æbelnæs		Æbelnæs, Mønbo, Præstø	single find	none	Vandkilde 1996, 423	
NM 26062 MA-170374	flanged axe, type Store-Heddinge		Ørnbølle Hede, Vennebjerg, Hjørring	burial in barrow	unknown	Vandkilde 1996, 422	Nørgaard et al. 2019, S2

Tab. 2 The artefacts with stylistic elements of Anglo-axes during LN II in Southern Scandinavia. The table gives context information (including original references), accompanying finds, and the reference to the open-access analytical data. Axe typology based on H. Vandkilde 1996.

Tab. 2 *Artefakte mit Stilelementen britischer Beile aus dem Spätneolithikum Stufe II in Südskandinavien. Die Tabelle enthält Befundinformationen (einschließlich Originalliteratur), vergesellschaftete Funde und den Verweis auf frei zugängliche Analysedaten. Typologie der Beile nach H. Vandkilde 1996.*

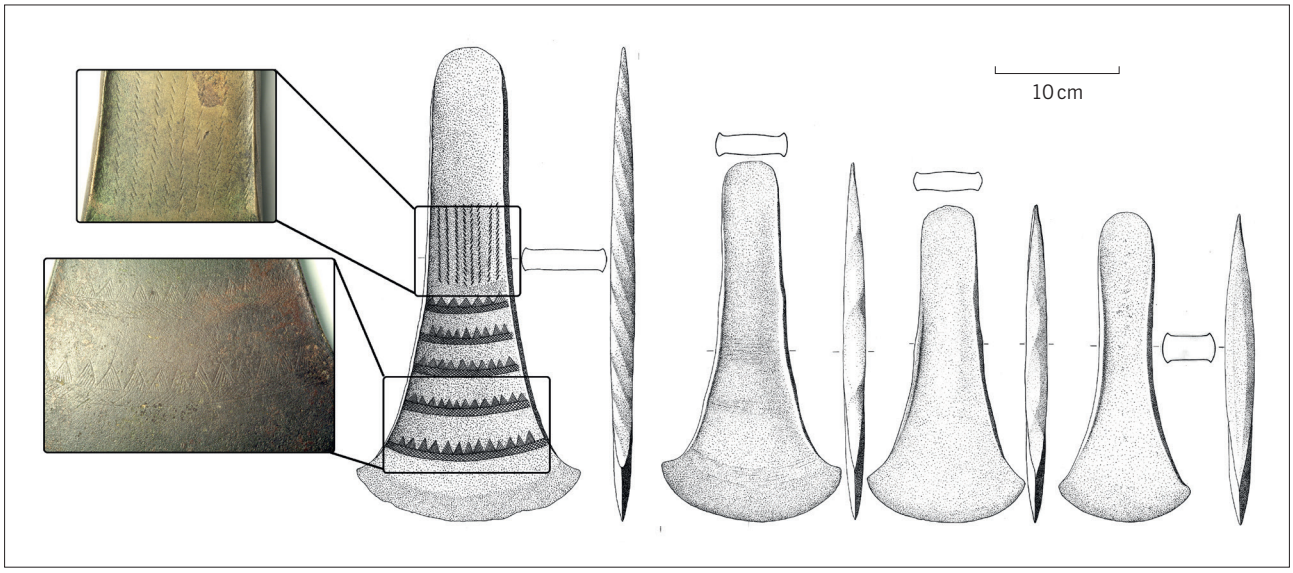

Fig. 4 The axes of the Store-Heddinge, Præstø (Denmark), hoard with details of the decoration of the Anglo-type axe MLXIX.

Abb. 4 *Die Beile des Horts von Store Heddinge, Præstø (Dänemark), mit den Verzierungsdetails auf Beil MLXIX vom Britischen Typ.*

Inspired by the composition of the Pile hoard (see Vandkilde 2017), which contains all potential metal types for the production of local Southern Scandinavian metal objects, the Danish metal objects from 2100/2000–1600 BC have been compared regarding their trace elements. The PCA (Fig. 6) clearly demonstrates the separation of ring metal and axe metal regarding the Ni content (see Nørgaard et al. 2019, 15). A definitive indication for the reuse of ring metal in local metal production is the appearance of local-style axes made of ring metal. The recast of Únětician axes with high Ni-content into local axe styles illustrates the reuse of these artefacts in local production. The comparable chemical fingerprint of local-style and Anglo-axes indicates a direct recast into local forms. The decrease in the tin content and the trace element concentrations could indicate a repetitive process or the mixing of different sources with strong differences in the trace element values (low-Ni fahlore vs high-Ni fahl-

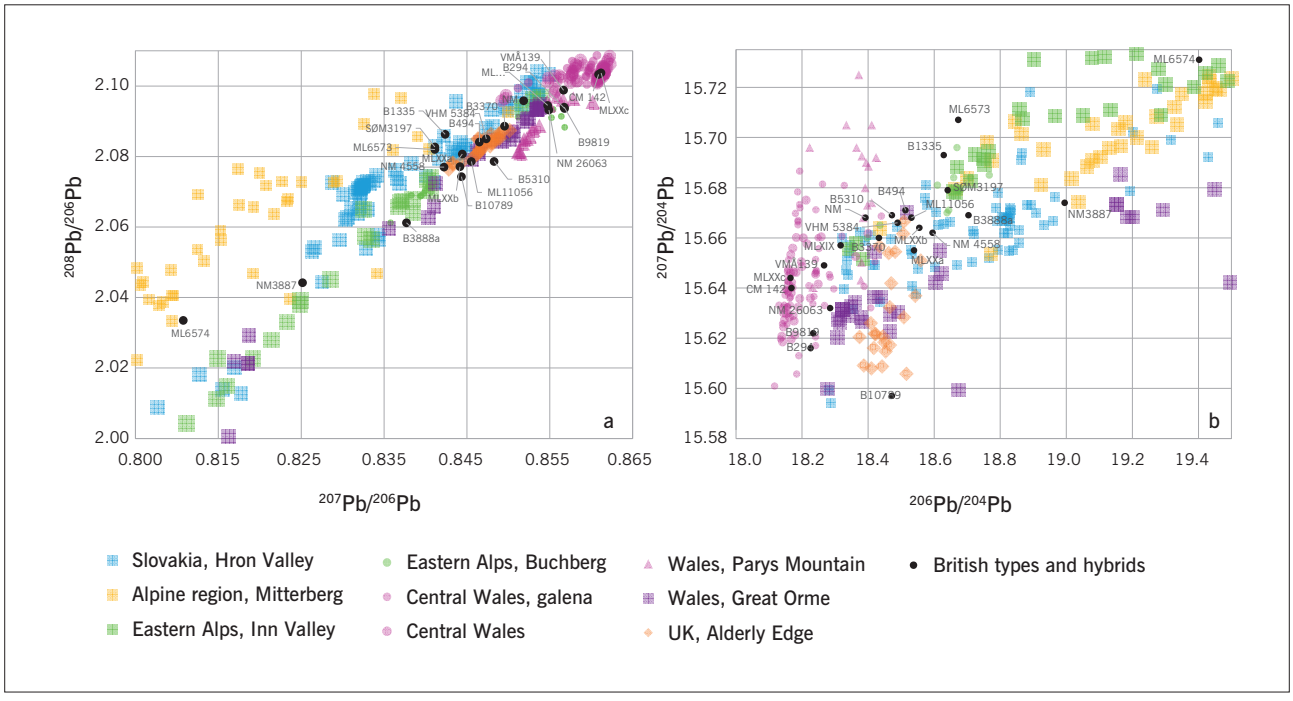

Fig. 5a–b Lead isotope ratios of artefacts that can be typologically described as hybrids and locally crafted artefacts made of low-impurity copper where a English/Welsh origin can be assumed.

Abb. 5a–b *Bleiisotopenverhältnisse in Artefakten, die typologisch als Hybride bezeichnet werden können, und in lokal hergestellten Artefakten aus Kupfer mit niedrigem Verunreinigungsgehalt, bei denen eine englische/walisische Herkunft angenommen werden kann.*

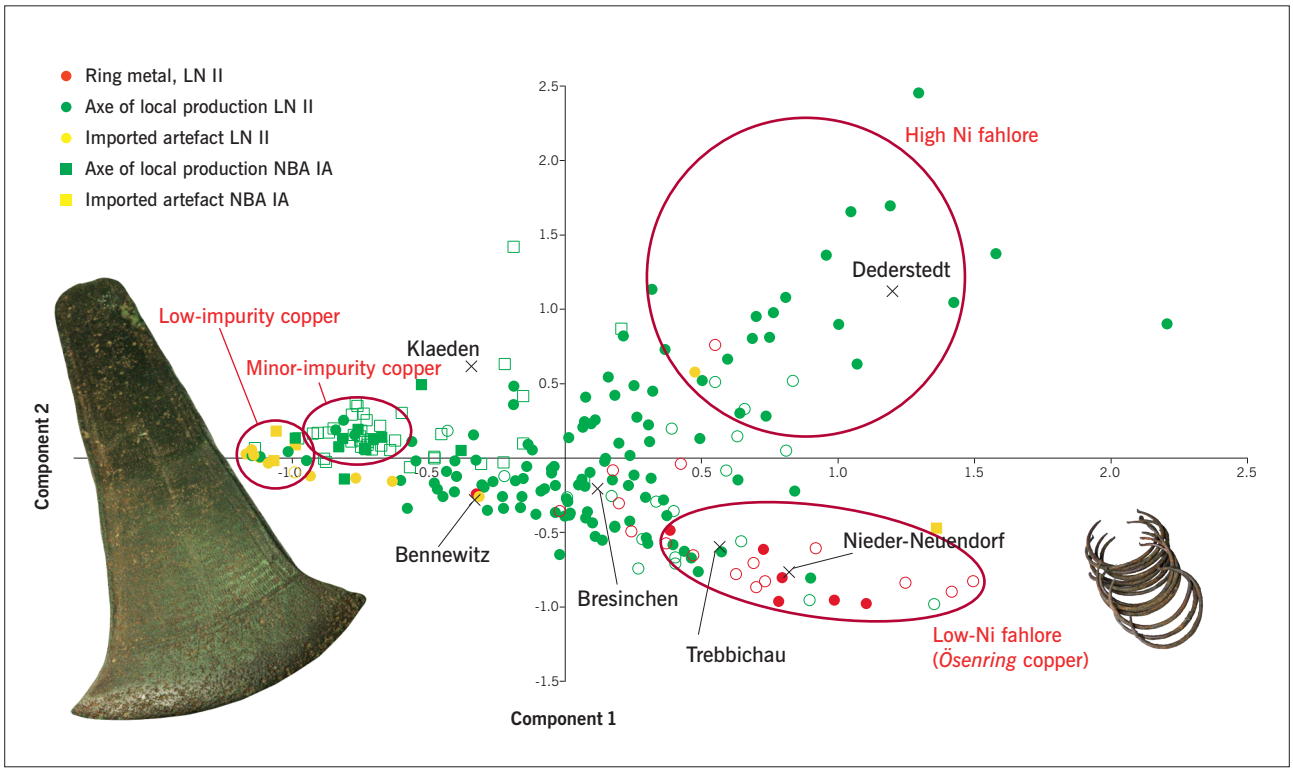

Fig. 6 Principal Component Analysis of the main trace elements (Ni, Sb, Ag, As) of the LN II (dots) and NBA IA (squares) artefacts from Denmark, including the LN II Pile hoard, Scania (Sweden). Colours indicate the artefact category, the data set of Pile (based on Vandkilde 2017) is highlighted with open symbols. The extended data set is compared with the median values for copper types (black X) defined by K. Rassmann (2005; 2010).

Abb. 6 *Hauptkomponentenanalyse der wichtigsten Spurenelemente (Ni, Sb, Ag, As) der in Dänemark gefundenen Artefakte aus dem Spätneolithikum Stufe II (Kreise) und der Nordischen Bronzezeit Periode IA (Quadrate), einschließlich des Depots von Pile, Skåne (Schweden), aus dem Spätneolithikum Stufe II. Die Farben geben die Art des Artefakts an. Die Daten der Funde aus Pile (nach Vandkilde 2017) sind mit ungefüllten Symbolen angegeben. Der erweiterte Datensatz wird mit den von K. Rassmann (2005; 2010) definierten Medianwerten für Kupfertypen verglichen (schwarzes X).*

ore). As the majority of the locally produced axes cannot be allocated clearly to one of the source metals, we need to assume, as already shown with the Store-Heddinge axes, that different artefact metals were mixed to achieve the right composition, colour, and hardness in the new artefact. The material properties of the desired metal are visualised in the object. Neck-rings symbolise a material that can withstand stress, and axes indicate a hard, resilient material. Colour differences may have been the main reason for the import of the high-tin bronzes from the British Isles but can be neglected when distinguishing the neck-ring copper from the axe copper. Even if nickel is also responsible for colour change in bronze, a visual effect would have been first achieved at a concentration above 2 wt % (see Mödlinger et al. 2017).

Thus, in the earliest stages of the Nordic Bronze Age, three main sources of metal paved the way towards the established Bronze Age: axes imported from the Únětician region and the British Isles and rings that originated in central Europe. The high-tin content in the Anglo-axes is responsible for the rapid adoption of bronze already in LN II. The mixing of high-Ni and low-Ni fahlores, both recognisable and separable by local metalworkers due to their visual differences, result in a high-impurity metal with a nickel content which is not known from ore bodies (see Nørgaard et al. 2019; Nørgaard et al. 2021).

Of axes, spearheads and swords

The intensive examination of the metal flow to Southern Scandinavia revealed that the first Bronze Age period (NBA IA, c. 1700–1600 BC) is characterised by the full implementation of bronze and probably the recycling of metal from the previous period (locally produced artefacts) as well as smaller amounts of incoming metal from sources and networks already used in LN II (Nørgaard et al. 2019, 24). It seems that this period is all about restructuring. A few centuries before, around 1750 BC, the classic phase of the Únětician Culture in Bohemia came to an end (Meller 2017, 1535). Baltic amber, which had been the major exchange good for the desired metal, was no longer omnipresent in the Únětician graves, and the shift of the rich amber burials towards the Mad'arovce-Větěrov cultural complex in the Northern Carpathian Basin (according to Ernée 2013; Meller 2017; Vandkilde et al. 2024) suggest a reconstruction of exchange networks.

Similar changes are visible in the material culture of the rising Bronze Age. From a bird's-eye-view, the finite chronological periods established for the Early Nordic Bronze Age (see Vandkilde 1989, Tab. 1) are characterised by a specific repertoire of tools and weapons. In Late Neolithic Denmark, axes, daggers, and halberds dominate (see Vandkilde 1993), whereas, in NBA IA, large hoards contain flanged axes combined with the earliest spearheads. In NBA IB, the earliest

swords appear. The changes in material culture in NBA IA are of specific interest to this study.

The NBA IA hoards of Bondesgårde near Torsted, Virring ved Randers, and Åbjerg near Ringkøbing in Central Jutland (Denmark; Fig. 7) exemplify the emerging custom of depositing partly vast sets of weapons. All these depositions contain a very specific local-style axe with a distinctly protruding cutting edge (the Virring-type axes) and socketed spearheads of Bagterp-type, variant Torsted (according to Vandkilde 1996, 101). The majority of these axes[6] have trace-element compositions showing high impurities, which, however, differ from the previously known metal sources. Some reflect the known fahlore-type metals common in LN II (based on Nørgaard et al. 2019).

Within the group of analysed artefacts one can find the complete inventory of the Virring depot from Central Jutland (Tab. 3; Fig. 7), which consists of a large flanged axe of Virring-type, a smaller axe of Torsted-type, three spearheads, variant Torsted, and a large decorated Central European spearhead (see Vandkilde 1996, 98). The metal of the Virring axe (B3962) from the eponymous depot and two of its spearheads (B3959, B3960) in the ^{206}Pb and ^{204}Pb isotope plot, could be allocated to South-Eastern European metal deposits, presumably from Serbian/Bulgarian mines[7]. In a thorough investigation of the remaining artefacts, two other Virring-type axes can be assigned to similar sources: the axes from Kragebæk (NM 21075), Holbæk, and from Ejstrup Holm (B108), Skanderborg (see Fig. 8). This evidence lends credence to the assumption that the appearance of Virring-type axes and spearheads is connected.

Assuming that a specific artefact, imported via a new connection, had entered the local metal pool, this new metal could have initiated the production of Virring axes. Some detected facts support this hypothesis. The majority of Virring axes plot in a very restricted space between a $^{206}Pb/^{204}Pb$ ratio of 18.80–18.95, a $^{207}Pb/^{204}Pb$ ratio of 15.645–15.665, and a $^{208}Pb/^{204}Pb$ ratio of 38.7–38.8. Half of the analysed socketed spearheads of the Torsted variant also plot here (Fig. 8). Interestingly, none of the known metal deposits in Europe match these ratios, and thus these values might have resulted from mixing. This would also mean that the »raw« materials used in producing Virring axes and spearheads are the same, if not that they were manufactured in a timely manner. Figure 9 illus-

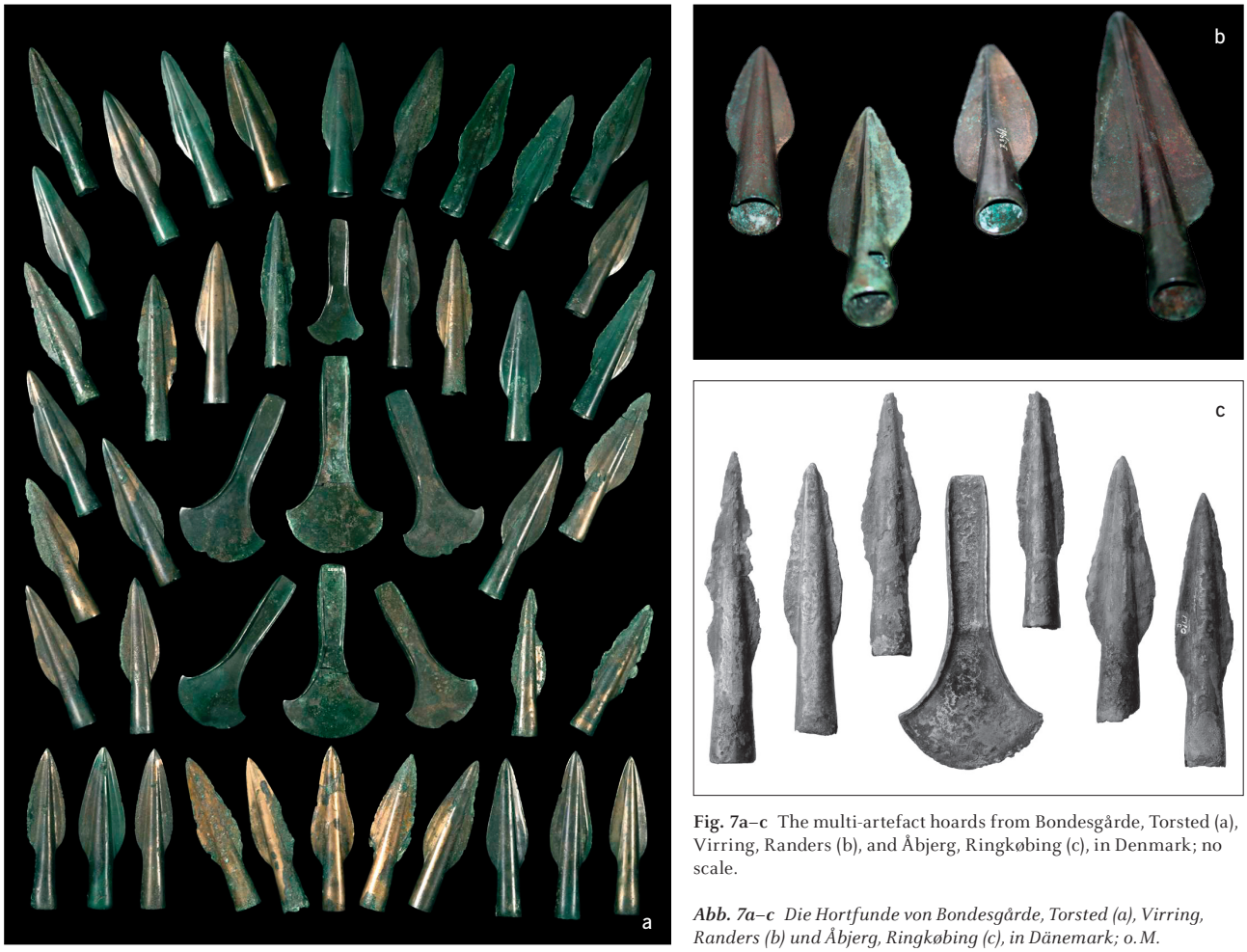

Fig. 7a–c The multi-artefact hoards from Bondesgårde, Torsted (a), Virring, Randers (b), and Åbjerg, Ringkøbing (c), in Denmark; no scale.

Abb. 7a–c *Die Hortfunde von Bondesgårde, Torsted (a), Virring, Randers (b) und Åbjerg, Ringkøbing (c), in Dänemark; o. M.*

6 Within the study by Nørgaard and colleagues in all 22 of 34 Virring-type axes have been analysed regarding their chemical and isotopic fingerprint (Nørgaard et al. 2019; Nørgaard et al. 2021).

7 The Serbian and Bulgarian copper deposits show wide ranges; for example, most of the data for the Rudna Glava mine, Bor district (Serbia), plots outside the diagrams presented in Fig. 9–10.

Museum ID	A-no.	Object	Date	Site	Context
HAM 1488	MA-170433	flanged axe, Virring-type	NBA IA	Als (Sundeved), Sønderborg	single-find
NM B15110	MA-180926	spearhead, Torsted-type		Bondesgårde, Torsted, Ringkøbing-Skjern	multi-type hoard, gravel
NM B15131	MA-180929				
NM B15117	MA-180925				
NM B15115	MA-180927				
NM B15101	MA-180928				
NM B15135	MA-180930				
NM 26072	MA-166640	flanged axe, Virring-type		Brejl, Vrads, Skanderborg	single-find, field
HOM B108	MA-170435			Ejstrup Holm, Vrads, Skanderborg	single-find, water
NM	MA-170414			unknown	unknown
NM B4489	MA-170419			unknown	unknown
NM B13535	MA-170420			unknown	unknown
HBV 2540	MA-170434			unknown	unknown
NM 10724	MA-170416			Hudevad, Åsum, Odense	single-find, meadow
NM B6821	MA-166655			Jutland	unknown
NM 21075	MA-166647			Kragebæk, Tuse, Holbæk	single-find, meadow
B10736	MA-170417			Kværkeby, Ringsted, Sorø	single-find, bog
FSM CM71	MA-170428			Nord Fünen, Odense	single-find
SØM 356	MA-170432			Saksgård, Als Sønder, Sønderborg	single-find, bog (?)
NM 26073	MA-170418			Silkeborg (near), Gjern, Skanderborg	single-find
NM B8687	MA-170422			Skannerup, Silkeborg, Gjern	single-find, under stone
NM 20948	MA-170421			Skenkelsø, Lynge, Frederiksborg	single-find, field
FSM 9708	MA-170427			Skovsbogård, Odense, Odense	single-find, meadow
NM 11820	MA-166653			Skørping, Hellum, Ålborg	single-find, gravel
NM 16783	MA-166637			Stensby, Skam, Odense	single-find, bog
NM B3963	MA-180962	flanged axe, Torsted-Tindsdahl-type		Virring, Sønderhald, Randers	multi-type hoard, field
NM B3962	MA-180963	flanged axe, Virring-type			
NM B3958	MA-180958	spearhead			
NM B3960	MA-180960	spearhead, Torsted-type			
NM B3961	MA-180961	spearhead, Torsted-type			
NM B3959	MA-180959	spearhead, Torsted-type			
AAM 1001A	MA-170440	flanged axe, Virring-type		West Himmerland, Ålborg	single-find
NM B3494	MA-170415	flanged axe, Virring-type		Øster-Mellerup, Børglum, Hjørring	single-find, field
ARV 1710A	MA-170437	flanged axe, Virring-type		Åbjerg, Hind, Ringkøbing	multi-type hoard, meadow

trates some possible scenarios in which the imported South-Eastern European axes and spearheads are one end-member of a possible mixing line, and artefacts based on fahlore (line A and B) or raw materials, respectively artefacts, from Welsh mines (line C and D) are the second end-member.

This targeted recycling would create a first generation of artefacts that imitate the style and shape of the imported pieces with a different archaeometallurgical fingerprint. Thereafter, these new items may have laid the foundation for a new mix and for the creation of a second generation of artefacts. It could be that cast residues and failed casts formed the basis for a new batch; however, depending on the time, complete artefacts might also have been remelted. Mixing line E illustrates such a scenario (Fig. 9). The axes from Als (Sundeved) near Sønderborg (HAM 1488) and

Associated artefacts	Reference	Analyical data
none	Vandkilde 1996, 432	Nørgaard et al. 2019, S2
large flanged axe, 6 flanged axes Virring-type, 40 spearheads Torsted-type	Aner/Kersten 1995, 66	
none	Vandkilde 1996, 433	
none		
unknown		
unknown	Vandkilde 1996, 432	
unknown		
unknown	Vandkilde 1996, 433	
none	Vandkilde 1996, 432	
unknown	Vandkilde 1996, 433	
none	Vandkilde 1996, 431	
none		
none	Vandkilde 1996, 432	
none		
none	Vandkilde 1996, 433	
none		
none	Vandkilde 1996, 431	
none	Vandkilde 1996, 432	
none	Vandkilde 1996, 433	
none	Vandkilde 1996, 432	
dagger blade, 3 Torsted-type spearheads, large spearhead of EBA type, 2 local-style flanged axes	Vandkilde 1996, 429	Nørgaard et al. 2021, S2 / Nørgaard et al. 2019, S2
none	Vandkilde 1996, 433	Nørgaard et al. 2019, S2
none		
local flanged axe Virring-type, 5 Torsted-type spearheads, 1 spearhead of EBA type		

Tab. 3 The axes of Virring-type and spearheads of Bagterp-type variant Torsted in Denmark for which analytical data is available. The table gives context information (including references), accompanying findings, and references to open-access analytical data.

Tab. 3 *Beile vom Typ Virring und Speerspitzen vom Typ Bagterp, Variante Torsted aus Dänemark, für welche Analysedaten vorliegen. Die Tabelle enthält Befundinformationen (einschließlich Verweise), vergesellschaftete Funde und den Verweis auf frei zugängliche Analysedaten.*

another axe from Jutland (NM B6821) could be seen as a first-generation mix, laying the foundation for another generation of axes with potentially one spearhead of the Bondesgårde hoard (B15110) as end-member. Interestingly, most of the spearheads from the Bondesgårde hoard are within the first-generation artefacts. Here a detailed techno-typological study of the 40 spearheads and additional analyses might offer further statements. The axe from Kværkeby near Ringsted on Zealand (B10736) could be one end-member of a parallel line. However, there are still several loose ends, and one of the more important ones is the possibility that the imported spearheads of European type play a distinct role. Next to the possibility that artefacts of fahlore are end-members in a potential mixing process, Switzerland's copper deposits, which have been little explored to date (see, i.e., Cattin et al. 2011; David-Elbiali 1994), may be of great importance.

Vandkilde describes the Virring-type axes as a local Scandinavian style with no convincing parallels in Central and Eastern Europe (Vandkilde 1996, 101). However, some parallels can be detected, all dating to 1700–1600 BC. W. David (2015) names three hoard finds in Southern Central Europe that contain, besides a possible Virring-type axe, also simple socketed spearheads similar to the Bagterp-type: the Lanquaid hoard with seven axes (one has the characteristic distinctly protruding cutting edge of the Virring axes), a small spearhead, and pins and rings; the Schillwitzhausen depot, Pfaffenhofen district (Germany) with three axes and a spearhead; and the Neumětely depot in central Bohemia with five axes, a simple spearhead, and pins and rings (David 2015, 102–104.). Further south-east, David postulates that the first appearance of spearheads is connected to the Hajdúsámson-Apa Horizon, which would make the socketed spearheads contemporaneous with the (in the north, well-known) Hajdúsámson-Apa swords (David 2006, 222.).

It is thus challenging, based on the current state of research, to trace a South-Eastern European predecessor of the Virring axes to a location near the Serbian/Bulgarian mining region and, in consequence, to explain the evidence that the earliest socketed spearheads in Southern Scandinavia are of South-Eastern European metal. In order to test the assumption made in this text that Virring-type axes and spearheads came to Denmark when metal supply networks were rearranged and the borders of the Únětician Culture became permeable, some tasks must still be fulfilled. A closer look at the Virring-type axes inside and outside Scandinavia is needed, from a techno-typological angle, to distinguish potential minor technological differences that might indicate the »first« axe with the characteristic distinctly protruding cutting edge. Additionally, we need to have profound and precise chronological knowledge regarding the appearance of the simple Bagterp-like socketed spearheads to reconstruct the possible exchange networks between 1700–1600 BC along the borders of the changing Únětice Culture.

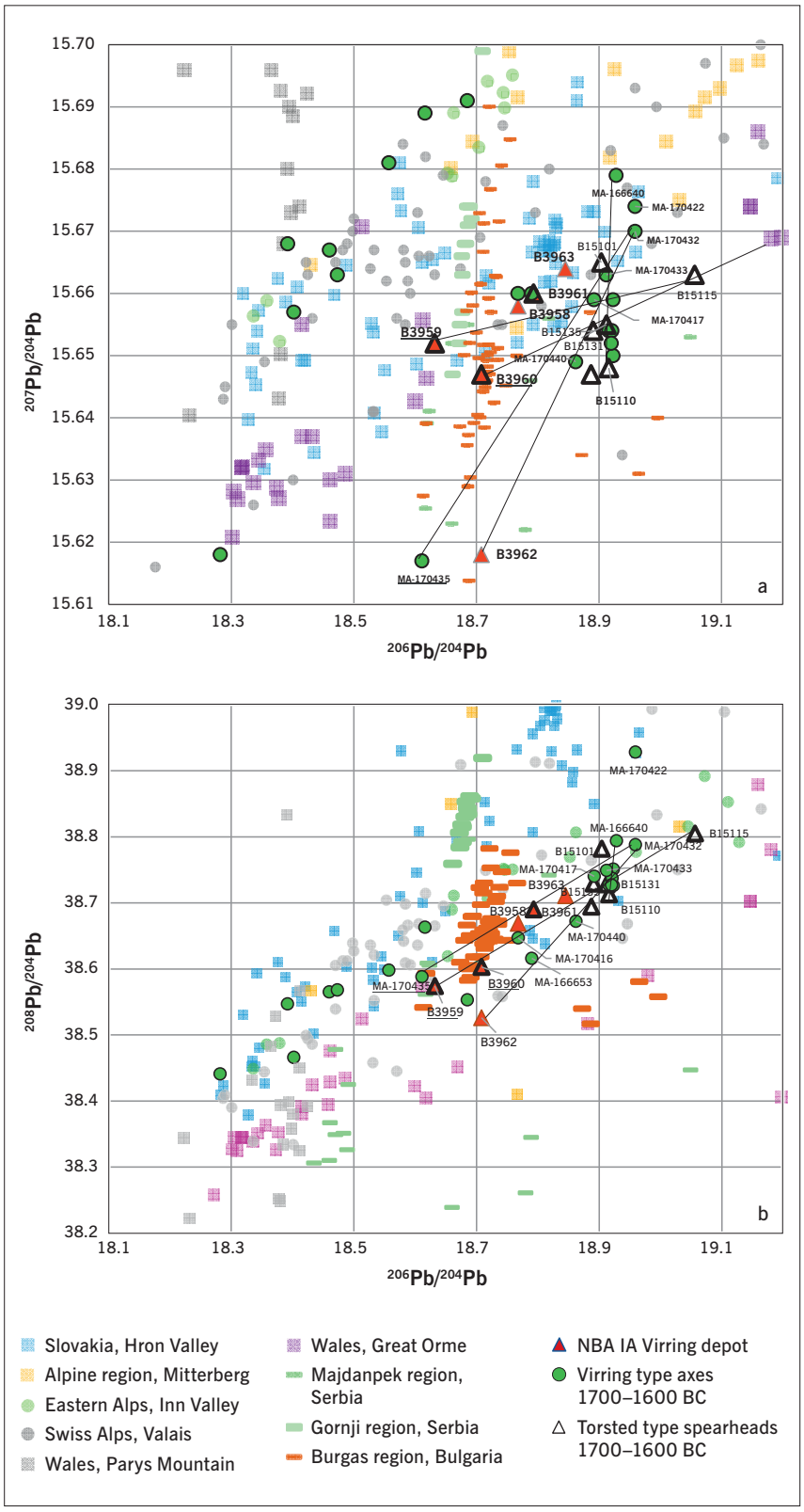

Fig. 8a–b Lead isotope ratios of the analysed Virring-type axes and socketed spearheads (a) compared to the known metal deposits in Early Bronze Age Europe (b). The black lines indicate possible mixing scenarios; for a detailed picture, see Fig. 9. Artefact data from Nørgaard et al. 2019; 2021; 2022. The ore-related data are from: Great Orme mining region and Central Wales (Fletcher et al. 1993; Joel et al. 1997; Rohl 1996; Rohl/Needham 1998; Williams 2014; Williams 2018); Alderley Edge mining region (Rohl 1996; Rohl/Needham 1998); Alpine ores (Cattin et al. 2011; Höppner et al. 2005; Pernicka et al. 2016; Schubert/Pernicka 2013); Hron Valley, Slovakian Ore Mountains (Modarressi-Teherani et al. 2016; Schreiner 2007); Serbian mining region, selection (Pernicka et al. 1993; Radivojević et al. 2010); Burgas region, Bulgaria (Kunze/Pernicka 2020; Stos-Gale et al. 1998).

Abb. 8a–b *Bleiisotopenverhältnisse der analysierten Beile vom Virring-Typ und Speerspitzen mit Tülle (a) im Vergleich zu den bekannten Metallvorkommen im frühbronzezeitlichen Europa (b). Die schwarzen Linien markieren mögliche Vermischungsszenarien; siehe Abb. 9 für eine detailliertere Darstellung. Artefaktdaten aus Nørgaard u. a. 2019; 2021; 2022; Herkunft der Daten zum Erz: Bergbauregion am Great Orme und in Zentralwales (Fletcher u. a. 1993; Joel u. a. 1997; Rohl 1996; Rohl/Needham 1998; Williams 2014; Williams 2018); Bergbauregion von Alderley Edge (Rohl 1996; Rohl/Needham 1998); Erze aus den Alpen (Cattin u. a. 2011; Höppner u. a. 2005; Pernicka u. a. 2016; Schubert/Pernicka 2013); Hrontal, Slowakisches Erzgebirge (Modarressi-Teherani u. a. 2016; Schreiner 2007); serbische Bergbauregion, Auswahl (Pernicka u. a. 1993; Radivojević u. a. 2010); Region um Burgas, Bulgarien (Kunze/Pernicka 2020; Stos-Gale u. a. 1998).*

Conclusion

Previous studies of the metal supply networks to Southern Scandinavia in the Early and Middle Bronze Age (i.e. Nørgaard et al. 2019; Nørgaard et al. 2021; Ling et al. 2014) have indicated that metallurgy in Southern Scandinavia was advanced not by the import of raw materials, but by the import of metal objects and their reuse. This article aimed to identify the parameters of this artefact-driven metal trade. It could be shown that the early adoption of tin bronze in Scandinavia's Late Neolithic was a result of the active reuse of high-tin bronzes imported from the British Isles. The high-tin concentrations in a few particularly elaborately designed local axe types demonstrate the reuse of English and Welsh

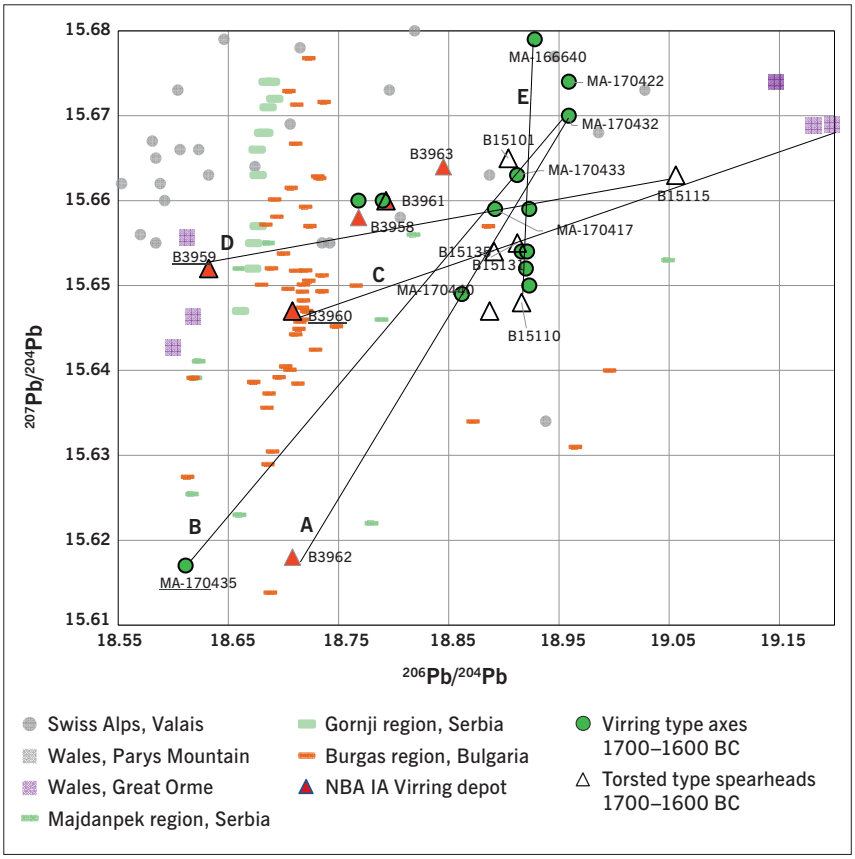

Fig. 9 Possible mixing scenarios within the group of Virring-type axes and Torsted variant spearheads based on Fig. 8. Scenario A/B and C/D shall be considered as the initial mixing of imported artefacts and existing materials. The resulting first-generation artefacts are lined up on the assumed black lines. These artefacts can be regarded as the end-members of a new mix in a second scenario. Background data and key as in Fig. 8.

Abb. 9 *Mögliche Vermischungsszenarien innerhalb der Beile vom Virring-Typ und der Speerspitzen der Torsted-Variante auf Grundlage von Abb. 8. Die Szenarien A/B und C/D sollten als erste Vermischung importierter Artefakte mit existierendem Material betrachtet werden. Die daraus entstandenen Artefakte der erster Generation liegen auf den angenommenen schwarzen Linien. Diese Artefakte können als Endglieder einer neuen Vermischung in einem zweiten Szenario betrachtet werden. Hintergrunddaten und Legende wie in Abb. 8.*

metal for local production. In addition, the reuse of the Ni-free *Ösenring* metal in local axe production could be identified. It is highly likely that Únětician axes, as well as loop neck-rings, were the main suppliers for the local production in the LN II period in Denmark. But there is also evidence of a continued supply of artefact-metal used as raw material in the following period. In NBA IA, the material culture of Southern Scandinavia was enriched by a new artefact type, the spearhead, which is visible in hoard finds from around 1700 BC. Until now, it was assumed that the Únětician Culture influenced the trade connection from the south-east to the north and that the sword, which appears around 1600 BC in Denmark, was the first artefact that testified to the active exchange networks with the South-Eastern European Bronze Age cultures. Archaeometallurgical data of Virring-type axes suggests now that some axes and metal of South-Eastern European origin came to Denmark as a result of an expanding metal trade already around 1700 BC. Whether the idea for the spearheads or the actual artefact was part of this exchange is unclear. It is, however, evident that Virring-type axes and the first spearheads of Torsted-type were made in local Scandinavian workshops, and it is highly possible that axes of South-Eastern European metal were reused to produce both the axes and spearheads.

Bibliography

Aner/Kersten 1995
E. Aner/K. Kersten, Ringkøbing Amt. Funde ältere Bronzezeit nordischen Kr. Dänemark, Schleswig-Holstein u. Niedersachsen 10 (Neumünster 1995).

Berger et al. 2022
D. Berger/G. Brügmann/J.-H. Bunnefeld/E. Pernicka, Identifying mixtures of metals by multi-isotope analysis: Disentangling the relationships of the Early Bronze Age swords of the Apa–Hajdúsámson type and associated objects. Archaeometry 64, 2022, 1–31.

Berger et al. 2023
D. Berger/K. Kaniuth/N. Borroffka/G. Brügmann/S. Krau et al., The rise of bronze in Central Asia: new evidence for the origin of Bronze Age tin and copper from multi-analytical research. Frontiers Earth Scien. 11, 2023, 1224873, doi:10.3389/feart.2023.1224873.

Boddum et al. 2011
S. Boddum/M. Mikkelsen/N. Terkildsen, Depotfund i yngre bronzealders lokale kulturlandskab. Seminarrapport fra seminariet »Depotfund i yngre bronzealders lokale kulturlandskab« afholdt i Viborg, 4. Marts 2010. Yngre bronzealders kulturlandskab 1 (Viborg 2011).

Boddum et al. 2015
S. Boddum/M. Mikkelsen/N.Terkildsen, Bronzestøbning i yngre bronzealders lokale kulturlandskab. Rapport fra seminaret »Bronzestøbning i yngre bronzealders lokale kulturlandskab« afholdt i Viborg, 6. marts 2014. Yngre bronzealders kulturlandskab 5 (Viborg 2015).

Brozio et al. 2023
J. P. Brozio/Z. Stos-Gale/J. Müller/N. Müller-Scheessel/S. Schultrich et al., The origin of Neolithic copper on the central Northern European plain and in Southern Scandinavia: Connectivities on a European scale. PLOS ONE 18,5, 2023, e0283007.

Burgess/Schmidt 1981
C. Burgess/P. K. Schmidt, The Axes of Scotland and Nothern England. PBF 9,7 (München 1981).

Butler 1955
Jay Butler, Irske Bronzeøkser fra Ulstrup. Kuml 5,5, 1955, 36–45.

Butler 1996
J. Butler, Bronze Age Metal and Amber in

the Netherlands (Part II:1). Catalogue of flat axes, flanged axes and stopridge axes. Palaeohistoria 37/38, 1996, 159–243.

Cattin et al. 2011
F. Cattin/B. Guénette-Beck/P. Curdy/N. Meisser/S. Ansermet et al., Provenance of Early Bronze Age metal artefacts in Western Switzerland using elemental and lead isotopic compositions and their possible relation with copper minerals of the nearby Valais. Journal Arch. Scien. 38, 2011, 1221–1233.

David 2006
W. David, Aus der großen Ungarischen Tiefebene bis zum Fuß der italienischen See-Alpen: Reichverzierte Lanzenspitzen als Zeugen überregionaler Beziehungen altbronzezeitlicher Eliten. In: A. Cardarelli/M. Pacciarelli/A. Vanzetti (eds.), Studi di Protostoria in Onore di Renato Peroni (Borgo San Lorenzo 2006) 213–231.

David 2015
W. David, Bronzedepotfunde der Früh- und Mittelbronzezeit in Ostbayern. Fines Transire 24, 2015, 87–112.

David-Elbiali 1994
M. David-Elbiali, Les influences culturelles en Valais au début du Bronze final au travers d es découvertes de Zeneggen-Kasteltschuggen. Annu. Soc. Suisse Prehist. Arch. 77, 1994, 35–52.

Ernée 2013
M. Ernée, Bernstein und der Zusammenbruch der klassischen Aunjetitzer Kultur in Böhmen. In: H. Meller/F. Bertemes/H.-R. Bork/R. Risch (eds.), 1600 – Cultural Change in the Shadow of the Thera-Eruption? 4th Archaeological Conference of Central Germany, October 14–16, 2011 in Halle (Saale). Tagungen Landesmus. Vorgesch. Halle 9 (Halle [Saale] 2013) 453–468.

Fletcher et al. 1993
C. J. N. Fletcher/I. G. Swainbank/T. B. Colman, Metallogenic evolution in Wales: constraints from lead isotope modelling. Journal Geol. Soc. 150,1, 1993, 77–82.

Gebauer et al. 2020
A. B. Gebauer/L. V. Sørensen/M. Taube/D. K. P. Wielandt, First metallurgy in Northern Europe: An Early Neolithic Crucible and a Possible Tuyére from Lønt, Denmark. European Journal Arch. 23,3, 2020, 1–21.

Harbison 1968
P. Harbison, Irish early Bronze Age exports found on the continent and their derivatives. Palaeohistoria 14, 1968, 175–186.

Harbison 1969
P. Harbison, The Axes of the Early Bronze Age in Ireland. PBF 9,1 (München 1969).

Höppner et al. 2005
B. Höppner/M. Barthelheim/M. Huijsmans/R. Krauss/K.-P. Martinek et al., Prehistoric Copper Production in the Inn Valley (Austria), and the Earliest Copper in Central Europe. Archaeometry 47,2, 2005, 293–315.

Joel et al. 1997
E. C. Joel/J. J. Taylor/R. A. Ixer/M. Goodway, Lead isotope analysis and the Great Orme mine. In: A. Sinclair/E. Slater/J. Gowlett (eds.), Archaeological Sciences 1995. Proceedings of a conference on the application of scientific techniques to the study of archaeology. Oxbow Monogr. 64 (Oxford 1997) 129–137.

Junghans et al. 1960
S. Junghans/E. Sangmeister/M. Schröder, Metallanalysen kupferzeitlicher und frühbronzezeitlicher Bodenfunde aus Europa. Stud. Anfängen Metallurgie 1 (Berlin 1960).

Junghans et al. 1968
S. Junghans/E. Sangmeister/M. Schröder, Kupfer und Bronze in der frühen Metallzeit Europas. Die Metallgruppen beim Stand von 12 000 Analysen. Stud. Anfängen Metallurgie 2,1–3 (Berlin 1968).

Junghans et al. 1974
S. Junghans/E. Sangmeister/M. Schröder, Kupfer und Bronze in der frühen Metallzeit Europas. Stud. Anfängen Metallurgie 2,4 (Berlin 1974).

Klassen 2000
L. Klassen, Frühes Kupfer im Norden. Untersuchungen zu Chronologie, Herkunft und Bedeutung der Kupferfunde der Nordgruppe der Trichterbecherkultur. Jysk Ark. Selskabs Skr. 36 (Aarhus 2000).

Klassen 2004
L. Klassen, Jade und Kupfer. Untersuchungen zum Neolithisierungsprozess im westlichen Ostseeraum unter besonderer Berücksichtigung der Kulturentwicklung Europas 5500–3500 BC. Jysk Ark. Selskabs Skr. 47 (Aarhus 2004).

Krause 2003
R. Krause, Studien zur kupfer- und frühbronzezeitlichen Metallurgie zwischen Karpartenbecken und Ostsee. Vorgesch. Forsch. 24 (Rahden/Westf. 2003).

Kunze/Pernicka 2020
R. Kunze/E. Pernicka, Pre-Industrial mining in Medni Rid. Geochemical analyses. In: R. Krauss/E. Pernicka/R. Kunze/K. Dimitrov/P. Leshtakov (eds.), Prehistoric Mining and Metallurgy at the Bulgarian Black Sea Coast. RessourcenKulturen 12 (Tübingen 2020) 391–418.

Ling et al. 2014
J. Ling/Z. Stos-Gale/L. Grandin/K. Billström/E. Hjärthner-Holdar et al., Moving metals II: provenancing Scandinavian Bronze Age artefacts by lead isotopes and elemental analyses. Journal Arch. Scien. 41, 2014, 106–132.

Ling et al. 2019
J. Ling/E. Hjärthner-Holdar/L. Grandin/Z. Stos-Gale/K. Kristiansen et al., Moving metals IV: Swords, metal sources and trade networks in Bronze Age Europe. Journal Arch. Scien., Reports 26, 2019, 1–34.

Megaw/Hardy 1938
J. W. S. Megaw/E. M. Hardy, British Decorated Axes and their Diffusion during the Early Part of the Bronze Age. Proc. Prehist. Soc. 4, 1938, 272–307.

Melheim 2015
A. L. Melheim, Recycling Ideas: Bronze Age Metal Production in Southern Norway. BAR Internat. Ser. 2715 (Oxford 2015).

Melheim et al. 2018
A. L. Melheim/L. Grandin/P.-O. Persson/K. Billström/Z. Stos-Gale et al., Moving metals III: Possible origins for copper in Bronze Age Denmark based on lead isotopes and geochemistry. Journal Arch. Scien. 96, 2018, 85–105.

Melheim/Sand-Eriksen 2020
A. L. Melheim/A. Sand-Eriksen, Rock Art and Trade Networks: From Scandinavia to the Italian Alps. Open Arch. 6, 2020, 86–106.

Meller 2017
H. Meller, Armies in the Early Bronze Age? An alternative interpretation of Únětice Culture axe hoards. Antiquity 91,360, 2017, 1529–1545.

Modarressi-Teherani et al. 2016
D. Modarressi-Teherani/J. Garner/M. Kvietok, Copper Production in the Slovak Ore Mountains – New Approaches. In: G. Körlin/M. Prange/T. Stöllner/Ü. Yalçin (eds.), From Bright Ores to Shiny Metals. Festschrift for Andreas Hauptmann on the Occasion of 40 Years Research in Archaeometallurgy and Archaeometry. Anschnitt, Beih. 29 (Bochum 2016) 109–123.

Mödlinger et al. 2017
M. Mödlinger/M. H. G. Kuijpers/D. Braekmans/D. Berger, Quantitative comparisons of the color of CuAs, CuSn, CuNi, and CuSb alloys. Journal Arch. Scien. 88, 2017, 14–23.

Muhly 1993
J. D. Muhly, Early Bronze Age Tin and the Taurus. Am. Journal Arch. 97,2, 1993, 239–253.

Needham 1983
S. Needham, The Early Bronze Age Axe-heads of Central and Southern England. Unpubl. Diss. Cardiff Univ. (Cardiff 1983).

Needham 2009
S. Needham, Encompassing the Sea: ›Maritories‹ and Bronze Age Maritime Interactions. In: P. Clark (ed.), Bronze Age Connections. Cultural contact in prehistoric Europe (Oxford 2009) 12–37.

Nørgaard et al. 2019
H. W. Nørgaard/E. Pernicka/H. Vandkilde, On the trail of Scandinavia's early metallurgy: provenance, transfer and mixing. PLOS ONE 14,7, 2019, e0219574, doi:10.1371/journal.pone.0219574.

Nørgaard et al. 2019a
H. W. Nørgaard/E. Pernicka/H. Vandkilde, Correction: On the trail of Scandinavia's early metallurgy: Provenance, transfer and mixing. PLOS ONE 14,12, 2019, e0227504, doi:10.1371/journal.pone.0227504.

Nørgaard et al. 2021
H. W. Nørgaard/E. Pernicka/H. Vandkilde, Shifting Networks and Mixing Metals: Changing metal-trading routes to Scandinavia correlate with Neolithic and Bronze Age transformations. PLOS ONE 16,6, 2021, e0252376, doi:10.1371/journal.pone.0252376

Nørgaard et al. 2022
H. W. Nørgaard/E. Pernicka/H. Vandkilde, 1600 BC: Fårdrup and Valsømagle-type axes and the first evidence of southern Alpine metal. Acta Arch. 92,2, 2022, 185–226.

Oldeberg 1974
A. Oldeberg, Die ältere Metallzeit in Schweden I. Numrerade Monogr. 53 (Stockholm 1974).

Pernicka et al. 1993
E. Pernicka/F. Begemann/S. Schmitt-Strecker/G. A. Wagner, Eneolithic and Early Bronze Age copper artefacts from the Balkans and their relation to Serbian copper ores. Prähist. Zeitschr. 68,1, 1993, 1–54.

Pernicka et al. 2016
E. Pernicka/J. Lutz/T. Stöllner, Bronze Age Copper Produced at Mitterberg, Austria, and its Distribution. Arch. Austriaca 100, 2016, 19–55.

Radivojević et al. 2010
M. Radivojević/T. Rehren/E. Pernicka/D. Šljivar/M. Brauns et al., On the origins of extractive metallurgy: new evidence from Europe. Journal Arch. Scien. 37, 2010, 2775–2787.

Rassmann 2005
K. Rassmann, Zur Chronologie der Hortfunde der Klassischen Aunjetitzer Kultur. Eine Auswertung von Metallanalysen aus dem Forschungsvorhaben »Frühe Metallurgie im zentralen Mitteleuropa«. In: B. Horejs/R. Jung/E. Kaiser/B. Teržan (eds.), Interpretationsraum Bronzezeit. Bernhard Hänsel von seinen Schülern gewidmet. Univforsch. Prähist. Arch. 121 (Bonn 2005) 463–480.

Rassmann 2010
K. Rassmann, Die frühbronzezeitlichen Stabdolche Ostmitteleuropas – Anmerkungen zu Chronologie, Typologie, Technik und Archäometallurgie. In: H. Meller/F. Bertemes (eds.), Der Griff nach den Sternen. Wie Europas Eliten zu Macht und Reichtum kamen. Internationales Symposium in Halle (Saale) 16.–21. Feb-

ruar 2005. Tagungen Landesmus. Vorgesch. Halle 5,2 (Halle [Saale] 2010) 807–821.

Rohl 1996
B. Rohl, Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 2, galena from Britain and Ireland. Archaeometry 38,1, 1996, 165–180.

Rohl/Needham 1998
B. Rohl/S. Needham, The Circulation of Metal in the British Bronze Age. The application of Lead Isotope Analysis. Occasional Paper 102 (London 1998).

Schreiner 2007
M. Schreiner, Erzlagerstätten im Hrontal, Slowakei. Genese und Prähistorische Nutzung. Forsch. Archäometrie u. Altwiss. 3 (Rhaden/Westf. 2007).

Schubert/Pernicka 2013
M. Schubert/E. Pernicka, Die frühbronzezeitliche Kupferverarbeitung auf dem Buchberg im Unterinntal, Tirol. In: K. Oeggl/V. Schaffer (eds.), Cuprum Tyrolense. 5550 Jahre Bergbau und Kupferverhüttung in Tirol (Brixlegg 2013) 123–152.

Stos-Gale et al. 1998
Z. Stos-Gale/N. H. Gale/N. Annetts/T. Todorov/P. Lilov et al., Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 5, ores from Bulgaria. Archaeometry 40,1, 1998, 217–226.

Vandkilde 1989
H. Vandkilde, Det ældste metalmiljø i Denmark. In: J. Poulsen (ed.), Regionale forhold i Nordisk Bronzealder. 5. Nordiske symposium for Bronzealderforskning på Sandbjerg Slot 1987. Jysk Ark. Selskabs Skr. 24 (Aarhus 1989) 29–45.

Vandkilde 1993
H. Vandkilde, Det første metalhåndværk. In: S. Hvass/B. Storgaard (eds.), Da klinger i Muld... 25 års arkæologi i Danmark (Aarhus 1993) 145–151.

Vandkilde 1996
H. Vandkilde, From Stone to Bronze. The Metalwork of the late Neolithic and earliest Bronze Age in Denmark. Jysk Ark. Selskabs Skr. 32 (Aarhus 1996).

Vandkilde 2005
H. Vandkilde, A Biographical Perspective on Ösenringe from the Early Bronze Age. In: T. L. Kienlin (ed.), Die Dinge als Zeichen: Kulturelles Wissen und Materielle Kultur. Univforsch. Prähist. Arch. 127 (Bonn 2005) 263–281.

Vandkilde 2017
H. Vandkilde, The Metal Hoard from Pile in Scania, Sweden. Place, things, time, metals, and worlds around 2000 BCE. Swedish Hist. Mus. Stud. 29 (Stockholm 2017).

Vandkilde et al. 2024
H. Vandkilde/C. Fischer Stephansen/P. Suchowska-Ducke/C. Skanning Andersen/L. Ahlqvist et al., Metal-for-Amber in the European Bronze Age. Prähist. Zeitschr. 99, 2024, 280–338, doi:10.1515/pz-2024-2003.

Williams 2014
R. A. Williams, Linking Bronze Age copper smelting slags from Pentrwyn on the Great Orme to ore and metal. Hist. Metallurgy 47,1, 2014, 93–110.

Williams 2018
R. A. Williams, Characterising Bronze Age copper from the Great Orme mine in North Wales to determine and interpret its distribution. Unpubl. Diss. Univ. Liverpool (Liverpool 2018).

Source of figures

1 author
2 author; using QGIS.org (2024), QGIS Geographic Information System, https://qgis.org on Natural Earth maps; the artefact data is from the catalogues from Harbison 1968; Harbison 1969; Megaw/Hardy 1938; Needham 1983; Vandkilde 1996; Burgess/Schmidt 1981; Vandkilde 2017; and for the Ösenhalsringe the catalogues from Junghans et al. 1960; Junghans et al. 1968; Junghans et al. 1974; Krause 2003.
3 grafic author; drawings E. Koch, L. Hilmar
4 drawings L. Hilmar; photo author
5 author
6 photo Ösenringe T. Puttkammer, Görlitzer Sammlungen für Geschichte und Kultur; other photos and graphic author
7 a, c L. Larsen, National Museum Denmark; b author
8–9 author

Tab. 1–3 author

Address

Dr. Heide Wrobel Nørgaard
Moesgaard Museum
Moesgård Allé 15
8270 Højbjerg
Denmark
hn@moesgaardmuseum.dk
ORCID: 0000-0002-9349-7516