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Moving metals IV: Swords, metal sources and trade networks in Bronze Age Europe

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ABSTRACT

European Bronze Age swords had high functional and symbolic value, and therefore they are an interesting case for approaching questions of provenance and trade in Bronze Age Europe. It is often assumed that there is a strong affinity between metal supplies and artefact type. However, this study demonstrates that metal supply and sword types are mostly unrelated. In this paper we present a comparative provenance study of 118 Bronze Age swords, which includes lead isotope and trace elemental data for swords from Scandinavia, Germany and Italy dated between 1600 and 1100 BCE. About 70% of the swords have been analysed and published before while about 30% have been sampled and analysed for this study. The chronology and geography of the deposited swords indicate that the different regions relied on different metal trade routes which changed during the course of the Bronze Age. The analytical data indicates that the largest variation of the origin of copper is in the period of 1600–1500 BCE, when copper ores from Wales, Austria and Slovakia constituted the major copper sources for the swords. There is a visible change around 1500 BCE, when copper mines in the Italian Alps become the main suppliers for Scandinavian and Italian swords, while swords from Germany were foremost based on copper from Slovakia and Austria. Further, in the period 1300–1100 BCE the sources in the Italian Alps became the dominant supplier of copper for the swords in all regions discussed here.

1. Introduction

The aim of this case study is to compare 82 analysed and published swords (Schwab et al., 2010; Bunnefeld and Schwenzer, 2011; Salzani, 2011; Ling et al., 2014; Bunnefeld, 2016a, 2016b; Canovaro, 2016; Melheim et al., 2018a) with 36 swords that were recently sampled and analysed. This is the first major compilation of analytical data, in terms of lead isotope and geochemical data, on swords dated to 1600–1100 BCE from Scandinavia and other parts of Europe. Furthermore, this compilation gives other researchers the opportunity to gain insight into our interpretations, and also the ability to make own interpretations of the analytical data of the swords. An important question to be addressed is whether the copper used to make these swords originated from many different copper ore deposits, or from a limited number of mines or mining regions. If correspondences between certain ore sources and the distribution of particular sword types are found, then how can this be best explained in terms of cultural transmission of craft and style between producers and consumers, metal networks, transportation, and exchange relations?

Lead isotope and chemical compositions of swords are used in this study as provenance indicators to uncover connections between copper supplies and sword typologies, and ultimately to address cultural connections and exchange patterns.

2. Theory

The Bronze Age was the first long period in human history when widespread trade networks connected Europe and the wider Eurasian continent, defining a pre-modern era of globalization, or, 'bronzization' (Vandkilde, 2016). One of the driving forces behind the inter-regional

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Table 1
Chronological framework employed in the different regions of our study, plus the number of analysed swords from each period/region (Montelius, 1917; Peroni, 1970; Reinecke, 1924).

Absolute dates BC	Scandinavia	Northern Germany	Southern Germany	Northern Italy	Analysed swords in total
1600–1500	IB (14 swords)	IB (2 swords)	Bronze B1 (0 swords)	MB1 (1 sword)	(17 swords)
1500–1300	IIa–IIbc (33 swords)	IIa–IIbc (15 swords	Bronze B2–C (6 swords)	MBA2–3/RBA1 (4 swords)	(58 swords)
1300–1100	III (36 swords)	III (3 swords)	Bronze D–Hallstatt A1 (0 swords)	RBA2 and FBA1 (4 swords)	(43 swords)

trade was the constant need for metals, and other raw materials and goods available only in certain parts of Europe (Radivojević et al., 2018). An important factor in the development of the widespread trade networks were the geographical distances between metal producers and consumers. In the Nordic realm, a new maritime economy supported the development towards long-distance trade networks (Ling et al., 2018). Some scholars argue that Bronze Age travellers, i.e. warriors and traders played a crucial role in this new economy, as competition must have arisen between different regions in Europe, or even between different local communities, to control the flow of goods and people (Earle et al., 2015; Vandkilde, 2016; Kristiansen, 2018).

In the context of theories about long-distance trade of metals, swords were considered particularly suited for analysis. First, the distribution of swords is often held to reflect trade routes (Kristiansen and Suchowska-Ducke, 2015). Second, swords are useful as indicators of group identities and craftsmanship as they were prestige objects of high symbolic and cultural value, and with high demands on quality and functionality (Jung et al., 2011; Jung and Mehofer, 2013). The Hajdúsámson-Apa swords dated to c. 1600–1500 BCE are a case in point; being high-end weapons that were exchanged across cultural borders (Bunnefeld, 2016a, 2016b; Pernicka et al., 2016a). The flange-hilted swords of Naue type were, on the other hand, functional warrior swords widely distributed across the Continent c. 1300–1100 BCE (Kristiansen and Suchowska-Ducke, 2015). While cross-regional stylistic repertories influenced sword typologies (Vandkilde, 2014), a high degree of local production may also be noted (e.g. von Quillfeldt, 1995; Bunnefeld, 2016a).

Recycling is also an important factor to consider. For the period in question 1600–1100 BCE, there are two competing opinions on recycling. One perspective goes in favour of seeing recycling as a standard phenomenon (Bray and Pollard, 2012). Another perspective considers recycling to be of less importance (Jung and Mehofer, 2013; Melheim et al., 2018a). In this context, swords are generally held as objects subject to minimal recycling, because of the need for technological control, and control of the alloy, and perhaps also because they were personal objects with histories of use, with related associations and memories which may have prevented recycling (Jung et al., 2011; Jung and Mehofer, 2013). The exceptional character of swords means that their production or recycling cannot be viewed in terms of routine practice. That said, swords were clearly also subject to regular damage, and recycling should therefore not be completely excluded. The absence of swords from Bronze Age graves in many parts of Europe emphasizes the extent to which these objects remained in circulation over generations (Kristiansen and Suchowska-Ducke, 2015). Another frequently used method for withdrawing swords from circulation were hoarding practices, and a preference for wetland depositions after c. 1500 BCE shows that swords often ended their use-lives by being handed over to water-bodies and not by being recycled (Bradley, 1998; Fontijn, 2002, 2008; Melheim and Horn, 2014).

3. Material and methods

3.1. Swords and daggers in the current study

Analytical data were obtained from 145 samples taken from 118 swords and daggers covering the period 1600–1100 BCE (see Table 2 for detailed data for each sword). It should be stressed that most swords have already been analysed and published (Schwab et al., 2010; Bunnefeld and Schwenzer, 2011; Salzani, 2011; Ling et al., 2014; Bunnefeld, 2016a, 2016b; Canovaro, 2016; Melheim et al., 2018a). However, 36 of the total number of 118 have recently been sampled and analysed within this project or are previously unpublished.

From some swords sampling was made from both blade and hilt, occasionally also rivets. Altogether 20 swords were subject to multiple sampling, to uncover if the same metal was used for the various sword parts. Since the main focus in this study is the overall potential trends in bulk data, the question whether blade and hilt were made from one or several copper sources will not be discussed further in the current paper. There are 101 chemical and lead isotope data from 83 swords/daggers from Scandinavia, 27 from 20 swords from Northern Germany seven from six swords from Southern Germany and 10 from 9 swords from Northern Italy. The periods and regions covered are shown in Table 1.

The following main sword types are comprised by this study: Full-hilted swords dated to c. 1600–1100 BCE, hilt-plated swords (1600–1100 BCE), flange-hilted swords (1500–1100 BCE) and octagonal-hilted swords from 1500 to 1300 BCE (Figs. 2–5). All these occur in various sub-types. Nordic full-hilted swords are generally distributed only in the Nordic zone, while the other sword types have a more widespread geographical distribution.

3.2. Sword data for each region

3.2.1. Scandinavia

In this paper we include 83 swords and daggers from Scandinavia (Figs. 2–4); 51 from Denmark (62 samples), 19 from Sweden (21 samples) and 13 from Norway (18 samples) (Table 2). Out of the total of 83 swords from Scandinavia there are 33 full-hilted swords and daggers. Eleven of the earliest type of full-hilted swords and daggers from Scandinavia date to around 1600–1500 BCE (IB) and are considered to be associated with the *Hajdúsámson-Apa type* found in Hungary (Table 2, Figs. 2–3). While some swords from Denmark, e.g. Stensgård (Bunnefeld, 2016a) are potential import pieces from Hungary; other swords found in Denmark and Norway should rather be seen as derivates of the Hungarian sword types (Melheim and Horn, 2014). There are, however, also swords and daggers (Table 2, Figs. 2–3) from the indigenous Valsømagle horizon (Vandkilde, 1996: 224ff). Additionally, eight full-hilted swords of typical Nordic type dated to 1500–1300 BCE, and nine dated to 1300–1100 BCE have been analysed (Table 2). Only four of the full-hilted swords belong to the octagonal-hilted subtype.

Early forms of short swords and daggers in Scandinavia (and Central Europe) tend to be dominated by the hilt-plated type with an organic

Table 2
This table includes information about chronology, typology, context and bibliography of each sword.

Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Denmark	1: B17618	1600–1500	Norddjurs	Ørum	Blade, lower part	Full-hilted sword. Type; Nordic Hajdusámson-Apa (derivate)	Hoard	Wincentz Rasmussen and Boas, 2006, Figs. 6, 13	Melheim et al., 2018a
Denmark	2: B17622	1600–1500	Norddjurs	Ørum	Blade, upper part	Full-hilted sword. Type; Nordic Hajdusámson-Apa (derivate)	Hoard	Wincentz Rasmussen and Boas, 2006, Figs. 10, 14	Melheim et al., 2018a
Denmark	3: B17623	1600–1500	Norddjurs	Ørum	Blade, middle part	Full-hilted sword. Type; Nordic Hajdusámson-Apa (derivate)	Hoard	Wincentz Rasmussen and Boas, 2006, Figs. 11, 14	Melheim et al., 2018a
Denmark	MA-135005	1600–1500		Stensgård	Hilt	Full-hilted sword. Type; Hajdusámson-Apa	See Bunnefeld, 2016a, A16: 244	Bunnefeld, 2016a, A16: 244	Bunnefeld, 2016a
Denmark	MA-134999	1600–1500		Guldbjerg		Full-hilted sword. Type; Hajdusámson-Apa	See Bunnefeld, 2016a, A18: 244	Bunnefeld, 2016a, A18: 244	Bunnefeld, 2016a
Denmark	MA-135003	1600–1500		Rind		Full-hilted sword. Type; Hajdusámson-Apa	See Bunnefeld, 2016a, A28: 245	Bunnefeld, 2016a, A28: 245	Bunnefeld, 2016a
Denmark	MA-135001	1600–1500		Valsømagle	Hilt	Full-hilted sword. Type; Valsømagle, A1	See Bunnefeld, 2016a, A11: 243	Bunnefeld, 2016a, A11: 243	Bunnefeld, 2016a
Denmark	MA-135012	1500–1300		Søgård	Hilt	Scheibengriffschwert (Sword with a disc pommel). Type; D2	See Bunnefeld, 2016a, B12: 250	Bunnefeld, 2016a, B12: 250	Bunnefeld, 2016a
Denmark	MA-134986	1500–1300		Ølstykke	Blade, from B16	Scheibengriffschwert (Sword with a disc pommel). Type; D2, SF	See Bunnefeld, 2016a, B16: 250	Bunnefeld, 2016a, B16: 250	Bunnefeld, 2016a
Denmark	MA-134987	1500–1300		Ølstykke	Rivet, from B16	Scheibengriffschwert (Sword with a disc pommel). Type; D2, SF	See Bunnefeld, 2016a, B16: 250	Bunnefeld, 2016a, B16: 250	Bunnefeld, 2016a
Denmark	MA-134980	1500–1300		Store-Fuglede	Blade, from B59	Rahmengriffschwert (Sword with a frame hilt)	See Bunnefeld, 2016a, B59: 256	Bunnefeld, 2016a, B59: 256	Bunnefeld, 2016a
Denmark	MA-134982	1500–1300		Store-Fuglede	Rivet, from B59	Rahmengriffschwert (Sword with a frame hilt)	See Bunnefeld, 2016a, B59: 256	Bunnefeld, 2016a, B59: 256	Bunnefeld, 2016a
Denmark	MA-134930	1500–1300		Skovgård	Blade, from B191	Nordic full-hilted sword. Type; SF	See Bunnefeld, 2016a, B191: 272	Bunnefeld, 2016a, B191: 272	Bunnefeld, 2016a
Denmark	MA-134932	1500–1300		Skovgård	Rivet, from B191	Nordic full-hilted sword. Type; SF	See Bunnefeld, 2016a, B191: 272	Bunnefeld, 2016a, B191: 272	Bunnefeld, 2016a
Denmark	MA-134965	1500–1300		Hårup	Blade, from B196	Nordic full-hilted sword. Type; E1	See Bunnefeld, 2016a, B196: 273	Bunnefeld, 2016a, B196: 273	Bunnefeld, 2016a
Denmark	MA-134966	1500–1300		Hårup	Hilt, from B196	Nordic full-hilted sword. Type; E1	See Bunnefeld, 2016a, B196: 273	Bunnefeld, 2016ac, B196: 273	Bunnefeld, 2016a
Denmark	MA-134968	1500–1300		Kongsted	Blade, from B225	Nordic full-hilted sword. Type; L3, SF	See Bunnefeld, 2016a, B225: 277	Bunnefeld, 2016a, B225: 277	Bunnefeld, 2016a
Denmark	MA-134970	1500–1300		Kongsted	Rivet, from B225	Nordic full-hilted sword. Type; L3, SF	See Bunnefeld, 2016a, B225: 277	Bunnefeld, 2016a, B225: 277	Bunnefeld, 2016a
Denmark	20: Ke 5538	1500–1300	Thisted	Tømmerby	Blade, middle part	Schwertklinge mit Heftplatte und Knauf (Sword with pommel, organic grip)	Burial	Aner and Kersten, 2001, Taf. 114	Melheim et al., 2018a
Denmark	21: Ke 5567	1500–1300	Thisted	Mors	Blade, middle part	Hilt-plated sword	Burial	Aner and Kersten, 2001, Taf. 118	Melheim et al., 2018a
Denmark	NMK 136: B13603	1500–1300	Gribskov	Ramløse	Blade	Octagonal full-hilted sword. Type; Ramløse	Burial	von Quillfeldt, 1995:69, Taf. 116B; Liversage, 2000	Melheim et al., 2018a
Denmark	19: Ke 5460	1500–1300	Thisted	Hurup	Blade, middle part	Schwertklinge mit bogenförmiger Heftabschluss, (Hilt-plated sword)	Burial	Aner and Kersten, 2001:203, Taf. 100, Abb. 153	Melheim et al., 2018a
Denmark	NMK 134: B353	1500–1300	Egedal	Stenløse	Blade	Full-hilted sword. Type; Nordic (blade)	Burial	Liversage, 2000	Melheim et al., 2018a
Denmark	NMK 135: B7106	1500–1300	Frederikssund	Græse	Blade	Sword with pommel, organic grip. Type; unknown	Burial	Liversage, 2000	Melheim et al., 2018a
Denmark	NMK 140: B12333	1500–1300	Thisted	Sønderhå	Blade	Sword blade. Type; unknown	Burial	Liversage, 2000	Melheim et al., 2018a

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Table 2 (*continued*)

Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Denmark	B10424	1500–1300	Viborg	Ramsing, Spøttrup	Hilt (?)	Full-hilted dagger. Type; Nordic	Burial	Aner and Kersten, 2001 p 286–289: no 6283	New
Denmark	B11294	1500–1300	Holbæk	Oddsherred, Asnæs, Aastofte Dragsholm	Blade (point)	Flange-hilted sword?, sword point	Hoard	Aner and Kersten, 2001 p 40: no 771	New
Denmark	B11298	1500–1300	Holbæk	Oddsherred, Asnæs, Aastofte Dragsholm	Blade	Full-hilted sword. Type; Nordic	Hoard	Aner and Kersten, 2001 p 40: no 771	New
Denmark	B11298a	1500–1300	Holbæk	Oddsherred, Asnæs, Aastofte Dragsholm	Blade	Full-hilted sword. Type; Nordic	Hoard	Aner and Kersten, 2001 p 40: no 771	New
Denmark	B15846	1500–1300	København	Melby	Hilt (?)	Full-hilted dagger. Type; Nordic	Burial Mound	Aner and Kersten, 2001 p 78: no 243; Varberg et al., 2015	New
Denmark	9221B*	1500–1100	Frederiksborg	Selsö	Blade	Short sword / dagger, tanged	Burial Mound	Aner and Kersten, 2001 p 41: no 150	New
Denmark	MA-134928	1400–1300		Ågerup	Hilt, from C14	Octagonal full-hilted sword. Type; Vasby	See Bunnefeld, 2016a, C14: 303	Bunnefeld, 2016a, C14: 303	Bunnefeld, 2016a
Denmark	MA-134906	1400–1300		Dalmosegård	Blade, from C15	Octagonal full-hilted sword. Type; "Schonen"	See Bunnefeld, 2016a, C15: 303	Bunnefeld, 2016a, C15	Bunnefeld, 2016a
Denmark	MA-134907	1400–1300		Dalmosegård	Hilt, from C15	Octagonal full-hilted sword. Type; "Schonen"	See Bunnefeld, 2016a, C15: 303	Bunnefeld, 2016a, C15: 303	Bunnefeld, 2016a
Denmark	MA-134944	1400–1300		Tvilde	Blade, from C90	Octagonal full-hilted sword. Type; Erbach	See Bunnefeld, 2016a, C90: 312	Bunnefeld, 2016a, C90: 312	Bunnefeld, 2016a
Denmark	MA-134945	1400–1300		Tvilde	Hilt, from C90	Octagonal full-hilted sword. Type; Erbach	See Bunnefeld, 2016a, C90: 312	Bunnefeld, 2016a, C90: 312	Bunnefeld, 2016a
Denmark	B10747	1300–1100	Frederiksborg	Vejby	Blade	Tanged dagger	Burial Mound	Aner and Kersten, 2001 p 24: no 98	New
Denmark	MA-134910	1300–1100		Over-Dråby	Hilt, from D2	Full-hilted sword. Type; Nordic, C1,SF	See Bunnefeld, 2016a, D2: 320	Bunnefeld, 2016a, D2: 320	Bunnefeld, 2016a
Denmark	MA-134911	1300–1100		Store-Lyngby	Blade, from D3	Griffangelschwert mit massivem Heft und Knauf (Tanged sword). Type G1	See Bunnefeld, 2016a, D3: 320	Bunnefeld, 2016a, D3: 320	Bunnefeld, 2016a
Denmark	MA-134912	1300–1100		Store-Lyngby	Hilt, from D3	Griffangelschwert mit massivem Heft und Knauf (Tanged sword). Type G1	See Bunnefeld, 2016a, D3: 320	Bunnefeld, 2016a, D3: 320	Bunnefeld, 2016a
Denmark	MA-134923	1300–1100		Olsker	Hilt, from D28	Full-hilted dagger.Type; Nordic, B1	See Bunnefeld, 2016a, D28: 323	Bunnefeld, 2016a, D28: 323	Bunnefeld, 2016a
Denmark	MA-134952	1300–1100		Hundborg	Blade, from D51	Full-hilted sword. Type; Nordic, C2	See Bunnefeld, 2016a, D51: 326	Bunnefeld, 2016a, D51: 326	Bunnefeld, 2016a
Denmark	MA-134953	1300–1100		Hundborg	Hilt, from D51	Full-hilted sword. Type; Nordic, C2	See Bunnefeld, 2016a, D51: 326	Bunnefeld, 2016a, D51: 326	Bunnefeld, 2016a
Denmark	MA-134919	1300–1100		Vester-Vandet	Hilt, from D73	Full-hilted sword. Type; Nordic, B2	See Bunnefeld, 2016a, D73: 329	Bunnefeld, 2016a, D73: 329	Bunnefeld, 2016a
Denmark	MA-134978	1300–1100		Trustrup	Pommel	Scheibengriffschwert (Sword with a disc pommel). Type; F2, SF	See Bunnefeld, 2016a, D102: 333	Bunnefeld, 2016a, D102: 333	Bunnefeld, 2016a
Denmark	MA-134914	1300–1100		Vestbirk	Hilt, from D112	Griffangeldolch mit massivem Heft und Knauf (Tanged sword). Type; G2	See Bunnefeld, 2016a, D112: 334	Bunnefeld, 2016a, D112: 334	Bunnefeld, 2016a
Denmark	MA-134951	1300–1100		Rind	Hilt, from D121	Full-hilted sword. Type; Nordic, C1,SF	See Bunnefeld, 2016a, D121: 335	Bunnefeld, 2016a, D121: 335	Bunnefeld, 2016a
Denmark	MA-134983	1300–1100		Umg. von Lejrskov	Blade, from D141	Scheibengriffschwert (Sword with a disc pommel). Type; F1	See Bunnefeld, 2016a, D141: 336	Bunnefeld, 2016a, D141: 336	Bunnefeld, 2016a
Denmark	MA-134984	1300–1100		Umg. von Lejrskov	Pommel, from D141	Scheibengriffschwert (Sword with a disc pommel). Type; F1	See Bunnefeld, 2016a, D141: 336	Bunnefeld, 2016a, D141: 336	Bunnefeld, 2016a

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Table 2 (*continued*)

Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Denmark	10: Ke 5077	1300–1100	Thisted	Hjardemål	Blade, middle part	Flange-hilted sword.	Burial	Aner and Kersten, 2001, Taf. 28–29	Melheim et al., 2018a
Denmark	12: Ke 5084	1300–1100	Thisted	Nors	Blade, middle part	Flange-hilted sword.	Burial	Aner and Kersten, 2001, Taf. 31, Abb. 33	Melheim et al., 2018a
Denmark	13: Ke 5115	1300–1100	Thisted	Vester Vandet	Blade, middle part	Flange-hilted sword.	Burial	Aner and Kersten, 2001, Taf. 37–39, Abb. 55, 58, 59	Melheim et al., 2018a
Denmark	15: Ke 5129	1300–1100	Thisted	Vester Vandet	Blade, middle part	Hilt-plated sword	Burial	Aner and Kersten, 2001, Taf. 42	Melheim et al., 2018a
Denmark	18: Ke 5237	1300–1100	Thisted	Torsted	Blade, lower part	Flange-hilted sword.	Burial	Aner and Kersten, 2001, Taf. 59	Melheim et al., 2018a
Denmark	4: Ke 5002	1300–1100	Thisted	Snedsted	Blade, middle part	Flange-hilted sword.	Burial	Aner and Kersten, 2001:21, Taf. 14	Melheim et al., 2018a
Denmark	7: Ke 5027	1300–1100	Thisted	Sønderhå	Blade, upper part	Hilt-plated sword.	Burial	Aner and Kersten, 2001: 33–34, Taf. 19, Abb. 16a–b	Melheim et al., 2018a
Denmark	8: Ke 5074	1300–1100	Thisted	Hillerslev	Blade, middle part	Flange-hilted sword.	Burial	Aner and Kersten, 2001, Taf. 29	Melheim et al., 2018a
Denmark	NMK 659: B 3810	1300–1100	København	Lyndby	See Liversage	Dagger	Burial?	Liversage, 2000	Melheim et al., 2018a
Denmark	5: Ke 5023 (A)	1300–1100	Thisted	Stagstrup	Blade, lower part, from Ke5023	Full-hilted sword. Type; Nordic	Burial	Aner and Kersten, 2001:29, Taf. 18	Melheim et al., 2018a
Denmark	6: Ke 5023 (B)	1300–1100	Thisted	Stagstrup	Hilt, from Ke5023 (drilled)	Full-hilted sword. Type; Nordic	Burial	Aner and Kersten, 2001:29, Taf. 18	Melheim et al., 2018a
Denmark	NMK 141: 19564	1300–1100	Haderslev	Nustrup	See Liversage	Flange-hilted sword. Type; Naue II / Sprockhoff Iia ?	Burial	Liversage, 2000	Melheim et al., 2018a
Denmark	NMK 142: B2295	1300–1100	Haderslev	Fole	See Liversage	Flange-hilted sword. Type; Naue II / Sprockhoff Iia ?	Burial	Liversage, 2000	Melheim et al., 2018a
Norway	ALM 25: C54227	1600–1500	Oppland	Jevnaker	Blade, from C54227	Full-hilted sword. Type; Nordic Hajdusámson-Apa (derivate)blade	(Deposit:)lake	Melheim & Horn, 2014	Melheim, 2015; Unpubl; Unpubl. report: Andersen & Simonsen, 2012
Norway	ALM 26: C54227	1600–1500	Oppland	Jevnaker	Hilt, from C54227	Full-hilted sword. Type; Nordic Hajdusámson-Apa (derivate) hilt	(Deposit:)lake	Melheim & Horn, 2014	Melheim, 2015; Unpubl; Unpubl. report: Andersen & Simonsen, 2012
Norway	B5469a	1600–1500	Vest-Agder	Farsund	Blade	Hilt-plated sword. Type; Sögel	Stray find	Austvoll, 2018	New
Norway	S1268 (1) (kl)	1500–1300	Rogaland, Sola m.	Sola	Blade	Hilt-plated dagger. Type; Horn hilted	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	S1268 (2) (n)	1500–1300	Rogaland, Sola m.	Sola	Rivet	Hilt-plated dagger. Type; Horn hilted	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	S6400a	1500–1300	Rogaland, Time m.	Time	Hilt	Hilt-plated dagger	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	S3410 (1) (kl)	1500–1300	Rogaland, Hå m.	Hå	Blade	Full-hilted dagger. Type; Nordic	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	S3410 (2) (gr)	1500–1300	Rogaland, Hå m.	Hå	Hilt	Full-hilted dagger. Type; Nordic	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	C27790a	1300–1100	Vest-Agder, Farsund m.	Farsund	Blade	Full-hilted sword: Type; Ottenjann type B	Single find	Johansen, 1986; Engedal, 2010	New
Norway	C566	1300–1100	Rogaland, Karmøy k.	Karmøy	Blade	Tanged sword with pommel	Burial	Møllerop, 1963; Engedal, 2010	New

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Table 2 (*continued*)

Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Norway	B5765c	1300–1100	Rogaland	Karmøy	Hilt	Flange-hilted sword.	Barrow with stone cist, sword in the fill, c. 60 cm from top	Austvoll, 2018	New
Norway	B5046 A	1300–1100	Rogaland	Karmøy	Hilt	Full-hilted sword, lamellar-hilted. Type; Ottenjann type F2, pommel variant b	Barrow, beneath a flat stone at the centre	Austvoll, 2018	New
Norway	B5046 B	1300–1100	Rogaland	Karmøy	Blade	Full-hilted sword, lamellar-hilted. Type; Ottenjann type F2, pommel variant b	Barrow, beneath a flat stone at the centre	Austvoll, 2018	New
Norway	S1022 (1) (kl)	1300–1100	Rogaland, Klepp k.	Klepp	Blade	Full-hilted sword. Type; Nordic	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	S1022 (2) (gr)	1300–1100	Rogaland, Klepp k.	Klepp	Hilt	Full-hilted sword. Type; Nordic	Burial	Møllerop, 1963; Engedal, 2010	New
Norway	T7501	1300–1100	Nord-Trøndelag	Steinkjer	Hilt	Flange-hilted sword.	Burial	Austvoll, 2018	New
Norway	S2969	1300–1100	Rogaland, Hå m.	Hå	Blade	Flange-hilted sword.	Deposit:lake	Møllerop, 1963; Engedal, 2010	New
Norway	S7425	1300–1100	Rogaland, Sola m.	Sola	Blade	Full-hilted sword.Type; Ottenjann type B	Burial	Møllerop, 1963; Engedal, 2010	New
Sweden	6: UM 40280_3006	1600–1500	Uppland	Viksta	Pommel	Full-hilted sword. Type; Valsømagle, A1	Burial	Forsman and Viktor, 2007; Vandkilde, 1996:224	Ling et al., 2014
Sweden	OEM863	1600–1500	Skåne	Gladsax	Probably same as OEM865 (hilt)	Hilt-plated dagger/short sword. Type; Sögel	Burial	OEM catalouge	New
Sweden	OEM865	1600–1500	Skåne	Gladsax	Probably same as OEM863 (blade)	Hilt-plated dagger/short sword. Type; Sögel	Burial	OEM catalouge	New
Sweden	SHM617282	1600–1500	Småland	Hagby, Vallby no 4, Vallby	Blade	Full-hilted sword. Type; Valsømagle, A1	Hoard	Montelius, 1917, fig. 905; Oldeberg, 1974:229; Vandkilde, 1996:224	New
Sweden	UM29218_458A	1600–1500	Bohuslän	Tanum	Blade	Full-hilted sword. Type; Valsømagle, A1	Stone setting	Gerdin and Munkenberg, 2005	New
Sweden	FG 050575	1600–1500	Östergötland	Vreta	Blade	Hilt-plated dagger/short sword. Type; Sögel		Oldeberg, 1974:296	Schwab et al., 2010
Sweden	OEM1149	1500–1300	Skåne	Borrby	Sword fragment, blade	Sword blade	Stray find	OEM catalouge	New
Sweden	OEM862	1500–1300	Skåne	Gladsax	Hilt	Hilt-plated sword	Burial	OEM catalouge	New
Sweden	LUHM 20797:32	1500–1300	Skåne		Hilt	Hilt-plated dagger	Grave, mound	Oldeberg, 1974:106 no 700:15; Hansen, 1938:57pp	New
Sweden	LUHM 20797:35	1500–1300	Skåne		Hilt	Hilt-plated dagger	Grave, mound	Oldeberg, 1974:106 no 700:16; Hansen, 1938:57pp	New
Sweden	SHM416674_blade	1500–1300	Västergötland	Falköping	Blade	Hilt-plated sword	Grave	Oldeberg, 1974:303 no 2378; Sahlström, 1931-32:64	New
Sweden	SHM416674_hilt	1500–1300	Västergötland	Falköping	Hilt	Hilt-plated sword	Grave	Oldeberg, 1974:303 no 2378; Sahlström, 1931-32:64	New
Sweden	20: VM 1205	1500–1300	Värmland	Glava	Hilt	Hilt-plated dagger	Wet find, lake	Oldeberg, 1974:335; Montelius, 1917:60	Ling et al., 2014
Sweden	21: VM 2931	1500–1300	Värmland	Övre Ulleryd	Blade	Hilt-plated dagger	Stray find	Oldeberg, 1974:337; Montelius, 1917:60; Engedal, 2010:67	Ling et al., 2014

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Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Sweden	SHM415450	1500–1300	Blekinge	Nättraby, Dalby	Blade	Hilt-plated sword	Grave, mound	Montelius, 1917:39 No 912	New
Sweden	16: LUHM 3527	1300–1100	Skåne		Blade	Flange-hilted sword. Type: Sprockhoff Ia	Stray find	Oldeberg, 1974:167 no 1275	Ling et al., 2014
Sweden	OEM1510	1300–1100	Skåne	Vitaby	Blade	Hilt-plated dagger/short sword	Stray find	OEM catalouge	New
Sweden	23: LUHM 24283	1300–1100	Skåne	Tullstorp	Blade	Hilt-plated sword. Type; Meinered	Grave	Bruzelius, 1860; Schauer, 1971:76	Ling et al., 2014
Sweden	24: LUHM 22268	1300–1100	Skåne	Östra Hoby	Blade	Flange-hilted sword.	Stray find	Oldeberg, 1974:144; Sprockhoff, 1931:56; Schauer, 1971:117	Ling et al., 2014
Sweden	25: LUHM 2846	1300–1100	Skåne		Blade	Flange-hilted sword.	Stray find	Oldeberg, 1974:164; Sprockhoff, 1931:13; Schauer, 1971:117	Ling et al., 2014
Sweden	29: AM 1213	1300–1100	Värmland	Sunne		Tanged sword	Wet find (bog)	Oldeberg, 1974:336; Montelius, 1917:66,7	Ling et al., 2014
Germany	MA-071222	1600–1500		Hambostel	Blade	Hilt-plated sword. Type; Sögel/ Wohlde	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071243	1600–1500		Nienburg	Blade	Hilt-plated sword. Type; Wohlde	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-135030	1500–1300		Kampen	Blade, from B299	Nordic full-hilted sword	See Bunnefeld, 2016a, B299: 285	Bunnefeld, 2016a, B299: 285	Bunnefeld, 2016a
Germany	MA-071212	1500–1300		Loxstedt	Pommel	Full-hilted sword. Type; Nordic	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071213	1500–1300		Loxstedt	Blade	Full-hilted sword. Type; Nordic	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071232	1500–1300		Soderstorf	Blade	Hilt-plated sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071234	1500–1300		Wessenstedt	Blade	Hilt-plated sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071235	1500–1300		Wehden	Blade	Flange-hilted sword. Type; Sprochhoff Ia	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071236	1500–1300		Nindorf	Blade	Flange-hilted sword. Type; Sprochhoff Ib	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071239	1500–1300		Harsefeld	Blade	Flange-hilted sword. Type; Sprochhoff Ia	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071240	1500–1300		Bramstedt	Blade	Flange-hilted sword. Type; Sprochhoff Ia	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071250	1500–1300		Harsefeld	Blade	Full-hilted sword. Type; Nordic, E2	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071224	1500–1300		Garlstorf	Blade	Hilt-plated sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-135048	1400–1300		Osterrade	Pommel from C114	Octagonal full-hilted sword. Type; Vasby	See Bunnefeld, 2016a, C114: 315	Bunnefeld, 2016a, C114: 315	Bunnefeld, 2016a
Germany	MA-135040	1400–1300		Windbergen	Pommel from C120	Octagonal full-hilted sword. Type; Hausmoning	See Bunnefeld, 2016a, C120: 316	Bunnefeld, 2016a, C120: 316	Bunnefeld, 2016a
Germany	MA-071203	1400–1300		Bremervörde	Blade	Octagonal full-hilted sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071204/1	1400–1300		Bremervörde	Pommel	Octagonal full-hilted sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071204/2	1400–1300		Bremervörde	Pommel	Octagonal full-hilted sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071205	1400–1300		Bremervörde	Hilt	Octagonal full-hilted sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011

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Table 2 (*continued*)

Country	Artefact/Sample number	BC cal	County	"Parish or Place"	Object description for sampling	Total typological description	Context	Biblo (Archaeology)	Biblo (Analysis)
Germany	MA-071206	1400–1300		unbekannt	Blade	Octagonal full-hilted sword	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071246	1400–1300		Wedel	Blade	Octagonal full-hilted sword. Type; Predecessor	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071247	1400–1300		Wedel	Rivet	Octagonal full-hilted sword. Type; Predecessor	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071248	1400–1300		Wedel	Hilt	Octagonal full-hilted sword. Type; Predecessor	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-071249	1400–1300		Wedel	Anguss	Octagonal full-hilted sword. Type; Predecessor	See Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011	Bunnefeld and Schwenzer, 2011
Germany	MA-135034	1300–1100		Norddorf	Pommel from D169	Full-hilted sword. Type; Nordic, B1, SF	See Bunnefeld, 2016a, D169: 341	Bunnefeld, 2016a, D169: 341	Bunnefeld, 2016a
Germany	MA-135073	1300–1100		Jahrsdorf	Blade, from D180	Full-hilted sword. Type; Nordic, B1, SF	See Bunnefeld, 2016a, D180: 342	Bunnefeld, 2016a, D180: 342	Bunnefeld, 2016a
Germany	MA-135037	1300–1100		Huje	Blade, from D187	Full-hilted sword. Type; Nordic, A2	See Bunnefeld, 2016a, D187: 343	Bunnefeld, 2016a, D187: 343	Bunnefeld, 2016a
Germany, south	KS 1 1969.248	1400	Southern Bavaria	Kirchbichl	Blade	Octagonal full-hilted sword. Type; Kirchbichl	Lake find	von Quillfeldt, 1995, Taf. 6, Nr. 18	New
Germany, south	KS 2 EM 301	1400–1300	Southern Bavaria	Ferthofen	Blade	Octagonal full-hilted sword. Type; unknown	See Quillfeld 1995, Taf. 13, Nr. 37	von Quillfeldt, 1995, Taf. 24, Nr. 73	New
Germany, south	KS 3 NM 3545	1400–1300	Southern Bavaria	Pflugdorf	Blade	Octagonal full-hilted sword. Type; Hausmoning	Lake find	von Quillfeldt, 1995, Taf. 12, Nr. 34	New
Germany, south	KS 4 1963.330	1400–1300	Southern Bavaria	Grab bei Reuth	Blade	Octagonal full-hilted sword. Type; Hausmoning	See Quillfeld 1995, Taf. 13, Nr. 37	von Quillfeldt, 1995, Taf. 13, Nr. 37	New
Germany, south	KS 7 IV, 571	1400–1300	Southern Bavaria	München Engelshalking	Blade	Octagonal full-hilted sword. Type; Leonberg	See Quillfeld 1995, Taf. 13, Nr. 37	von Quillfeldt, 1995, Taf. 17, Nr. 53	New
Germany, south	KSa 5 1927.54	1400–1300	Southern Bavaria	Ergertshausen/Icking	Blade, from 1927.54	Octagonal full-hilted sword. Type; unknown, blade	Lake find	von Quillfeldt, 1995, Taf. 22, Nr. 66	New
Germany, south	KSa 6 1927.54	1400–1300	Southern Bavaria	Ergertshausen/Icking	Hilt, from 1927.54	Octagonal full-hilted sword. Type; unknown, hilt	Lake find	von Quillfeldt, 1995, Taf. 22, Nr. 66	New
Italy	n.205518	1650–1550	Bor di Pacengo, Lazise (VR)		Sword	simple base, with trapezoidal shape	Settelment (pile dwelling)	Salzani, 2011	Salzani, 2011
Italy	Mus-S3	1650–1350/1300	Muscoli, Cervignano del Friuli (UD)		Fragment of sword	Flange-hilted sword. Type; Sprockhoff Ia, Traun/Sacile	Hoard	Canovaro, 2016	Canovaro, 2016
Italy	ON 95	1550–1450	Olmo di Nogara (VR)		Sword	Flange-hilted sword. Type; Boiu Iia, Castion di strada	Necropoli, tomb 95	Angelini in press	Angelini in press
Italy	ON 95P	1550–1450	Olmo di Nogara (VR)		Rivet of the sword ON 95	Rivet	Necropoli, tomb 95	Angelini in press	Angelini in press
Italy	CdSA-S	1550–1350/1300	Castion di Strada (UD)		Sword blade fragment	Flange-hilted sword. Type; Boiu Ib-Iia/Kezsethely type	Hoard, B	Canovaro, 2016	Canovaro, 2016
Italy	Cel-S	1550–1150	Celò, Pulfero (UD)		Fragment of sword	Tanged sword	Hoard	Canovaro, 2016	Canovaro, 2016
Italy	BEL-S	1450–1350/1300	S. Marco di Belvedere, Aquileia (UD)		Sword	Flange-hilted sword. Type; Sprockhoff Ia, Traun/Montegiorgio	Isolated find	Canovaro, 2016	Canovaro, 2016
Italy	Mus-S2	1350/1300–1150	Muscoli, Cervignano del Friuli (UD)		Fragment of sword	Flange-hilted sword.Type; Naue II / Sprockhoff Iia, A/Cetona	Hoard	Canovaro, 2016	Canovaro, 2016
Italy	n.2356	1350/1300–1150	Bacino Marina, Peschiera (VR)		Sword	Tanged sword. Type; Rixheim	Settlement (pile dwelling)	Salzani, 2011	Salzani, 2011
Italy	n.673	1350/1300–1150	Imboccatura del Mincio, Peschiera (VR)		Fragment of sword	Tanged sword. Type; Pepinville	Settlement (pile dwelling)	Salzani, 2011	Salzani, 2011

Table 3
Data on lead isotope of each sword in this study as well as suggested provenance.

Country	Artefact/sample number	BC cal	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	Suggested ore region
Denmark	1: B17618	1600–1500	18.3236	15.6257	38.327	0.85276	2.09169	British Isles, Wales, Great Orme
Denmark	2: B17622	1600–1500	18.3367	15.6257	38.337	0.85216	2.09075	British Isles, Wales, Great Orme
Denmark	3: B17623	1600–1500	18.3503	15.6049	38.290	0.85039	2.08659	British Isles, Wales, Great Orme
Denmark	MA-135005	1600–1500	19.6150	15.7270	39.683	0.80178	2.02309	Austria, Mitterberg
Denmark	MA-134999	1600–1500	18.5310	15.6700	38.608	0.84561	2.08343	Slovakia
Denmark	MA-135003	1600–1500	18.4130	15.6430	38.440	0.84956	2.08766	British Isles, Wales, Great Orme
Denmark	MA-135001	1600–1500	18.3580	15.6350	38.375	0.85167	2.09037	British Isles, Wales, Great Orme
Denmark	MA-135012	1500–1300	18.2740	15.6540	38.427	0.85663	2.10282	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134986	1500–1300	18.8430	15.6820	38.843	0.83225	2.06140	Austria, Mitterberg
Denmark	MA-134987	1500–1300	18.8210	15.6750	38.797	0.83285	2.06137	Austria, Mitterberg
Denmark	MA-134980	1500–1300	18.9630	15.6950	39.088	0.82766	2.06128	Austria, Mitterberg
Denmark	MA-134982	1500–1300	18.7430	15.6840	38.865	0.83679	2.07357	Austria, Mitterberg
Denmark	MA-134930	1500–1300	18.4580	15.6620	38.578	0.84852	2.09004	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134932	1500–1300	18.4080	15.6580	38.519	0.85061	2.09251	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134965	1500–1300	18.3750	15.6640	38.501	0.85246	2.09529	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134966	1500–1300	18.4010	15.6630	38.522	0.85120	2.09347	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134968	1500–1300	18.6550	15.6770	38.842	0.84036	2.08212	Austria, Mitterberg
Denmark	MA-134970	1500–1300	18.4800	15.6700	38.630	0.84794	2.09037	Italy Eastern Alps - Southalpine AATV
Denmark	20: Ke 5538	1500–1300	19.3190	15.7080	39.302	0.81309	2.03437	Austria, Mitterberg
Denmark	21: Ke 5567	1500–1300	18.1611	15.6379	38.350	0.86107	2.11163	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 136: B13603	1500–1300	18.4323	15.6656	38.571	0.84990	2.09258	Italy Eastern Alps - Southalpine AATV
Denmark	19: Ke 5460	1500–1300	18.3917	15.6668	38.531	0.85184	2.09501	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 134: B353	1500–1300	18.3610	15.6630	38.486	0.85306	2.09607	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 135: B7106	1500–1300	18.4167	15.6687	38.543	0.85078	2.09284	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 140: B12333	1500–1300	18.5440	15.6500	38.552	0.84394	2.07895	Slovakia
Denmark	B10424	1500–1300	17.9577	15.6430	38.168	0.87110	2.12543	Italy Eastern Alps - Southalpine AATV
Denmark	B11294	1500–1300	18.0900	15.6104	38.200	0.86293	2.11167	Sardinia, Montevecchio
Denmark	B11298	1500–1300	18.2208	15.6584	38.403	0.85937	2.10765	Italy Eastern Alps - Southalpine AATV
Denmark	B11298a	1500–1300	18.4643	15.6376	38.396	0.84691	2.07948	Slovakia
Denmark	B15846	1500–1300	18.3058	15.6668	38.505	0.85584	2.10341	Italy Eastern Alps - Southalpine AATV
Denmark	9221B*	1500–1100	18.7870	15.6687	39.013	0.83402	2.07660	Slovakia
Denmark	MA-134928	1400–1300	18.2700	15.6500	38.470	0.85660	2.10564	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134906	1400–1300	18.3810	15.6590	38.499	0.85191	2.09450	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134907	1400–1300	18.3040	15.6580	38.445	0.85544	2.10036	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134944	1400–1300	18.6410	15.6760	38.869	0.84094	2.08513	Austria, Mitterberg
Denmark	MA-134945	1400–1300	18.3950	15.6640	38.539	0.85154	2.09508	Italy Eastern Alps - Southalpine AATV
Denmark	B10747	1300–1100	18.1794	15.6651	38.407	0.86169	2.11267	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134910	1300–1100	18.3600	15.6740	38.542	0.85370	2.09924	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134911	1300–1100	18.1600	15.6510	38.349	0.86184	2.11173	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134912	1300–1100	18.1690	15.6510	38.355	0.86141	2.11101	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134923	1300–1100	18.0360	15.6420	38.229	0.86727	2.11959	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134952	1300–1100	18.1510	15.6460	38.339	0.86199	2.11223	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134953	1300–1100	18.1980	15.6450	38.338	0.85971	2.10672	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134919	1300–1100	18.1760	15.6510	38.352	0.86108	2.11004	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134978	1300–1100	18.1700	15.6540	38.370	0.86153	2.11172	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134914	1300–1100	18.3590	15.6630	38.489	0.85315	2.09646	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134951	1300–1100	18.1520	15.6460	38.317	0.86194	2.11090	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134983	1300–1100	18.1650	15.6540	38.356	0.86177	2.11153	Italy Eastern Alps - Southalpine AATV
Denmark	MA-134984	1300–1100	18.2230	15.6600	38.411	0.85935	2.10783	Italy Eastern Alps - Southalpine AATV
Denmark	10: Ke 5077	1300–1100	18.2953	15.6519	38.465	0.85552	2.10244	Italy Eastern Alps - Southalpine AATV
Denmark	12: Ke 5084	1300–1100	18.1215	15.6498	38.324	0.86360	2.11486	Italy Eastern Alps - Southalpine AATV
Denmark	13: Ke 5115	1300–1100	18.1050	15.6410	38.303	0.86390	2.11560	Italy Eastern Alps - Southalpine AATV
Denmark	15: Ke 5129	1300–1100	18.1925	15.6518	38.374	0.86034	2.10935	Italy Eastern Alps - Southalpine AATV
Denmark	18: Ke 5237	1300–1100	18.3447	15.6588	38.487	0.85359	2.09797	Italy Eastern Alps - Southalpine AATV
Denmark	4: Ke 5002	1300–1100	18.1900	15.6450	38.385	0.86009	2.11023	Italy Eastern Alps - Southalpine AATV
Denmark	7: Ke 5027	1300–1100	18.1525	15.6498	38.356	0.86213	2.11301	Italy Eastern Alps - Southalpine AATV
Denmark	8: Ke 5074	1300–1100	18.1725	15.6548	38.388	0.86145	2.11245	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 659: B 3810	1300–1100	18.3204	15.6683	38.504	0.85523	2.10171	Italy Eastern Alps - Southalpine AATV
Denmark	5: Ke 5023 (A)	1300–1100	18.5575	15.6570	38.727	0.84370	2.08687	Sardinia, Calabona
Denmark	6: Ke 5023 (B)	1300–1100	18.1690	15.6410	38.308	0.86086	2.10843	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 141: 19564	1300–1100	18.1265	15.6506	38.328	0.86341	2.11447	Italy Eastern Alps - Southalpine AATV
Denmark	NMK 142: B2295	1300–1100	18.2244	15.6509	38.389	0.85879	2.10648	Italy Eastern Alps - Southalpine AATV
Norway	ALM 25: C54227	1600–1500	18.6856	15.6832	38.757	0.83932	2.07417	Slovakia
Norway	ALM 26: C54227	1600–1500	18.5356	15.6718	38.655	0.84550	2.08545	Slovakia
Norway	B5469a	1600–1500	18.4070	15.6738	38.562	0.85151	2.09496	Italy Eastern Alps - Southalpine AATV
Norway	S1268 (1) (kl)	1500–1300	18.3624	15.6712	38.519	0.85344	2.09770	Italy Eastern Alps - Southalpine AATV
Norway	S1268 (2) (n)	1500–1300	18.3562	15.6498	38.458	0.85256	2.09510	Italy Eastern Alps - Southalpine AATV
Norway	S6400a	1500–1300	18.5530	15.6407	38.612	0.84303	2.08120	Slovakia
Norway	S3410 (1) (kl)	1500–1300	18.5348	15.6664	38.643	0.84525	2.08489	Slovakia
Norway	S3410 (2) (gr)	1500–1300	18.6323	15.6734	38.741	0.84119	2.07926	Slovakia
Norway	C27790a	1300–1100	18.2094	15.6663	38.428	0.86034	2.11032	Italy Eastern Alps - Southalpine AATV
Norway	C566	1300–1100	18.1830	15.6518	38.379	0.86079	2.11069	Italy Eastern Alps - Southalpine AATV
Norway	B5765c	1300–1100	18.2537	15.6717	38.480	0.85855	2.10807	Italy Eastern Alps - Southalpine AATV
Norway	B5046 A	1300–1100	18.3055	15.6792	38.555	0.85653	2.10620	Italy Eastern Alps - Southalpine AATV

(*continued on next page*)

Table 3 (*continued*)

Country	Artefact/sample number	BC cal	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	Suggested ore region
Norway	B5046 B	1300–1100	18.2789	15.6771	38.487	0.85766	2.10554	Italy Eastern Alps - Southalpine AATV
Norway	S1022 (1) (kl)	1300–1100	18.4093	15.6728	38.556	0.85135	2.09437	Italy Eastern Alps - Southalpine AATV
Norway	S1022 (2) (gr)	1300–1100	18.4246	15.6634	38.542	0.85014	2.09187	Italy Eastern Alps - Southalpine AATV
Norway	T7501	1300–1100	18.0666	15.6399	38.262	0.86568	2.11781	Italy Eastern Alps - Southalpine AATV
Norway	S2969	1300–1100	18.1356	15.6492	38.344	0.86290	2.11428	Italy Eastern Alps - Southalpine AATV
Norway	S7425	1300–1100	18.3153	15.6620	38.469	0.85513	2.10040	Italy Eastern Alps - Southalpine AATV
Sweden	6: UM 40280_3006	1600–1500	18.4600	15.6810	38.612	0.84946	2.09166	Italy Eastern Alps - Southalpine AATV
Sweden	OEM863	1600–1500	18.2504	15.6666	38.472	0.85842	2.10800	Italy Eastern Alps - Southalpine AATV
Sweden	OEM865	1600–1500	18.0346	15.6275	38.175	0.86653	2.11673	Italy Eastern Alps - Southalpine AATV
Sweden	SHM617282	1600–1500	18.6092	15.5873	38.423	0.83761	2.06472	Cyprus
Sweden	UM29218_458A	1600–1500	18.8843	15.6827	38.963	0.83046	2.06327	Slovakia
Sweden	FG 050575	1600–1500	18.1470	15.6090	38.105	0.86014	2.09980	Aznalcollar, South Spain
Sweden	OEM1149	1500–1300	18.2122	15.6622	38.424	0.85998	2.10978	Italy Eastern Alps - Southalpine AATV
Sweden	OEM862	1500–1300	18.2395	15.6528	38.406	0.85818	2.10567	Italy Eastern Alps - Southalpine AATV
Sweden	LUHM 20797:32	1500–1300	18.4946	15.6775	38.678	0.84768	2.09131	Italy Eastern Alps - Southalpine AATV
Sweden	LUHM 20797:35	1500–1300	18.2535	15.6683	38.449	0.85837	2.10637	Italy Eastern Alps - Southalpine AATV
Sweden	SHM416674_blade	1500–1300	18.2906	15.6588	38.447	0.85611	2.10200	Italy Eastern Alps - Southalpine AATV
Sweden	SHM416674_hilt	1500–1300	18.1882	15.6515	38.375	0.86053	2.10988	Italy Eastern Alps - Southalpine AATV
Sweden	20: VM 1205	1500–1300	18.7390	15.6780	38.859	0.83665	2.07370	Slovakia
Sweden	21: VM 2931	1500–1300	18.2680	15.6510	38.395	0.85674	2.10176	Italy Eastern Alps - Southalpine AATV
Sweden	SHM415450	1500–1300	18.3491	15.6601	38.479	0.85345	2.09708	Italy Eastern Alps - Southalpine AATV
Sweden	16: LUHM 3527	1300–1100	18.1450	15.6490	38.320	0.86244	2.11188	Italy Eastern Alps - Southalpine AATV
Sweden	OEM1510	1300–1100	18.2321	15.6549	38.405	0.85865	2.10645	Italy Eastern Alps - Southalpine AATV
Sweden	23: LUHM 24283	1300–1100	18.3300	15.6610	38.396	0.85439	2.09471	Italy Eastern Alps - Southalpine AATV
Sweden	24: LUHM 22268	1300–1100	18.3124	15.6717	38.519	0.85579	2.10344	Italy Eastern Alps - Southalpine AATV
Sweden	25: LUHM 2846	1300–1100	18.1372	15.6586	38.348	0.86335	2.11433	Italy Eastern Alps - Southalpine AATV
Sweden	29: AM 1213	1300–1100	18.2210	15.6550	38.397	0.85917	2.10729	Italy Eastern Alps - Southalpine AATV
Germany	MA-071222	1600–1500	18.5090	15.6364	38.447	0.84480	2.07720	Slovakia
Germany	MA-071243	1600–1500	19.1020	15.6904	39.402	0.82140	2.06270	Austria, Mitterberg
Germany	MA-135030	1500–1300	18.6780	15.6790	38.856	0.83944	2.08031	Austria, Mitterberg
Germany	MA-071212	1500–1300	18.3600	15.6519	38.472	0.85250	2.09540	Italy Eastern Alps - Southalpine AATV
Germany	MA-071213	1500–1300	18.3940	15.6202	38.412	0.84920	2.08830	Slovakia
Germany	MA-071232	1500–1300	18.5400	15.6496	38.623	0.84410	2.08320	Slovakia
Germany	MA-071234	1500–1300	18.4730	15.6355	38.522	0.84640	2.08530	Slovakia
Germany	MA-071235	1500–1300	17.9970	15.6376	38.181	0.86890	2.12150	Italy Eastern Alps - Southalpine AATV
Germany	MA-071236	1500–1300	18.4310	15.6424	38.495	0.84870	2.08860	Slovakia
Germany	MA-071239	1500–1300	18.4090	15.6403	38.455	0.84960	2.08890	Slovakia
Germany	MA-071240	1500–1300	18.3520	15.6579	38.479	0.85320	2.09670	Italy Eastern Alps - Southalpine AATV
Germany	MA-071250	1500–1300	18.4400	15.6648	38.543	0.84950	2.09020	Slovakia
Germany	MA-071224	1500–1300	18.8440	15.6631	38.755	0.83120	2.05660	Austria, Mitterberg
Germany	MA-135048	1400–1300	18.2970	15.6610	38.460	0.85593	2.10198	Italy Eastern Alps - Southalpine AATV
Germany	MA-135040	1400–1300	18.2890	15.6560	38.428	0.85603	2.10115	Italy Eastern Alps - Southalpine AATV
Germany	MA-071203	1400–1300	18.3200	15.6453	38.459	0.85400	2.09930	Slovakia
Germany	MA-071204/1	1400–1300	18.3050	15.6416	38.406	0.85450	2.09810	Slovakia
Germany	MA-071204/2	1400–1300	18.3090	15.6469	38.425	0.85460	2.09870	Slovakia
Germany	MA-071205	1400–1300	18.3170	15.6391	38.442	0.85380	2.09870	Slovakia
Germany	MA-071206	1400–1300	18.1100	15.6307	38.248	0.86310	2.11200	Sardinia, Montevecchio
Germany	MA-071246	1400–1300	18.3640	15.6608	38.520	0.85280	2.09760	Italy Eastern Alps - Southalpine AATV
Germany	MA-071247	1400–1300	18.6510	15.6855	38.770	0.84100	2.07870	Austria, Mitterberg
Germany	MA-071248	1400–1300	18.3150	15.6410	38.458	0.85400	2.09980	Slovakia
Germany	MA-071249	1400–1300	19.2320	15.7010	39.278	0.81640	2.04230	Austria, Mitterberg
Germany	MA-135034	1300–1100	18.2600	15.6630	38.446	0.85778	2.10548	Italy Eastern Alps - Southalpine AATV
Germany	MA-135073	1300–1100	18.1580	15.6460	38.353	0.86166	2.11218	Italy Eastern Alps - Southalpine AATV
Germany	MA-135037	1300–1100	18.1890	15.6530	38.376	0.86058	2.10985	Italy Eastern Alps - Southalpine AATV
Germany, south	KS 11969.248	1400	18.3079	15.6673	38.505	0.85577	2.10320	Italy Eastern Alps - Southalpine AATV
Germany, south	KS 2 EM 301	1400–1300	17.9229	15.6292	38.094	0.87203	2.12543	Italy, Valsuguana VMS
Germany, south	KS 3 NM 3545	1400–1300	18.3799	15.6654	38.513	0.85231	2.09537	Italy Eastern Alps - Southalpine AATV
Germany, south	KS 41963.330	1400–1300	18.2244	15.6541	38.418	0.85896	2.10807	Italy Eastern Alps - Southalpine AATV
Germany, south	KS 7 IV, 571	1400–1300	18.8078	15.6754	38.848	0.83345	2.06552	Slovakia
Germany, south	KSa 51,927.54	1400–1300	17.9136	15.6207	38.046	0.87200	2.12388	Italy, Valsuguana VMS
Germany, south	KSa 61,927.54	1400–1300	17.9484	15.6373	38.139	0.87124	2.12494	Italy, Valsuguana VMS
Italy	n.205518	1650–1550	18.7770	15.6925	39.037	0.83573	2.07900	Italy, Tuscany Temperino mine
Italy	Mus-S3	1650–1350/1300	18.2162	15.6735	38.438	0.86042	2.11008	Italy Eastern Alps - Southalpine AATV
Italy	ON 95	1550–1450	18.5025	15.6916	38.707	0.84808	2.09201	Italy Eastern Alps - Southalpine AATV
Italy	ON 95P	1550–1450	18.3522	15.6827	38.565	0.85454	2.10137	Italy Eastern Alps - Southalpine AATV
Italy	CdSA-S	1550–1350/1300	18.1354	15.6576	38.357	0.86337	2.11506	Italy Eastern Alps - Southalpine AATV
Italy	Cel-S	1550–1150	18.1602	15.6589	38.401	0.86226	2.11456	Italy Eastern Alps - Southalpine AATV
Italy	BEL-S	1450–1350/1300	18.3039	15.6687	38.481	0.85603	2.10234	Italy Eastern Alps - Southalpine AATV
Italy	Mus-S2	1350/1300–1150	18.1974	15.6628	38.417	0.86072	2.11113	Italy Eastern Alps - Southalpine AATV
Italy	n.2356	1350/1300–1150	18.0920	15.6442	38.290	0.86470	2.11640	Italy Eastern Alps - Southalpine AATV
Italy	n.673	1350/1300–1150	18.0950	15.6496	38.302	0.86486	2.11670	Italy Eastern Alps - Southalpine AATV

Table 4
Trace element data of each sword in this study.

Country	Artefact/sample number	BC cal	S	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au
Denmark	1: B17618	1600–1500	0.40	0.01	0.02	0.51	89.68		0.38	0.00	7.28	0.03	0.03	0.14	0.02
Denmark	2: B17622	1600–1500	0.50	0.01	0.02	0.54	90.09		0.58	0.02	7.67	0.03	0.04	0.29	0.02
Denmark	3: B17623	1600–1500	0.12	0.66	0.93	0.03	95.71		0.00	0.01	3.18	0.02	0.03	0.05	0.02
Denmark	MA-135005	1600–1500		0.19	0.01	0.13	92.08	< 0.1	0.06	0.02	7.50	0.00	0.01	0.01	
Denmark	MA-134999	1600–1500		0.05	0.02	0.65	92.62	< 0.1	0.61	0.06	5.95	0.05	0.01	0.01	
Denmark	MA-135003	1600–1500		0.05	0.01	0.50	91.51	< 0.1	0.31	0.03	7.58	0.01	0.01	0.02	
Denmark	MA-135001	1600–1500		0.05	0.01	0.11	87.83	< 0.1	0.23	0.04	11.64	0.01	0.01	0.11	
Denmark	MA-135012	1500–1300		0.06	0.03	0.58	86.90	< 0.1	0.36	0.08	11.91	0.01	0.01	0.07	
Denmark	MA-134986	1500–1300		0.51	0.01	0.02	88.63	< 0.1	0.17	0.01	10.53	0.00	0.01	0.11	
Denmark	MA-134987	1500–1300		0.59	0.01	0.02	89.55	< 0.1	0.13	0.01	9.65	0.00	0.01	0.02	
Denmark	MA-134980	1500–1300		0.13	0.02	0.48	87.75	< 0.1	0.28	0.28	11.03	0.01	0.01	0.03	
Denmark	MA-134982	1500–1300		0.05	0.01	0.47	87.95	< 0.1	0.27	0.26	11.00	0.01	0.01	0.01	
Denmark	MA-134930	1500–1300		0.05	0.02	0.37	90.76	< 0.1	0.27	0.04	8.50	0.01	0.01	0.01	
Denmark	MA-134932	1500–1300		0.05	0.02	0.41	91.03	< 0.1	0.27	0.03	8.20	0.01	0.01	0.01	
Denmark	MA-134965	1500–1300		0.05	0.02	0.62	86.58	< 0.1	0.23	0.10	11.31	0.00	0.01	1.08	
Denmark	MA-134966	1500–1300		0.26	0.03	0.74	85.33	< 0.1	0.41	0.17	12.95	0.01	0.01	0.11	
Denmark	MA-134968	1500–1300		0.06	0.02	0.18	88.18	< 0.1	0.52	0.22	10.79	0.01	0.01	0.01	
Denmark	MA-134970	1500–1300		0.22	0.03	0.37	84.78	< 0.1	0.59	0.33	13.61	0.01	0.01	0.08	
Denmark	20: Ke 5538	1500–1300	0.64	0.01	0.03	0.57	84.61	0.00	0.19	0.01	14.12	0.01	0.03	0.08	0.02
Denmark	21: Ke 5567	1500–1300	0.25	0.02	0.01	0.00	89.27	0.00	0.02	0.00	7.62	0.30	0.05	0.68	0.04
Denmark	NMK 136: B13603	1500–1300		0.06	0.07	0.48	88.29	0.00	0.32	0.06	10.63	0.05	0.00	0.04	0.00
Denmark	19: Ke 5460	1500–1300	1.01	0.03	0.05	1.07	86.75	0.00	0.40	0.19	10.38	0.02	0.02	0.09	0.04
Denmark	NMK 134: B353	1500–1300		0.04	0.03	1.44	84.76	0.00	0.60	0.19	12.73	0.00	0.00	0.21	0.00
Denmark	NMK 135: B7106	1500–1300		0.48	0.04	0.70	88.15	0.00	0.59	0.34	9.57	0.01	0.00	0.09	0.03
Denmark	NMK 140: B12333	1500–1300		0.04	0.03	0.43	85.45	0.00	0.25	0.00	13.74	0.00	0.00	0.06	0.00
Denmark	B10424	1500–1300	1.16	0.01	0.03	0.81	85.50	0.04	0.31	0.05	10.89	0.02	0.01	0.07	0.04
Denmark	B11294	1500–1300	0.43	0.26	0.03	0.33	86.47	0.05	0.11	0.01	8.36	0.03	0.02	0.12	0.03
Denmark	B11298	1500–1300	0.17	0.01	0.02	0.80	84.86	0.04	0.23	0.05	12.74	0.02	0.01	0.09	0.05
Denmark	B11298a	1500–1300	0.04	0.03	0.03	1.05	86.16	0.05	0.26	0.13	11.84	0.01	0.01	0.08	0.04
Denmark	B15846	1500–1300	0.26	0.02	0.04	0.89	86.14	0.04	0.25	0.12	11.61	0.02	0.01	0.14	0.03
Denmark	9221B*	1500–1100	1.17	0.07	0.00	0.02	87.69	0.05	0.01	0.00	9.51	0.02	0.02	0.06	0.06
Denmark	MA-134928	1400–1300		0.25	0.04	0.23	91.83	< 0.1	0.18	0.09	7.21	0.03	0.01	0.13	
Denmark	MA-134906	1400–1300		0.05	0.02	0.35	89.95	< 0.1	0.19	0.03	9.38	0.01	0.01	0.03	
Denmark	MA-134907	1400–1300		0.05	0.02	0.62	90.83	< 0.1	0.51	0.32	7.39	0.02	0.01	0.23	
Denmark	MA-134944	1400–1300		0.29	0.08	0.63	91.10	< 0.1	0.44	0.14	7.30	0.01	0.01	0.01	
Denmark	MA-134945	1400–1300		0.16	0.05	0.67	91.19	< 0.1	0.44	0.09	7.36	0.01	0.01	0.04	
Denmark	B10747	1300–1100	0.20	0.02	0.02	0.44	90.41	0.01	0.18	0.02	8.52	0.04	0.01	0.10	0.04
Denmark	MA-134910	1300–1100		0.05	0.03	0.21	91.97	< 0.1	0.13	0.05	7.48	0.03	0.01	0.07	
Denmark	MA-134911	1300–1100		0.15	0.03	0.49	89.24	< 0.1	0.31	0.06	9.45	0.06	0.02	0.20	
Denmark	MA-134912	1300–1100		0.14	0.05	0.47	88.77	< 0.1	0.33	0.07	9.95	0.05	0.02	0.15	
Denmark	MA-134923	1300–1100		0.19	0.02	0.22	88.71	< 0.1	0.16	0.53	9.69	0.07	0.03	0.39	
Denmark	MA-134952	1300–1100		0.06	0.03	0.20	87.12	< 0.1	0.09	0.07	11.93	0.04	0.01	0.45	
Denmark	MA-134953	1300–1100		0.09	0.03	0.26	91.17	< 0.1	0.17	0.05	7.94	0.04	0.01	0.25	
Denmark	MA-134919	1300–1100		1.13	0.05	0.40	89.61	< 0.1	0.20	0.04	8.49	0.02	0.01	0.06	
Denmark	MA-134978	1300–1100		0.11	0.03	0.34	88.87	< 0.1	0.20	0.07	10.05	0.09	0.02	0.23	
Denmark	MA-134914	1300–1100		0.05	0.02	0.92	87.61	< 0.1	0.36	0.12	9.82	0.03	0.01	1.06	
Denmark	MA-134951	1300–1100		0.05	0.03	0.20	88.03	< 0.1	0.09	0.05	11.31	0.03	0.01	0.21	
Denmark	MA-134983	1300–1100		0.05	0.03	0.42	90.53	< 0.1	0.29	0.09	8.34	0.17	0.01	0.10	
Denmark	MA-134984	1300–1100		0.05	0.02	0.48	91.05	< 0.1	0.38	0.14	7.77	0.03	0.01	0.10	
Denmark	10: Ke 5077	1300–1100	0.91	0.01	0.01	0.06	85.67	0.00	0.02	0.00	13.27	0.01	0.05	0.05	0.01
Denmark	12: Ke 5084	1300–1100	0.52	0.23	0.03	0.29	87.20	0.00	0.08	0.02	11.42	0.05	0.04	0.29	0.03
Denmark	13: Ke 5115	1300–1100	1.20	0.55	0.03	0.02	88.58	0.00	0.04	0.01	8.82	0.06	0.04	0.39	0.02
Denmark	15: Ke 5129	1300–1100	1.89	0.11	0.10	0.20	84.61	0.00	0.59	0.00	11.53	0.02	0.04	0.10	0.03
Denmark	18: Ke 5237	1300–1100	0.71	0.02	0.01	0.04	88.85	0.00	0.01	0.00	10.57	0.02	0.05	0.06	0.02
Denmark	4: Ke 5002	1300–1100	0.79	0.06	0.02	0.20	86.69	0.00	0.06	0.00	11.93	0.02	0.03	0.08	0.01
Denmark	7: Ke 5027	1300–1100	0.48	0.03	0.04	0.35	85.50	0.00	0.25	0.03	13.10	0.05	0.04	0.21	0.03
Denmark	8: Ke 5074	1300–1100	1.37	0.01	0.02	0.10	88.40	0.00	0.07	0.00	9.74	0.04	0.04	0.21	0.03
Denmark	NMK 659: B 3810	1300–1100	1.09	0.00	0.06	0.31	88.18	0.09	0.32	0.08	6.56	0.05	0.10	0.02	0.00
Denmark	5: Ke 5023 (A)	1300–1100	0.95	0.02	0.03	0.47	86.70	0.00	0.05	0.00	11.94	0.01	0.03	0.06	0.02
Denmark	6: Ke 5023 (B)	1300–1100	0.04	0.02	0.03	0.26	87.77		0.28	0.00	12.04	0.00	0.01	0.05	0.00
Denmark	NMK 141: 19564	1300–1100		0.01	0.03	0.32	87.44	0.00	0.10	0.14	11.77	0.07	0.00	0.07	0.05
Denmark	NMK 142: B2295	1300–1100		0	0.03	0.19	87.35	0.001	0.49	0.54	11.34	0.06	0	0.001	0.00
Norway	ALM 25: C54227	1600–1500	0.07	0.07	0.04	0.07	88.62	0	0.13	0.02	10.88	0.01	0	0.02	0.04
Norway	ALM 26: C54227	1600–1500	0.08	0.07	0	0.13	88.1	0.03	0.3	0.45	10.74	0.02	0.01	0	0.02
Norway	B5469a	1600–1500	0.09	0.03	0.03	0.42	88.21	0.07	0.32	0.24	9.72	0.01	0.01	0.10	0.03
Norway	S1268 (1) (kl)	1500–1300	0.16	0.00	0.02	0.68	88.73	0.04	0.24	0.00	10.35	0.02	0.00	0.08	0.02
Norway	S1268 (2) (n)	1500–1300	0.52	0.01	0.02	0.89	86.44	0.04	0.26	0.09	10.37	0.04	0.01	0.14	0.04
Norway	S6400a	1500–1300	0.47	0.00	0.02	0.62	87.79	0.04	0.34	0.11	9.35	0.02	0.01	0.04	0.04
Norway	S3410 (1) (kl)	1500–1300	1.29	0.60	0.04	1.13	85.13	0.05	0.29	0.08	9.47	0.03	0.01	0.06	0.03
Norway	S3410 (2) (gr)	1500–1300	0.87	0.53	0.04	1.18	85.58	0.05	0.28	0.09	9.60	0.02	0.01	0.05	0.03
Norway	C27790a	1300–1100	0.03	0.00	0.02	0.65	87.72	0.06	0.30	0.05	9.64	0.05	0.02	0.05	0.03
Norway	C566	1300–1100	0.40	0.01	0.01	0.22	86.72	0.08	0.06	0.00	10.56	0.03	0.01	0.07	0.04
Norway	B5765c	1300–1100	0.25	0.01	0.01	0.34	86.42	0.08	0.08	0.01	11.88	0.02	0.01	0.07	0.06
Norway	B5046 A	1300–1100	0.38	0.01	0.00	0.13	86.52	0.07	0.04	0.00	12.37	0.02	0.01	0.03	0.04

(continued on next page)

Table 4 (*continued*)

Country	Artefact/sample number	BC cal	S	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au
Norway	B5046 B	1300–1100	0.25	0.01	0.02	0.50	90.58	0.09	0.28	0.01	8.54	0.02	0.02	0.03	0.03
Norway	S1022 (1) (kl)	1300–1100	0.45	0.04	0.04	0.92	87.93	0.05	0.27	0.00	10.92	0.01	0.01	0	0.09
Norway	S1022 (2) (gr)	1300–1100	0.12	0.03	0.04	1.04	85.95	0.04	0.37	0.00	12.54	0.01	0.01	0.05	0.04
Norway	T7501	1300–1100	0.46	0.01	0.01	0.07	88.03	0.09	0.03	0.01	10.21	0.05	0.02	0.29	0.02
Norway	S2969	1300–1100	0.55	0.15	0.03	0.31	85.61	0.06	0.17	0.03	12.08	0.03	0.02	0.15	0.04
Norway	S7425	1300–1100	0.03	0.14	0.03	0.53	88.18	0.06	0.17	0.05	8.72	0.05	0.01	0.11	0.04
Sweden	6: UM 40280_3006	1600–1500	0.33	0.04	0.03	0.31	85.87	0.04	0.31	0.38	10.23	0.03		0.19	0.07
Sweden	OEM863	1600–1500	0.61	0.09	0.05	0.71	83.95	0.04	0.24	0.04	12.28	0.03	0.00	0.13	0.01
Sweden	OEM865	1600–1500	0.05	0.05	0.05	0.78	85.83	0.06	0.22	0.03	12.66	0.04	0.01	0.13	0.01
Sweden	SHM617282	1600–1500	0.14	0.01	0.01	0.01	89.39	0.05	0.06	0.00	8.37	0.02	0.01	0.01	0.01
Sweden	UM29218_458A	1600–1500	0.50	0.11	0.04	1.04	81.56	0.04	0.27	0.00	13.59	0.03	0.00	0.02	0.01
Sweden	FG 050575	1600–1500		0.15	0.01	0.11	90	0.1	0.14	0.005	9.1	0.015	0.01	0.01	< 0.1
Sweden	OEM1149	1500–1300	0.04	0.04	0.03	0.69	87.28	0.05	0.28	0.00	10.50	0.04	0.01	0.16	0.01
Sweden	OEM862	1500–1300	0.57	0.09	0.06	0.63	86.60	0.06	0.38	0.12	9.66	0.04	0.01	0.16	0.01
Sweden	LUHM 20797:32	1500–1300	0.76	0.08	0.06	0.47	90.42	0.05	0.47	0.28	6.51	0.03	0.01	0.07	0.01
Sweden	LUHM 20797:35	1500–1300	0.30	0.01	0.03	0.76	88.57	0.05	0.37	0.04	8.44	0.05	0.01	0.10	0.02
Sweden	SHM416674_blade	1500–1300	0.15	0.03	0.03	0.69	84.67	0.04	0.20	0.00	11.66	0.04	0.02	0.27	0.01
Sweden	SHM416674_hilt	1500–1300	0.01	0.10	0.04	0.45	89.95	0.05	0.12	0.00	8.25	0.03	0.01	0.05	0.00
Sweden	20: VM 1205	1500–1300	0.24	0.04	0.04	0.25	83.70	0.05	0.29	0.24	11.18	0.02		0.10	
Sweden	21: VM 2931	1500–1300	0.41	0.04	0.03	0.59	82.28	0.03	0.26	0.11	12.63	0.04		0.16	
Sweden	SHM415450	1500–1300	0.68	0.03	0.04	0.63	87.21	0.06	0.21	0.00	7.89	0.04	0.01	0.84	0.01
Sweden	16: LUHM 3527	1300–1100	0.97	0.05	0.04	0.15	86.01	0.06	0.08	0.05	10.93	0.07		0.09	0.08
Sweden	OEM1510	1300–1100	0.32	0.06	0.03	0.71	91.06	0.05	0.15	0.03	7.41	0.03	0.00	0.04	0.01
Sweden	23: LUHM 24283	1300–1100	0.41	0.03	0.05	0.25	86.05	0.03	0.17	0.12	10.45	0.05		0.19	0.09
Sweden	24: LUHM 22268	1300–1100	0.54	0.09	0.05	0.62	85.07	0.03	0.15	0.10	11.41	0.03		0.06	0.09
Sweden	25: LUHM 2846	1300–1100	0.50	0.13	0.05	0.08	86.82	0.06	0.07	0.15	9.65	0.10		0.39	0.08
Sweden	29: AM 1213	1300–1100		0.04	0.04	0.24	86.38	0.06	0.04	0.07	10.14	0.04		0.11	0.10
Germany	MA-071222	1600–1500		0.06	0.01	0.28	87.00	< 0.2	0.78	0.05	12.00	0.047	0.01	0.04	nm
Germany	MA-071243	1600–1500		0.02	0.01	0.25	94.00	< 0.2	0.40	0.01	5.50	0.008	0.03	0.01	nm
Germany	MA-135030	1500–1300		0.10	0.03	0.24	88.83	< 0.1	0.46	0.34	9.98	0.01	0.01	0.02	
Germany	MA-071212	1500–1300		4.00	0.04	0.55	75.00	< 0.2	0.71	0.11	19.10	0.016	0.03	0.06	nm
Germany	MA-071213	1500–1300		0.29	0.05	0.70	83.00	< 0.2	0.40	0.07	15.60	0.015	0.01	0.05	nm
Germany	MA-071232	1500–1300		0.06	0.02	0.18	89.00	< 0.2	0.28	0.42	10.30	0.013	0.01	0.03	nm
Germany	MA-071234	1500–1300		0.13	0.03	1.11	80.00	< 0.2	1.23	0.40	16.80	0.023	0.01	0.04	nm
Germany	MA-071235	1500–1300		0.06	0.03	0.20	87.00	< 0.2	0.21	0.05	12.00	0.014	0.01	0.03	nm
Germany	MA-071236	1500–1300		0.02	0.03	0.64	89.00	< 0.2	0.22	0.27	9.80	0.02	0.01	0.02	nm
Germany	MA-071239	1500–1300		0.13	0.04	0.29	88.00	< 0.2	0.21	0.03	10.90	0.004	0.01	0.04	nm
Germany	MA-071240	1500–1300		0.10	0.04	0.85	89.00	< 0.2	0.31	0.07	9.50	0.009	0.01	0.03	nm
Germany	MA-071250	1500–1300		0.02	0.10	0.19	88.00	< 0.2	0.07	0.02	11.60	0.005	0.01	0.01	nm
Germany	MA-071224	1500–1300		0.02	0.01	0.02	91.00	< 0.2	0.09	0.005	8.60	0.002	0.01	0.01	nm
Germany	MA-135048	1400–1300		0.05	0.03	0.42	92.45	< 0.1	0.19	0.03	6.79	0.01	0.01	0.03	
Germany	MA-135040	1400–1300		0.19	0.03	0.41	89.30	< 0.1	0.23	0.06	9.66	0.01	0.01	0.11	
Germany	MA-071203	1400–1300		0.58	0.06	0.62	89.00	< 0.2	0.34	0.20	9.00	0.014	0.01	0.03	nm
Germany	MA-071204/1	1400–1300		0.09	0.04	0.53	89.00	< 0.2	0.25	0.10	9.70	0.014	0.01	0.05	nm
Germany	MA-071204/2	1400–1300		0.09	0.04	0.53	89.00	< 0.2	0.25	0.10	9.70	0.014	0.01	0.05	nm
Germany	MA-071205	1400–1300		0.64	0.06	0.60	90.00	< 0.2	0.26	0.20	8.60	0.011	0.01	0.04	nm
Germany	MA-071206	1400–1300		0.65	0.03	0.76	85.00	< 0.2	0.88	0.03	12.50	0.014	0.02	0.05	nm
Germany	MA-071246	1400–1300		0.02	0.03	0.16	89.00	< 0.2	0.15	0.14	10.60	0.021	0.01	0.07	nm
Germany	MA-071247	1400–1300		0.02	0.04	0.75	90.00	< 0.2	0.28	0.22	8.40	0.014	0.01	0.01	nm
Germany	MA-071248	1400–1300		0.06	0.04	0.15	88.00	< 0.2	0.13	0.09	11.50	0.019	0.01	0.05	nm
Germany	MA-071249	1400–1300		0.32	0.03	0.33	84.00	< 0.2	0.42	0.09	14.70	0.007	0.01	0.02	nm
Germany	MA-135034	1300–1100		0.09	0.02	0.30	90.04	< 0.1	0.49	0.12	8.76	0.05	0.01	0.12	
Germany	MA-135073	1300–1100		0.25	0.01	0.01	88.08	< 0.1	0.07	0.05	10.68	0.13	0.03	0.68	
Germany	MA-135037	1300–1100		0.15	0.04	0.77	89.58	< 0.1	0.40	0.14	8.68	0.04	0.01	0.19	
Germany, south	KS 11969.248	1400	0.43	0.07	0.03	0.26	87.23	0.05	0.23	0.00	9.19	0.06	0.02	0.13	0.13
Germany, south	KS 2 EM 301	1400–1300	0.10	0.01	0.01	0.06	86.63	0.05	0.02	0.00	11.36	0.03	0.09	0.07	0.07
Germany, south	KS 3 NM 3545	1400–1300	0.22	0.02	0.02	0.49	88.24	0.04	0.11	0.00	9.41	0.01	0.01	0.14	0.14
Germany, south	KS 41,963.330	1400–1300	0.31	0.41	0.03	0.84	89.19	0.06	0.16	0.00	8.35	0.03	0.01	0.04	0.04
Germany, south	KS 7 IV, 571	1400–1300	0.26	0.02	0.01	0.09	87.62	0.05	0.04	0.00	10.35	0.02	0.01	0.03	0.03
Germany, south	KSa 51,927.54	1400–1300	0.25	0.01	0.02	0.22	89.76	0.05	0.04	0.00	8.11	0.04	0.01	0.10	0.10
Germany, south	KSa 61,927.54	1400–1300	0.43	0.01	0.01	0.18	86.83	0.06	0.02	0.00	10.95	0.05	0.01	0.14	0.14
Italy	n.205518	1650–1550		0.020	0.012	0.237	89.00	0.200	0.220	0.127	9.90	0.015	0.010	0.012	0.024
Italy	Mus-S3	1650–1350/1300	0.020	0.050	0.040	0.380	86.76	0.010	0.210	0.000	12.66	0.040	0.020	0.050	nd
Italy	ON 95	1550–1450	0.000	0.240	0.030	0.180	84.16	0.000	0.090	0.000	14.74	0.000	0.000	0.060	nd
Italy	ON 95P	1550–1450	0.000	0.100	0.030	0.200	89.86	0.000	0.200	0.000	9.01	0.030	0.040	0.050	nd
Italy	CdSA-S	1550–1350/1300	0.010	0.240	0.040	0.230	90.27	0.010	0.130	0.000	10.06	0.050	0.020	0.040	nd
Italy	Cel-S	1550–1150	0.040	0.010	0.030	0.100	89.50	0.010	0.070	0.000	10.61	0.100	0.020	0.060	nd
Italy	BEL-S	1450–1350/1300	0.000	0.050	0.030	0.550	89.79	0.020	0.230	0.000	9.58	0.040	0.080	0.040	nd
Italy	Mus-S2	1350/1300–1150	0.110	0.010	0.040	0.650	86.69	0.020	0.350	0.000	11.97	0.050	0.000	0.060	nd
Italy	n.2356	1350/1300–1150		0.310	0.031	0.035	90.00	0.200	0.011	0.087	9.20	0.081	0.018	0.590	0.010
Italy	n.673	1350/1300–1150		0.130	0.028	0.014	90.00	0.200	0.012	0.155	9.00	0.081	0.018	0.680	0.010

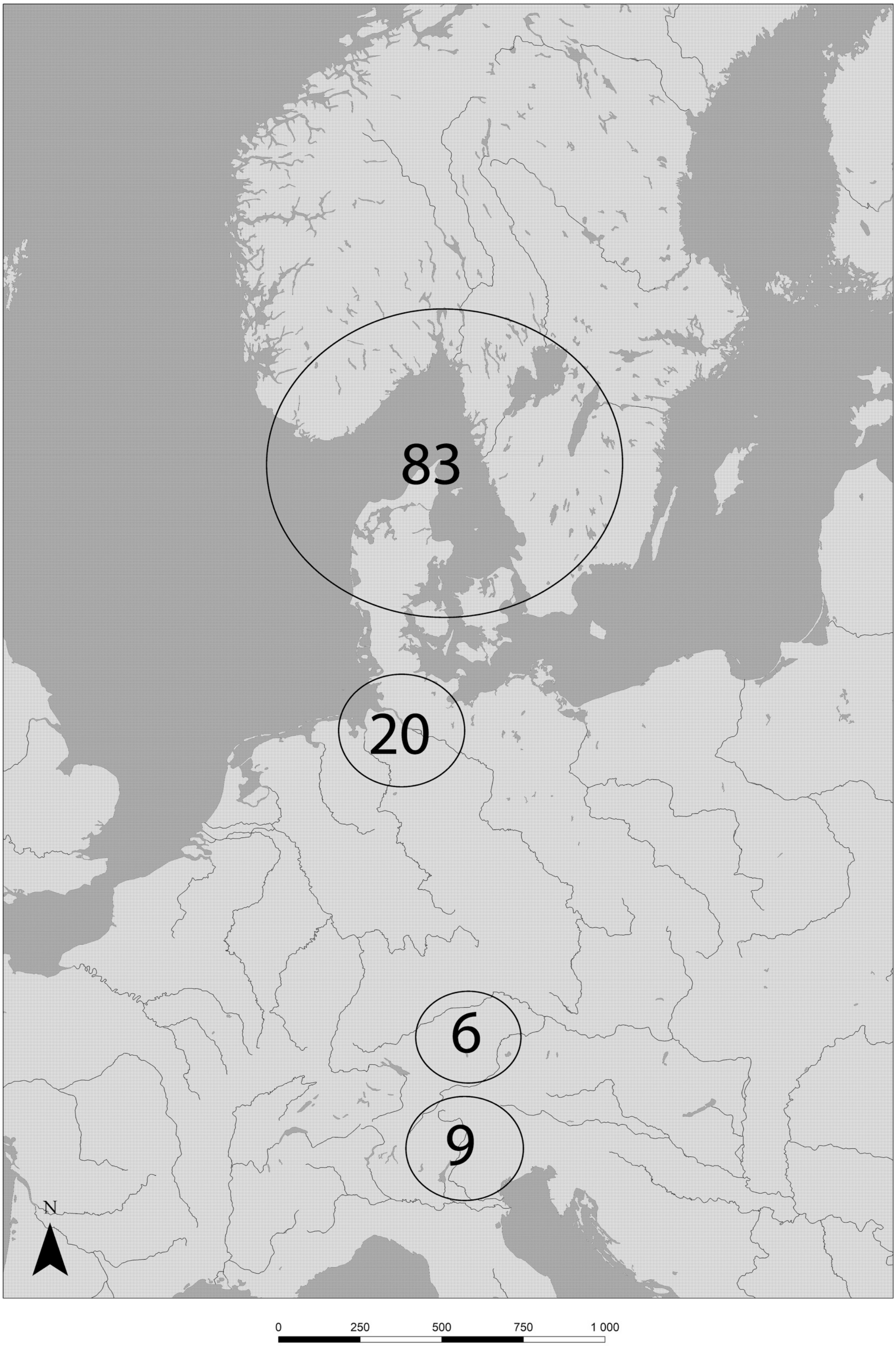

Fig. 1. Map showing the regional distribution of all swords included in this comprehensive provenance study. It comprises a total number of 118 Bronze Age swords and daggers from Scandinavia in the north to Italy in the south.

hilt. For this study we have included 17 hilt-plated swords and daggers (Table 2, Figs. 2–3). Imports from Central Europe as well as local replicas date to about 1700–1600 BCE (Vandkilde, 1996, pp. 214–222, see also Table 2). Additionally, 15 flange-hilted swords and daggers have been analysed, including the so-called Naue type (Table 2). The remaining objects are six tanged swords and daggers as well as two blades of unspecified type (Table 2).

Fig. 2. Images of Danish swords and daggers dated to 1600–1100 BCE. To the left: 1. Full-hilted sword of Apa type, 2. Pommel and handle of a Nordic full-hilted sword. To the right 3–8: flange-hilted swords and hilt-plated swords. Photo by A. L. Melheim & E. Hjarthner-Holdar.

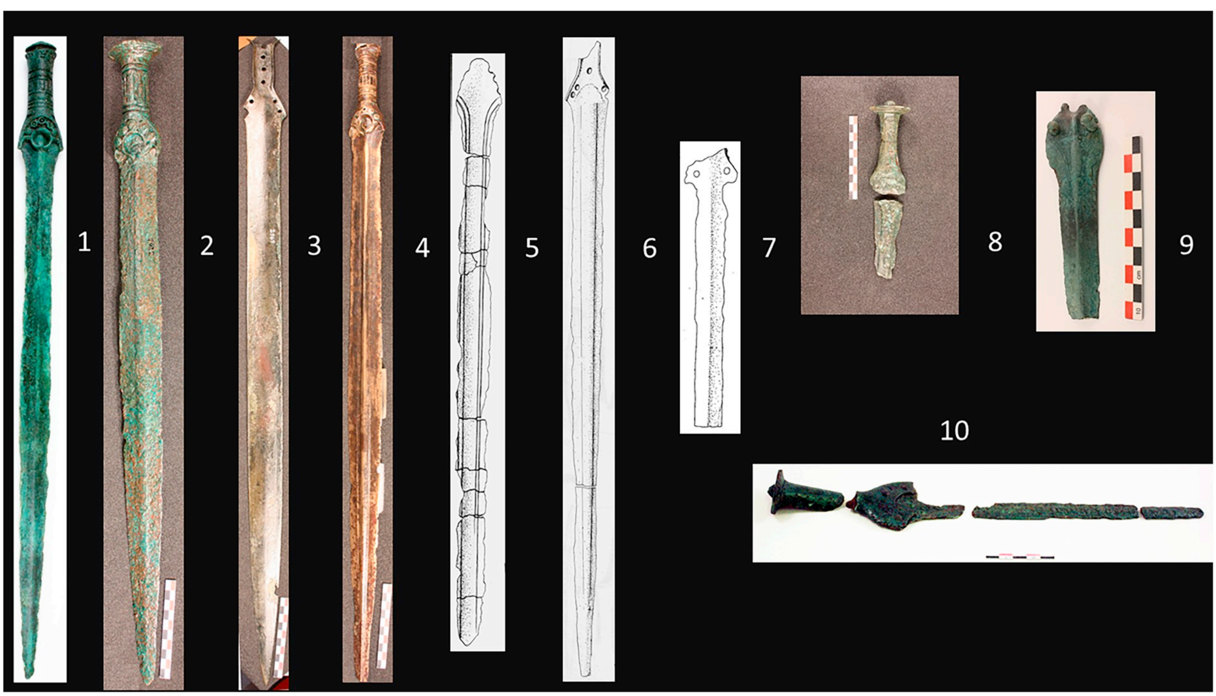

Fig. 3. Images of Norwegian and Swedish swords and daggers dated to 1600–1100 BCE. From the left; 1–7: Nordic full-hilted swords, flange-hilted swords and hilt-plated swords. To the right: Nordic full-hilted daggers and a hilt-plated dagger. Photo by A. L. Melheim, E. Hjarthner-Holdar, L. Grandin & J. Ling. Illustrations after Oldeberg, 1974.

3.2.2. Northern Germany

For comparison we included lead isotope and chemical data for 20 swords (27 samples) (Table 2) published by Bunnefeld and Schwenzer (2011) and Bunnefeld (2016a, 2016b) for swords from Schleswig-Holstein, in Northern Germany close to the Danish border. This material includes five hilt-plated swords (one of Sögel/Wohlde type, one of Wohlde type) dated to 1600–1500 BCE. However, a majority of the swords are of the full-hilted type and can be dated to 1500–1300 BCE. Five of the full-hilted swords belong to the subtype octagonal-hilted sword; the remaining three to the typical Nordic type. There are four flange-hilted swords dated to 1500–1300 BCE. From the succeeding phase, 1300–1100 BCE, there are three full-hilted swords of the Nordic type.

3.2.3. Southern Germany

Six octagonal swords (seven samples, Fig. 5) from southern Bavaria from the archaeological state collection in Munich were analysed for lead isotope and chemical compositions in the current study (Table 2). They are distributed in southern Bavaria between the Lech in the west and the Salzach and the Danube in the east (Fig. 6). Four swords were

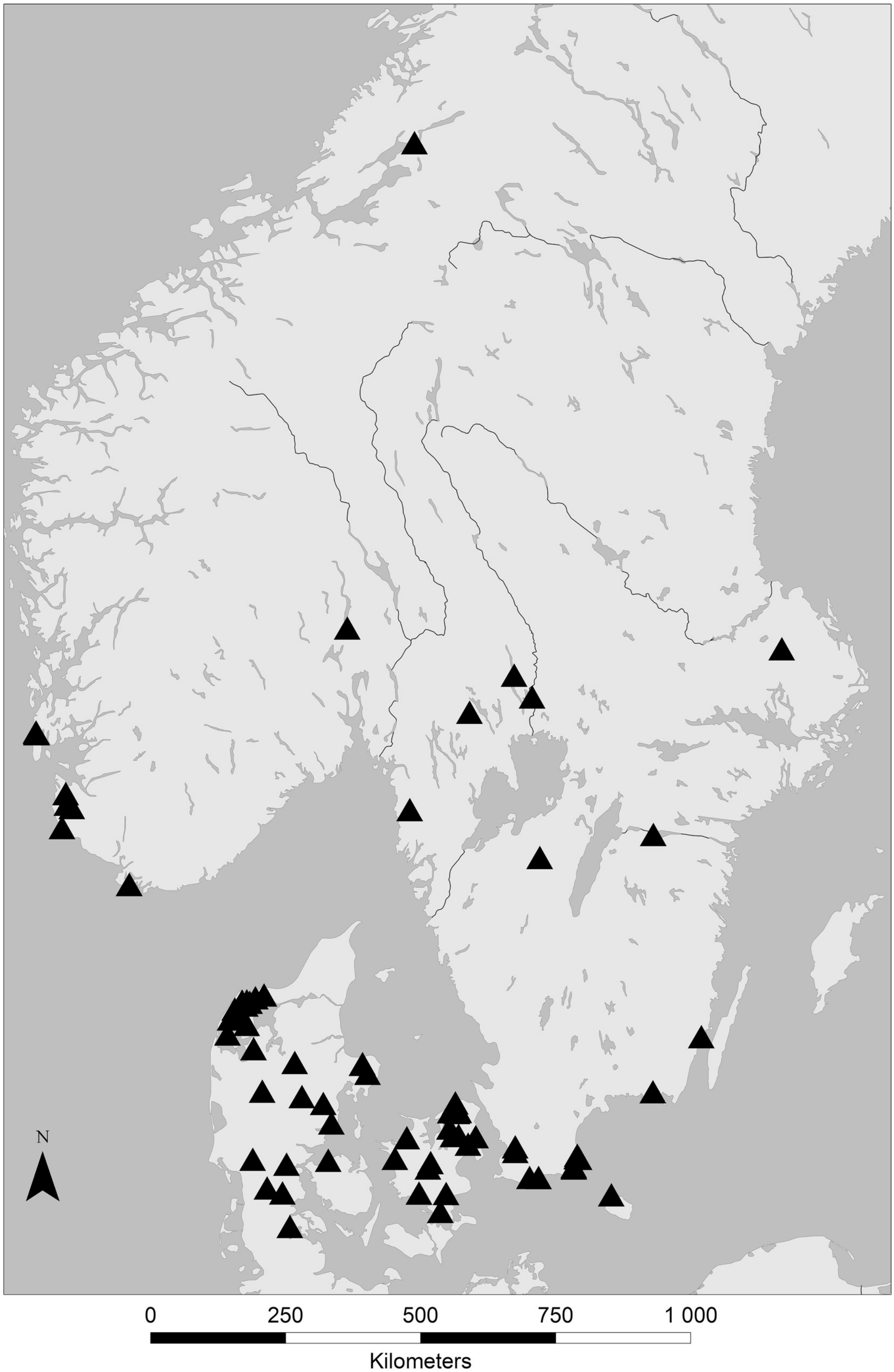

Fig. 4. Map showing the location and distribution of all the analysed Scandinavian swords.

found in, and in the vicinity of, Munich, at the Lakes Ammersee and Starnberg (see map by von Quillfeldt, 1995, plate 108/109).

The sampled swords from southern Bavaria are assigned to the types Kirchbichl and Hausmoning with circle eye decorations on the octagonal handle and the type Leonberg with paragraph rows on the handle. Two of the metal-hilted swords cannot be associated with one type. The six southern Bavarian full-hilted swords with decorated octagonal grip cover geographically the core zone of the north-alpine

Fig. 5. Photo of the sampled octagonal-hilted swords from the museum in Munich. Photo by R. Krause.

distribution of these swords, as well as the characteristic types. Chronologically, they are dated to the later 15th and the 14th century BCE.

3.2.4. Northern Italy

The samples (10) from Italy included in the current paper, are from 9 swords and 1 rivet from one of them (Table 2). All the objects come from Northern Italy, in particular from the Veneto and Friuli-Venezia Giulia regions (Fig. 7). The age of the swords varies from the Middle Bronze Age 1 (MBA1) to the Recent Bronze Age (RBA) that in absolute date corresponds to 1650–1150 BCE. In Table 2 the age, typology and absolute date of each find are summarized and simplified for comparison purposes.

The oldest Italian find in Table 2, dated to the beginning of the MBA (Salzani, 2011), is from Bor di Pacengo, Lazise (VR). The sword has a simple base with trapezoidal shape, and it is the only one that can be referred to 1650–1550 BCE (Fig. 7). Generally, these sword types have a large distribution from Northern Italy to Central and Central-Eastern Europe. The analysed samples dated to 1500–1300 BCE are the sword ON 95 from Olmo di Nogara – VR (Boiu IIa – Castion di Strada type: De Marinis and Salzani, 2005; Cupitò, 2006), the sword blade from Castion di Strada - UD (Boiu Ib-IIa/Kezsethely type: Peroni, 1970; Carancini and Peroni, 1997, 1999; Cupitò, 2006), and the two samples of Sprockhoff Ia swords, that is a Traun/Montegiorgio sword from S. Marco di Belvedere – UD, and a Traun/Sacile type sword from Muscoli di Cervignano del Friuli (Peroni, 1970; Cupitò, 2006). Generally, these sword types have a large distribution from Northern Italy to Central and Central-Eastern Europe.

The investigated swords dating to the Italian Recent Bronze Age (the RBA swords) are tanged swords of the Pepinville and Rixheim types, and Naue II Type C swords, or Sprockhoff IIa - Allerona type (Table 2). The distribution of the Pepinville sword cover the areas of Northern Italy, Central Italy and Central-Eastern Europe (Carancini and Peroni, 1997).

3.3. Sampling procedure, analytical methods and isotope database

All new samples were drilled or cut from blade and/or hilt, and the analytical procedures were identical for all the samples (cf Ling et al., 2013, 2014; Melheim et al., 2018a). The samples were divided, and one half was mounted in resin, ground and polished. An optical microscope with polarised reflected light was used in order to define the structure and texture and prepare for succeeding electron microprobe analysis (EPMA). Wavelength dispersive analyses (WDS) were made using the JEOL JXA-8530 F at the Centre for Experimental Mineralogy, Petrology and Geochemistry at Uppsala University, as point analyses of individual phases as well as in area scans (maximum 50 by 50 μm). Due to the heterogeneity of copper alloys, multiple area scans were made, and mean values calculated. Operating conditions during runs involved an acceleration voltage of 20 kV and an electron beam current of 20 nA. The obtained analytical data were related to standards (oxides, sulphides, metals) and ZAF corrected.

The other half of the sample was used for the lead isotope analysis. Prior to dissolution they were leached for a few minutes in HNO_3 at room temperature in order to remove possible surface contamination and some of the alteration products such as malachite and subsequently digested in hot 6 M HNO_3. After dissolution the lead was extracted on anion exchange columns. The isotope ratios measurements were performed with the high-resolution Multi-Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS) of the type Nu Plasma II,

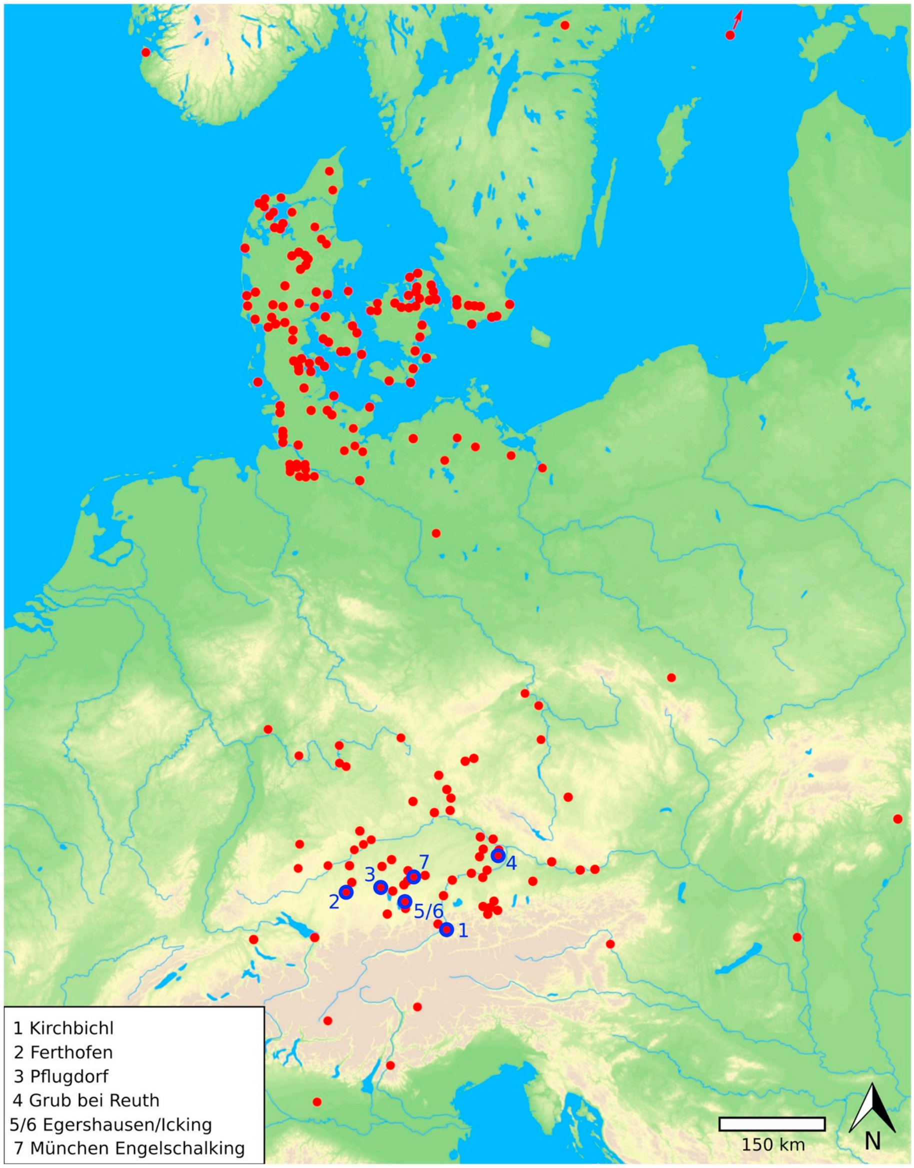

Fig. 6. Map showing the distribution of all octagonal-hilted swords in Europe as well as the location of the southern octagonal-hilted swords analysed within this study from the museum in Munich. Map by R. Krause.

hosted by the Vegacenter facility at the Department of Geosciences at the Swedish Museum of Natural History. The SRM NBS-981 Pb standard was run at regular intervals, and all samples were analysed in duplicate. The obtained numbers for the standard are within error of those given by Todt et al. (1996), and the external reproducibility is estimated to be between 0.04% ($^{206}Pb/^{204}Pb$) and 0.08% ($^{208}Pb/^{204}Pb$), whereas the other listed ratios have uncertainties of 0.05% or better. The external precision for unknowns is of a similar order, but in order to account for errors arising also during the chemical treatment in the clean laboratory, accepted overall uncertainty for all independent lead isotope ratios is ± 0.10%.

Our interpretations of lead isotope and trace elemental data are based on comprehensive databases (i.e. the Alpine ArchaeoCopper Database for the Alpine area (Nimis et al., 2012; Artioli et al., 2016a), which has been merged into the extensive databases based on OXALID, n.d. and expanded as described in Ling et al., 2014, which are constantly updated with new evidence, most recently from the Italian Alps, Spain (Montero-Ruiz, 2017) and Mitterberg (Pernicka et al., 2016a). All ore data used for comparisons with the lead isotope ratios of the swords were either measured by TIMS or MC-ICP-MS, both with the same overall analytical error of 0.1%, even if the within run errors of the latter are mostly much smaller than in the former. Moreover, the interpretation of the analytical data is discussed in this paper is carefully evaluated against the archaeological context. The interpretation of data is, conventionally, a lengthy process not relying only on the comparisons of sets of lead isotope ratios and trace elemental compositions but also on the known history of mining in discussed regions, as extensively discussed previously (e.g. Pernicka et al., 1993; Stos-Gale et al., 1997; Niederschlag et al., 2003; Höppner et al., 2005; Ling et al., 2014; Pernicka et al., 2016a; Artioli et al., 2016a; Melheim et al., 2018a).

It is important to emphasize that we treat and interpret both the

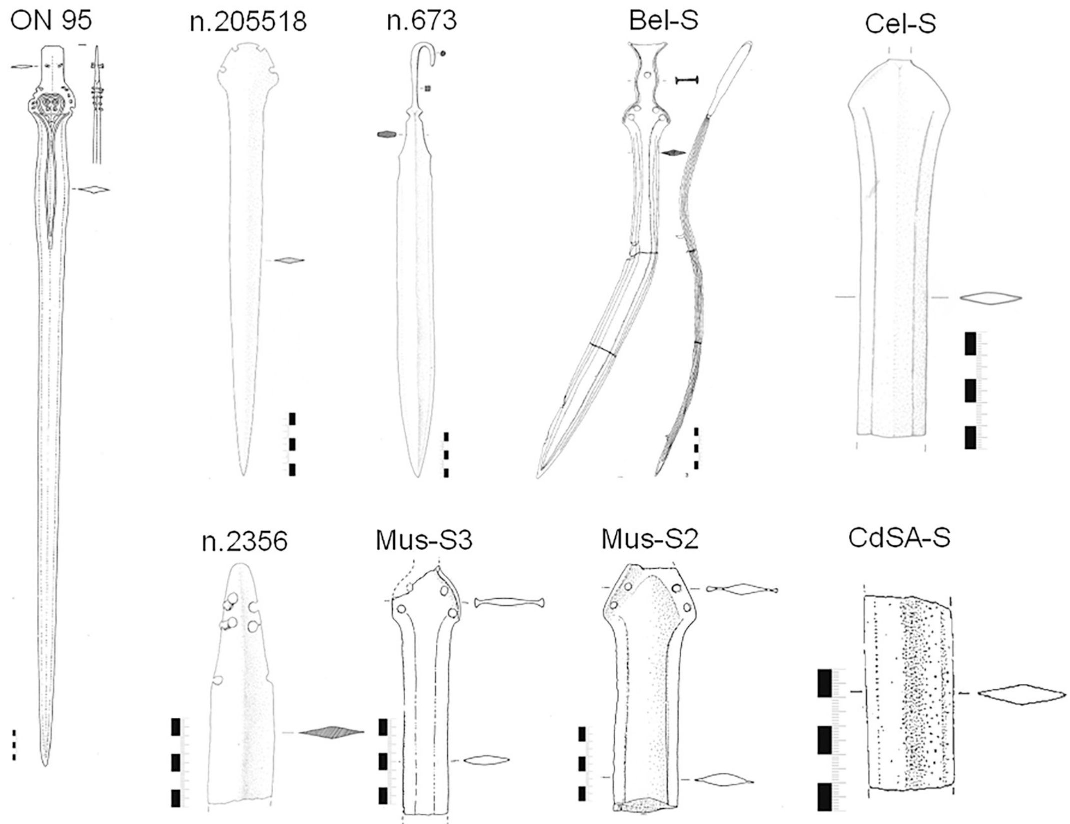

Fig. 7. Archaeological drawings of nine Italian swords included in the present work (ON 95 from Cupitò, 2006; samples n. 205518, n. 2356, n. 673 from Salzani, 2011; Bel-S, Mus-S2, Mus-S3, CdsA-S from Borgna 2001; Cel-S from Borgna 2007).

lead isotope and geochemical signatures not only as individual objects but for groups of objects. When it comes to our interpretations of provenance of the copper in the swords, these ascriptions must be regarded as tentative, following the principle of the maximum likelihood. Concerning the issue of recycling, we discuss this in Section 4.5.

4. Results

4.1. Chronological change of copper sources for making swords

The analytical results (Figs. 8–11; Tables 3, 4) show that the small number of the earliest swords, dated to 1600–1500 BCE, have large spread of lead isotope compositions indicative of several sources of copper. Swords dated to this period generally have low concentrations of nickel (Ni) and/or arsenic (As), but exceptionally up to about 1% and 0.8%, respectively. Antimony (Sb) and silver (Ag) are present in low concentrations in a few swords, but characteristic fahlore signatures, with significant As, Sb and Ag, are not observed. Seven different deposits can be identified as possible sources of copper for the swords dated to 1600–1500 BCE (see Section 4.2).

The swords dated to after 1500 BCE show more homogeneous compositions, both in terms of lead isotope and trace elemental data (Figs. 12–13). The main impurities, approximately up to 1% in the majority of the swords dated to 1500–1100 BCE are Ni and As, but some swords are nearly free of impurities. In general, for the bulk of the samples, the concentrations are slightly shifted towards lower concentrations of these elements for the later swords, dated to 1300–1100 BCE. The same feature can be noted for Sb, but its concentrations are lower by an order of magnitude. The concentrations of Ag are generally much lower than of the other three elements (< 0.1%), and there seem to be a shift towards somewhat higher levels for the later swords (Fig. 13).

The swords dated to 1500–1300 BCE show consistency with five ore deposits but only three of them are predominant (see Section 4.3), however, during the latest phase, 1300–1100 BCE, most swords seem to be made of copper from one dominant region (see Section 4.4). It was observed that all analysed swords can be divided into several groups with very similar chemical and lead isotope compositions (details in Tables 2–4), therefore single samples, or swords, will not be discussed separately. However, some of them have very different isotopic and/or chemical compositions and they merit individual assessment. In addition, for some of the swords alternative interpretations of data are also discussed. In the following sections, the provenance ascriptions of the analysed swords will be discussed in relation to the chronology and typology.

4.2. Several sources: 1600–1500 BCE

The chemical and lead isotope compositions of the sixteen (18 samples) Scandinavian and German swords (Table 1) dated to 1600–1500 BCE are consistent with the geochemical characteristics of several mining regions known to be exploited at that time in Europe, including the Great Orme in Wales (Ixer and Budd, 1998; Williams, 2015, 2017), Italian Eastern Alps (Cierny, 2008; Artioli et al., 2014, 2015, 2016a, 2016b), Mitterberg in Austrian Alps (Pernicka et al., 2016a), Slovakian Ore Mountains (Schreiner, 2007; Modarressi-Tehrani

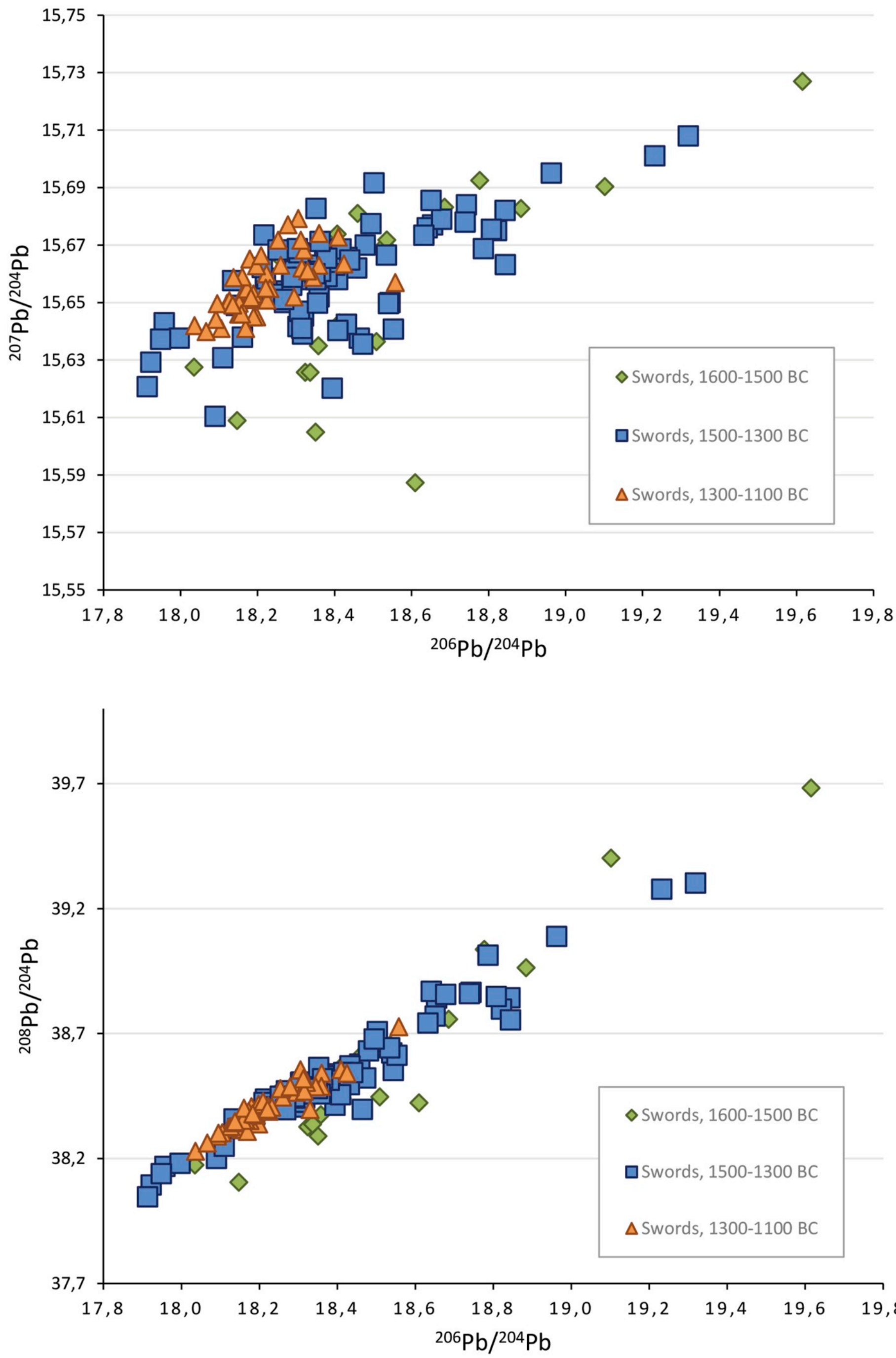

Fig. 8. Chronological pattern of the lead isotope data of the swords discussed in this paper.

and Garne, 2014), South Spain (Rovira Llorens et al., 1997; Hunt-Ortiz, 2003; OXALID, n.d.) and Cyprus (Stos-Gale et al., 1998a, 1998b; Gale et al., 2003, 2009; OXALID, n.d.). Additionally, one sword from Italy dated to this period (Fig. 10), has lead isotope and chemical compositions consistent with the ores from Tuscany, Campiglia Marittima, Temperino mine (Artioli et al., 2017) (Fig. 10, Tables 3–4).

Copper ores from the British Isles are potential sources for five swords dating to 1600–1500 BCE (Fig. 10). All of them are full-hilted swords from Denmark. Among these are three swords of the Nordic Hajdúsámson-Apa type from Dystrupgård (see Wincentz Rasmussen and Boas, 2006; Melheim and Horn, 2014; Melheim et al., 2018a) and the Hajdúsámson-Apa sword MA-135003 (Bunnefeld, 2016a). These, and also the Valsømagle type sword MA-135001, have lead isotope ratios consistent with the copper ores from the Great Orme mine in Wales, which was exploited throughout the Bronze Age, however with a peak in production 1600–1400 BCE (O'Brien, 2015, pp. 146–150; Williams, 2015, 2017, 2018). The As concentration in these swords (Fig. 11) are somewhat low in relation to Ni compared to typical signatures for ores from Great Orme but within the Great Orme range. Also, the low Sb impurity levels (maximum in these swords is 0.04%) are coherent with

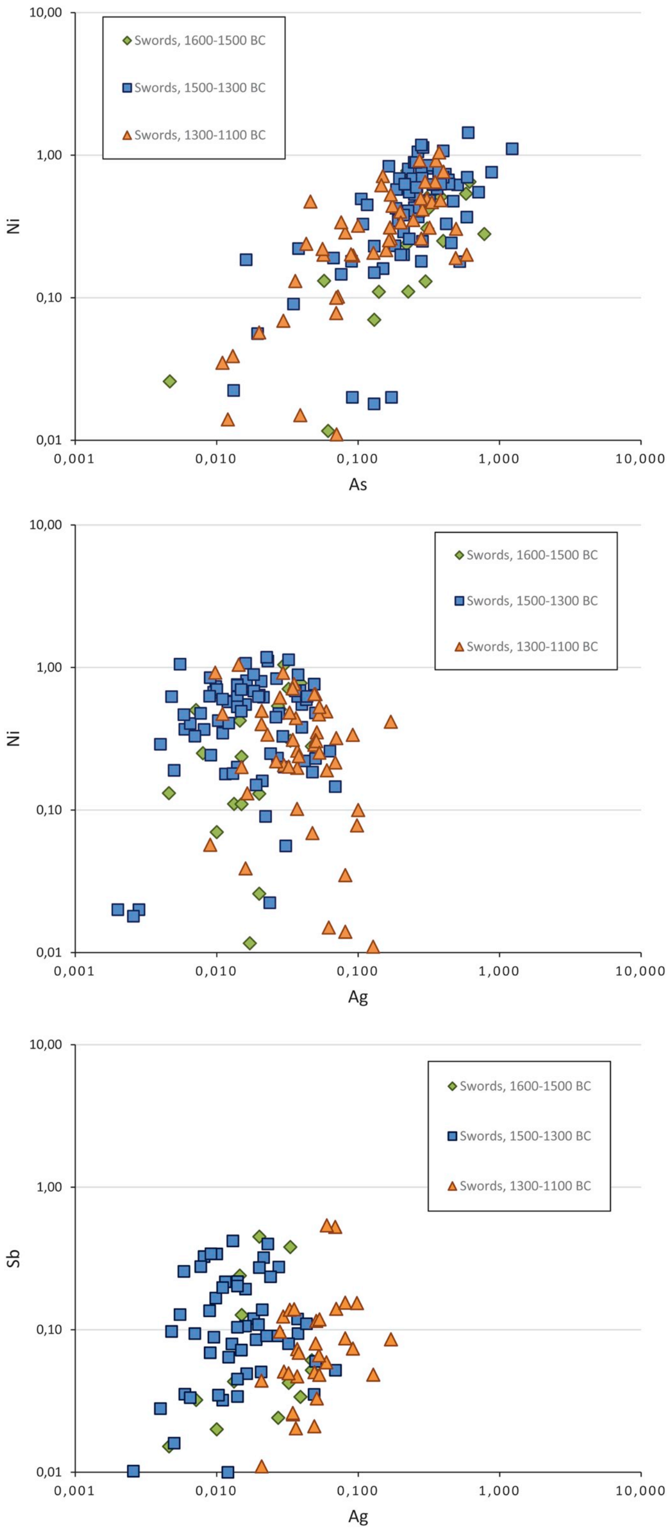

Fig. 9. Logarithmic plots of trace elements; Ni vs Ag, Ni vs As, Sb vs Ag for the sword samples included in this project, plotted by chronology.

copper from Great Orme. There is, furthermore, a clear distinction between the two Scandinavian countries, Denmark and Sweden, since the ores from the Great Orme in Wales are not represented at all among the swords from Sweden. This difference may be due to the relatively small number of analysed swords from Sweden, but is nonetheless worth noting.

One sword (UM 40280_3006), a hilt-plated dagger (two samples; OEM 863 and OEM 865), both from Sweden, and a hilt-plated sword from Norway (B5469a) are isotopically consistent with the ores from the Italian Eastern Alps (Southalpine AATV). The dagger is comparatively rich in Ni (c. 0.7%) with less As; the sword from Sweden contains Ni and As (0.3% each) but also Sb at similar level which is among the highest noted in the samples from 1600 to 1500 BCE. These swords are the earliest examples in our data-set with such origin. At present, this interpretation is tentative since these swords pre-date most of the Italian swords with such origin, and there is currently no convincing evidence of mining from this region 1600–1500 BCE (Artioli et al., 2014).

The full-hilted Danish sword, MA-135005, low in impurities, is consistent with the ores from Mitterberg, in the Austrian Alps. Two hilt-plated swords from Northern Germany, with mutually similar contents of Ni (ca 0.3%) are different in terms of lead isotopes and content of As and Ag (Tables 3–4, Figs. 10–11). One (MA-071243), has lead isotope ratios characteristic of the radiogenic lead, consistent with the ores from Mitterberg. The other, with slightly higher Ag (MA-071222), has the LI ratios consistent with the ores from Slovakia. Also, the lead isotope compositions of two samples from the full-hilted sword from Norway (ALM 25 and 26; blade and hilt) are consistent with the Slovakian ores from Spania Dolina (compare however Melheim and Horn, 2014), although not identical. Both alloys have low concentrations of Ni and As but are different in terms of Sb (Tables 3–4). Two other full-hilted swords are consistent isotopically with the ores from Slovakia (Banska Štiavnica): from Denmark (MA-134999; Hajdúsámson-Apa), and from Sweden (UM29218_458A).

The Hajdúsámson-Apa swords MA-135005 and MA-134999 from Denmark, analysed by Bunnefeld (2016a), and an associated sword from Norway (ALM 25 and 26) fit well with lead isotope and chemical data of objects, including swords, from the Hajdúsámson and Apa hoards, probably suggesting that the copper derived from ores in the Mitterberg area or the Slovakian Ore Mountains (Pernicka, 2013; Pernicka et al., 2016b). While the two first swords are best understood as import pieces, the third sword has strong Nordic elements and is likely to be cast in Scandinavia (Melheim and Horn, 2014). Interestingly, the Nordic Hajdúsámson-Apa type swords from Dystrupgård in Denmark deviate from this pattern, being consistent with copper ores from the Great Orme mine in Wales.

Some swords have lead isotope and elemental compositions that are also consistent with other ore sources than these major sources listed above. One of these is a sword from Vreta in Sweden (FG 050575; see also Schwab et al., 2010) with a very low concentrations of impurities (Tables 3–4). In terms of manufacture, the sword from Vreta is quite extraordinary and shows strong typological links with the swords from the Nebra hoard as well as the ones from the Hajdúsámson-Apa hoards, which were identified as produced from the copper from Mitterberg (Schwab et al., 2010). However, its lead isotope ratios seem consistent with the copper ores from an ancient copper mine of Aznalcollar near Seville, in the copper rich region Huelva in southern Spain where copper has been exploited in the Bronze Age (Hunt-Ortiz, 2003). Another sword that is made of copper geochemically different from the majority of the analysed swords, is a full-hilted sword of the Valsømagle type from Sweden (SHM 617282) which has lead isotope ratios that are consistent with the Cypriot copper ores and slags as well as with the copper of oxhide ingots from Uluburun (Gale and Stos-Gale, 2005; the OXALID, n.d.). The unusually low concentration of trace elements in this sword (Table 4) further supports such an interpretation.

Overall, the swords dated to 1600–1500 BCE show a notable variation in ore sources. They indicate a very dynamic diffusion of metal

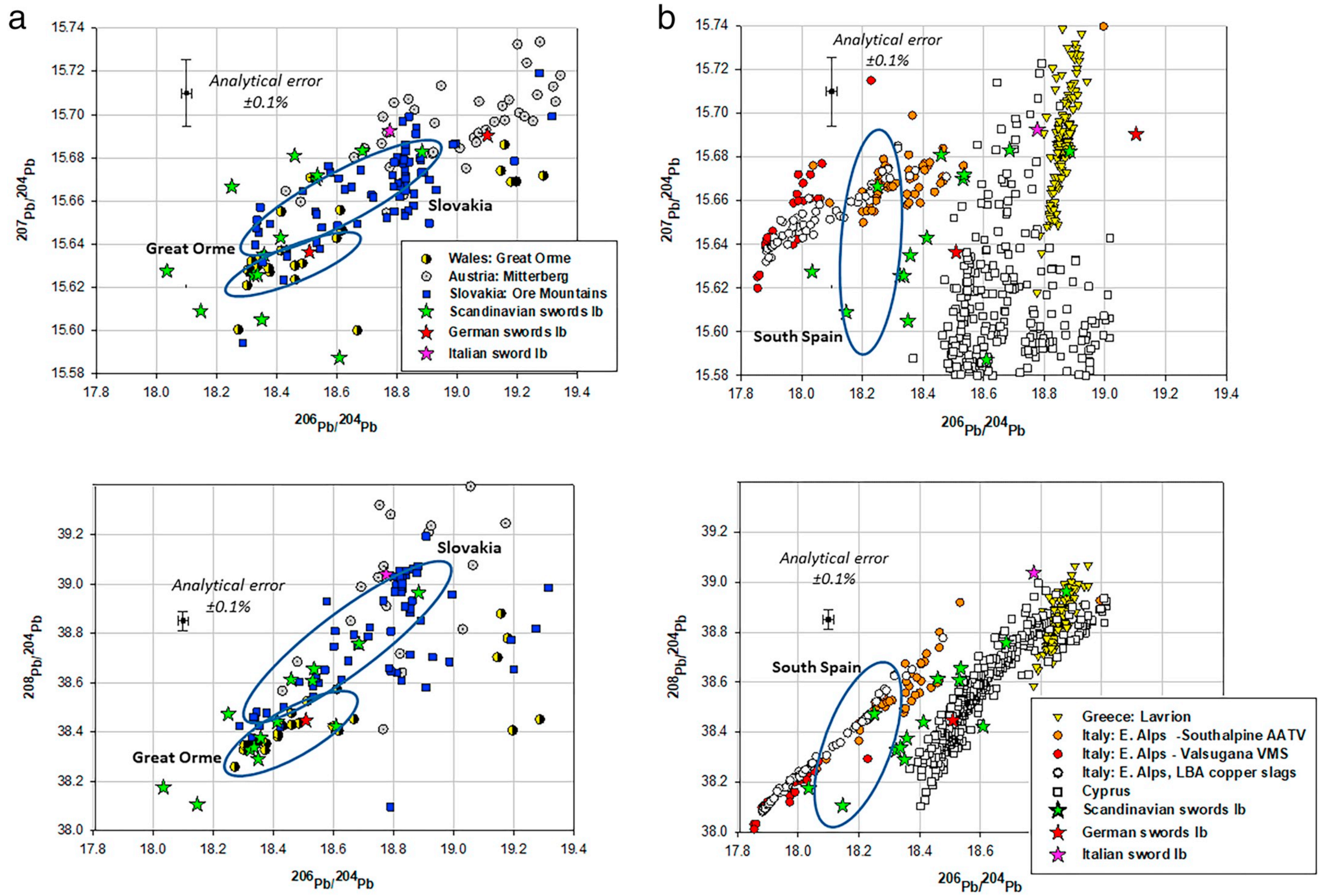

Fig. 10. a. Symmetrical comparative plots for the lead isotope ratios of the swords dated to 1600–1500 BCE (period IB) compared with the ores from the Slovakian Ore Mountains, Mitterberg and Great Orme. All three of these deposits have radiogenic lead and they do not follow the lines of their geological age. The ellipses do not encompass the whole range of the LI data for the Slovakian and British ores, they are only to guide the eye.
10. b. Symmetrical comparative plots for the lead isotope ratios of the swords dated to 1600–1500 BCE (period IB) compared with the data for copper ores from the Italian Alps, Cyprus and Greece. To avoid clutter, the position on this plot of the data for the ores from southern Spain is indicated by the ellipses. The position of the datapoints for each deposit along the $^{206}Pb/^{204}Pb$ axis is related to the age of the formation of these ores, with the oldest ores on the left.

across Europe. Furthermore, metalworking styles and metal in most cases seem to have different origins. The period 1600–1500 BCE is traditionally thought to represent the ‘breakthrough’ of the Nordic Bronze Age, with the development of Nordic metalworking styles, emerging from established connections with Bronze Age cultures in the Carpathian Basin and the Mediterranean (Vandkilde, 2014). In contrast with this, the sword data indicate that metal was brought to Scandinavia from several different sources, and not mainly from the Slovakian Ore Mountains. This may be a reflection of traditions going back to the preceding period, when Scandinavia was supplied with copper from both Central Europe and the British Isles (Vandkilde, 2017: Figs. 83 and 103; Melheim et al., 2018a).

4.3. More limited range of sources: 1500–1300 BCE

The large group of 58 swords dated to 1500–1300 BCE shows consistency with five ore deposits, and of these three are predominant: Italian Eastern Alps, Austrian Mitterberg and Slovakian Ore Mountains. However, other copper ore deposits may be considered also as potential sources for their copper, and therefore we will also discuss various alternative interpretations for them.

Out of these 58 swords (78 samples) the lead isotope data for 24 swords (30 samples) are consistent with ores from the Italian Eastern Alps in the region of Trentino-Alto Adige (Figs. 12, 17, Table 3). The trace elemental compositions of these swords are characterised mainly by Ni and As (ca. 0.2–1% Ni and 0.1–0.7% As) (Fig. 13; Table 4). Some of these swords also contain Sb (< 0.3%) and generally Ag is below 0.05%. These impurities indicate that the copper used for these swords was smelted mainly from sulphide copper minerals, such as chalcopyrite, or oxidized ores; while the chemistry of fahlores is not represented (see also discussion below).

However, some of the swords that are consistent with the ores from the Italian Eastern Alps, have isotopic ratios that are on the outer border of isotopic fields identified for these ores. The lead isotope compositions of the Eastern Alpine deposits in the region of Trentino-Bolzano are of a similar geological age as the ores in Jaen and Alcudia Valley in south-east Spain, therefore their lead isotope compositions are in a narrow range very similar se (Artioli et al., 2016b; Montero-Ruiz, 2017). The lead isotope compositions of some of the swords dated to 1500–1300 BCE fall exactly in this narrow range and it is not possible to

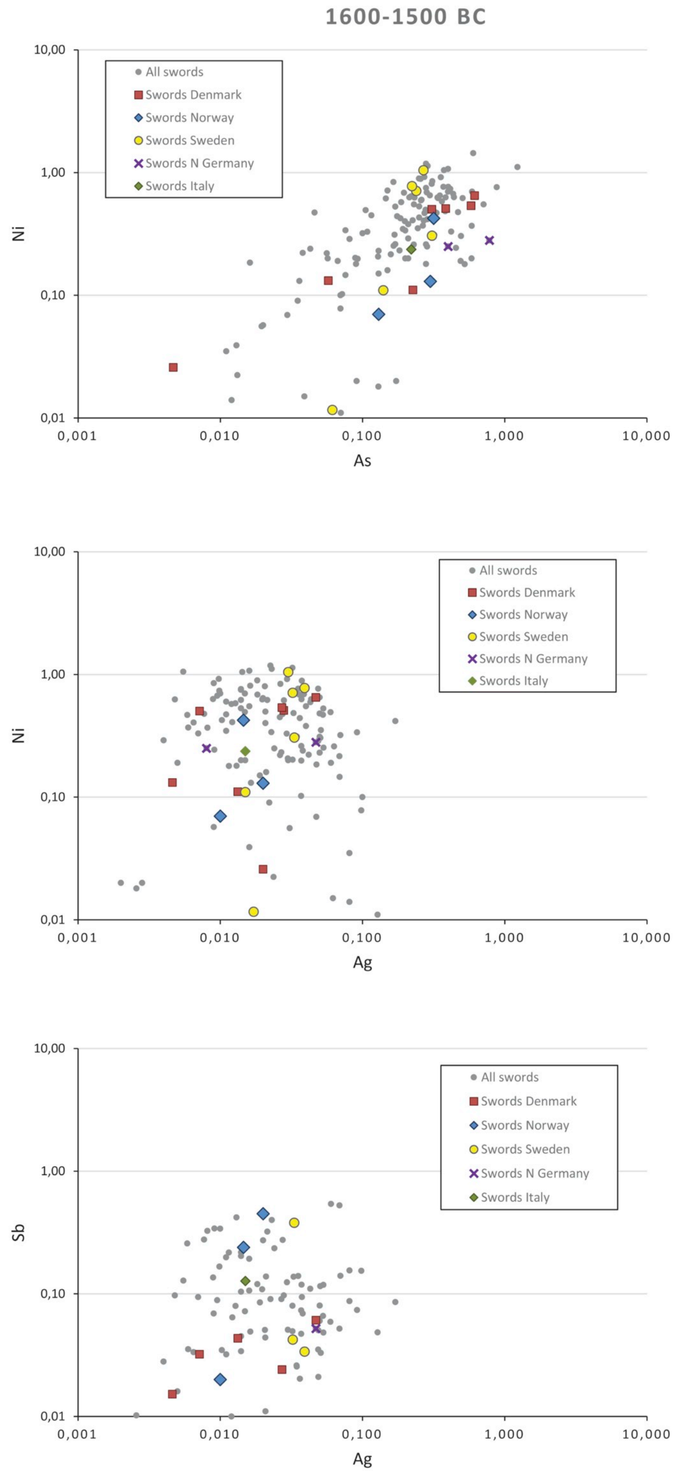

Fig. 11. Logarithmic plots of trace elements; Ni vs As, Ni vs Ag and Sb vs Ag for the sword samples dated to 1600–1500 BCE from various countries compared with the data for swords from all periods included in this project.

decide if their copper derives from the Italian Eastern alps of from the ore deposits in southern Spain (Fig. 12b). Among those is a hilt-plated Danish sword (Ke5567). This sword has very low Ni and As (< 0.05) but higher Ag (0.3%) (see discussion in Melheim et al., 2018a). Also, one sword from Germany (MA-071206) and another Danish sword (B11294) may be consistent with the ores from South Spain. However, a comparison of the radiogenic ratios to ^{206}Pb suggests that there is a higher degree of consistency with the Italian ore data (see however also Sardinia below).

Six Scandinavian swords (seven samples) and eight (11 samples) of 15 swords from Northern Germany have compositions consistent with the ores from Slovakian Ore Mountains (Fig. 12, Table 3). These swords are mainly characterised by Ni varying from ca. 0.2 to 1% and from 0.1 to 0.4% for As. Some also contain Sb (< 0.4%) and generally Ag is below 0.03% (Table 4).

According to our interpretation of the 15 swords analysed by Bunnefeld (2016a, 2016b) (22 samples) from Northern Germany, two (four samples) are consistent with the ores from the Mitterberg mines and other deposits in the Austrian Alps (Fig. 12) (cf. Bunnefeld, 2016a, 2016b). We have made a corresponding interpretation for a smaller group of five swords from Denmark and Norway (cf. also Pernicka et al., 2016a). Among these are MA-134986 and MA-134987 (from the same sword) from Denmark and MA-071224 from North Germany that are characterised by very low impurities. Such are similar to Kitzbühel, Kelchalm in the Salzburg region (Pernicka et al., 2016a). The remaining swords generally have higher Ni (0.3–0.8%) and As (0.3–0.5%) but low Ag (< 0.01%), which is also more common in the Mitterberg ores. Thus, according to our interpretation of Bunnefeld's sword data (2016a, 2016b) a majority of the swords, recovered in Northern Germany (10 out of 15) were made from copper originating in the Slovakian Ore Mountains and the Austrian Alps. However, Bunnefeld (2016a) holds that the Slovakian Ore Mountains was the main source for most of the analysed swords from this phase, even if there is no direct evidence of Bronze Age mining in the Slovakian Ore Mountains.

The six octagonal-hilted swords from Southern Germany merit a more detailed assessment. Two swords (KS 2 EM 301 and 1927.54), the latter sampled from the hilt and the blade (KS 5 and 6) have very low ^{206}Pb/^{204}Pb values in the range 17.91–17.95 (Fig. 12, Table 3). Such low values are characteristic of very few European copper ore deposits: one of them is the Southern Alpine VMS-type deposits located along the Valsugana Valley. Others include some Spanish ores, and there are a few chalcopyrite deposits located in Austrian Styria (Walchen) and Carinthia (Knappenstube, Plaiken, Kaser Wieserl). These two swords have lead isotope ratios that are consistent with four lead isotope ratios published for the Austrian chalcopyrite ores (Koppel and Schroll, 1983). Based on the fact that there is no evidence among the Italian swords of copper extracted in this period from the VMS Valsugana ores and there is limited evidence of ore extraction and smelting in the region during this period (with the notable exception of the Cortaccia/Kurtatsch furnaces: Nothdurfter, 1993; Anguilano et al., 2009), we consider the Austrian chalcopyrite mines to be a more likely source for the copper in these two swords. They are different from the bulk of the Scandinavian swords with generally much lower level of impurities. In general Ni is < 0.2% and As < 0.05%, and Sb below the detection limit (Fig. 13, Table 4). Similar low trace element signatures are observed in two other swords from Southern Germany (KS 3 NM 3545 and KS 7 IV, 571), while somewhat higher As and Ni (> 0.2%) and an outlier with 0.8% Ni is noted in two other octagonal-hilted swords (KS 4 1963.330 and KS 1 1969.248). The lead isotope composition for (KS 7 I, 571) is consistent with the ores from Slovakian Ore Mountains and the remaining three are consistent with the ores from the Italian Alps. However, all four have lead isotope compositions that are also within the range of lead isotope ratios for Austrian chalcopyrite ores. Approaching the six octagonal-hilted swords from Southern Germany as a group, and not as individual data points, a careful evaluation suggests that the most likely scenario is that they were all made of copper originating from Austrian

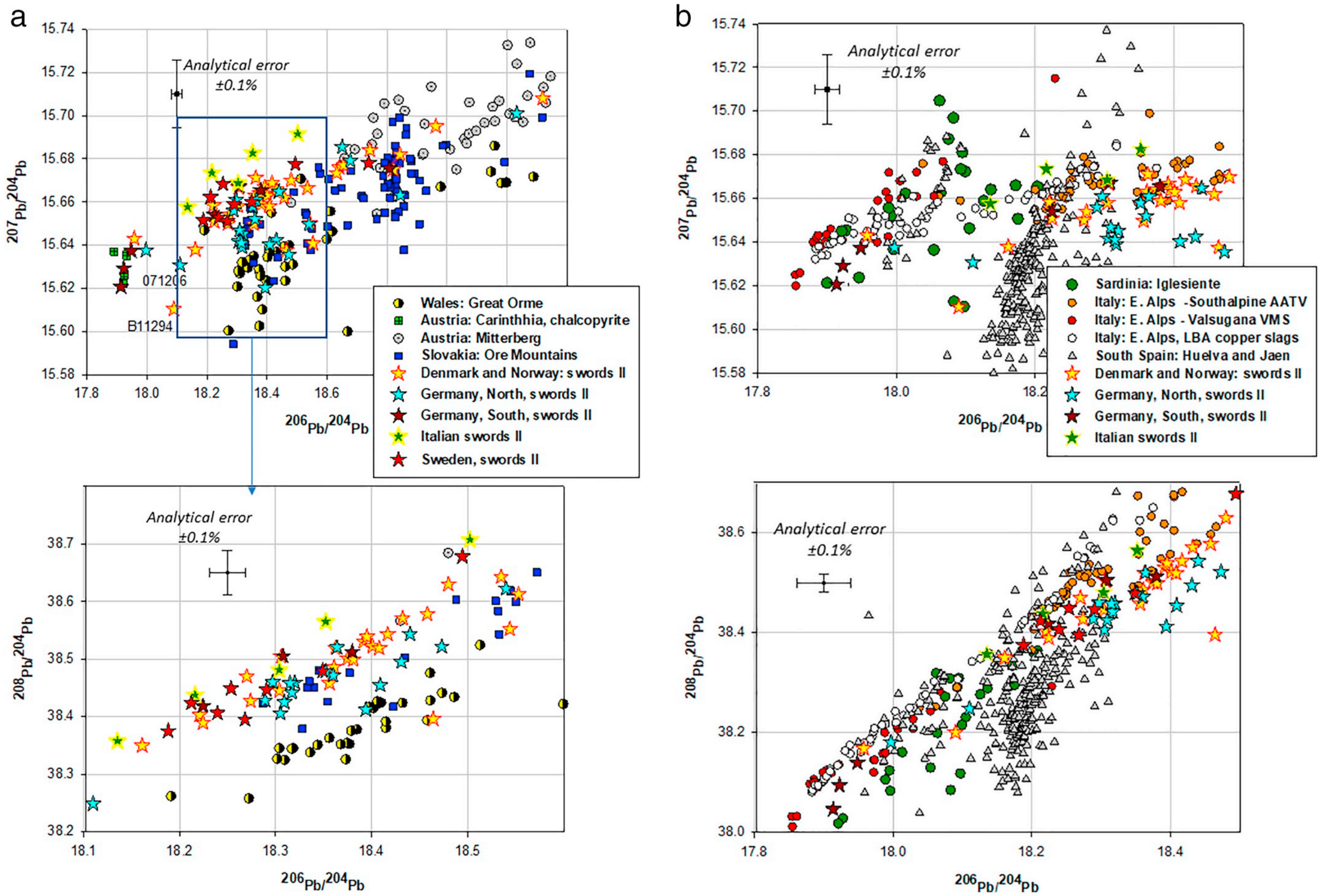

Fig. 12. a. Comparative plot of the lead isotope ratios of the swords dated to 1500–1300 BCE (period II) with the ores from the Slovakian ore Mountains, Great Orme, Mitterberg and a deposit of chalcopyrite in Carinthia. Lower plot is the enlarged section of the upper one showing the set of ratios of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ to demonstrate that the group of swords from northern Germany is not consistent with the ores from Great Orme, in spite of the overlap on the $^{207}Pb/^{204}Pb$ plot, but only with the ores from Slovakia.
12. b. Comparative plot of the lead isotope ratios of the swords dated to 1500–1300 BCE (period II) with the ores from the Italian Alps, Southern Spain and Sardinia. Lower plot shows the set of ratios of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ to demonstrate consistency of lead isotope ratios of the Danish and Swedish swords, as well as some of the ones from northern Germany with the ores from Italy. Note the overlap between the ore data from Southern Spain and Italian Alps.

Eastern Alps.

Three swords (B11294, MA071206 and Ke5567; see also above), have similar lead isotope ratios that are not consistent with any of the ore deposits discussed previously within the range of the analytical errors. Their lead isotope ratios (Fig. 12, Table 3) plot on a line below the ores from Italy and lie on the line of the Sardinian ores and seem consistent with the ores from the deposits of the district. Among lead isotope and chemical data for swords from the Nuragic hoards, dated to the 14th–12th centuries BCE, found in Arzachena and Ittirredu (Begemann et al., 2001), two swords are also consistent with the lead isotope ratios for the ores of the Iglesiente area (Fig. 12, Table 3). The chemical compositions of their metal are similar to the Scandinavian swords apart from lower values for Ni. In the general pattern, the swords B11294 and MA071206 fit better with the Sardinian ores and artefacts than with the ores from the Italian Eastern Alps. However, this interpretation remains tentative, because there is no strong evidence of Bronze Age copper mining of copper on Sardinia in the 2nd millennium BCE.

A difference can also be noted between the swords from the three Scandinavian countries dated to this period. The swords from Sweden are almost exclusively consistent with the ores from the Italian Eastern Alps, and one only with ores in Slovakia; both these ores sources are also present in the small Norwegian data-set. The Danish data-set differs a little from the other two; although the Italian Alps appears to be a dominant source, ores in the Austrian Alps were other significant sources. These results are comparable to the sword data from Northern Germany (Bunnefeld, 2016a, 2016b), although Slovakian ores seem to be more commonly in use in Northern Germany, at least within the analysed number of swords (Bunnefeld, 2016a, 2016b). The data-set from Southern Germany is consistent with the geochemistry of the copper ores from the Austrian Alps. Not surprisingly, the swords from the Italian sites seem to be consistent with an origin from ores in the Italian Alps.

4.4. One exclusive source of copper for the swords in 1300–1100 BCE?

The trace elemental compositions (Fig. 16) for the majority of the 43 analysed swords (48 samples) dated to 1300–1100 BCE are characterised mainly by Ni and As (ca. 0.2–1% Ni and 0.1–0.6% As). Generally, Ag is below or much below 0.10%; the same is generally noted

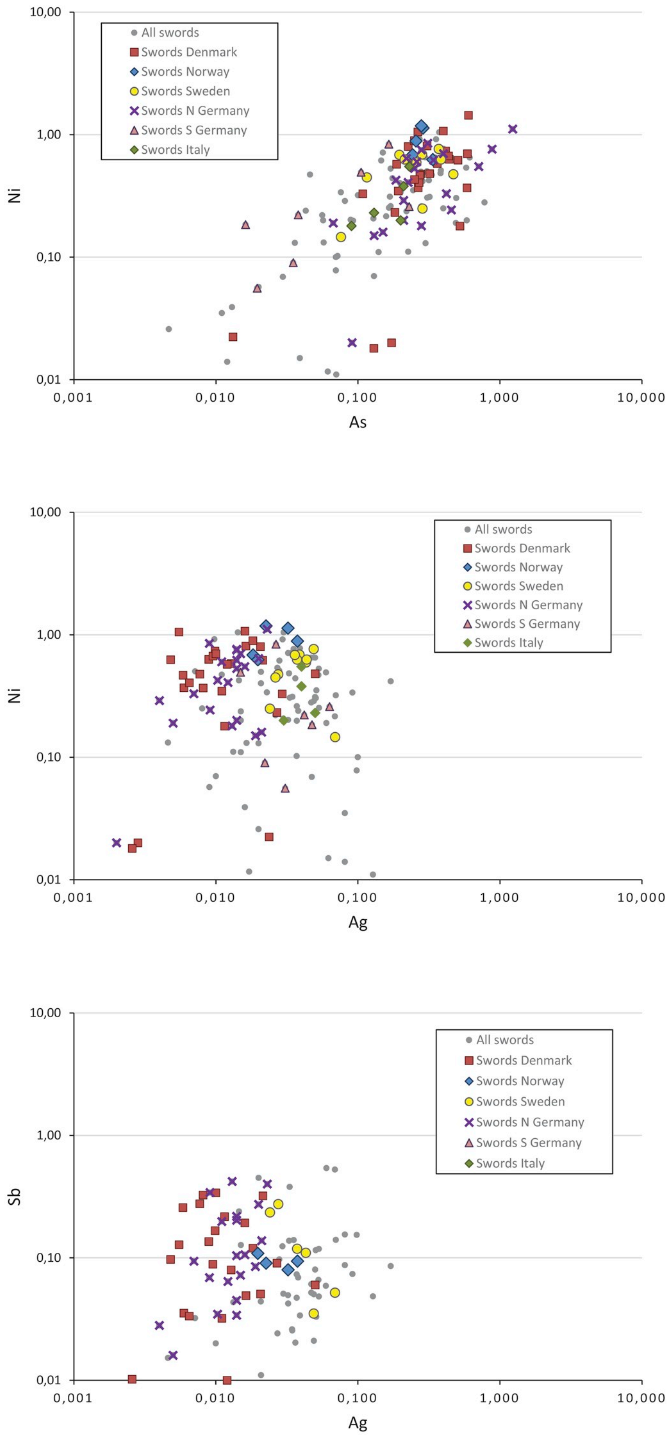

Fig. 13. Logarithmic plots of trace elements; Ni vs As, Ni vs Ag and Sb vs Ag for the sword samples dated to 1500–1300 BCE from various countries compared with the data for swords from all periods included in this project.

for Sb (Table 4). However, some of the swords have very low impurity levels, distinguishing them from the majority. The lead isotope ratios show that the great majority has lead isotope ratios consistent with the ores and slags dated to 1300–1100 BCE (Artioli et al., 2015, 2016a, 2016b) from the Eastern Alpine deposits of Trentino–Alto Adige (Figs. 14–15) and are also consistently well aligned with the isochron of the south-eastern Alpine deposits.

However, a few of the swords found in Denmark have lead isotope ratios suggesting other copper ores; e.g. the sample from the blade of a full-hilted sword of Nordic type (5: Ke 5023 A) is consistent with the ores from the mine of Calabona in northern Sardinia, but also very close to some ores in the Slovakian Ore Mountains. The hilt of the same sword (6: Ke 5023 B) seems more consistent with the ores from the Italian Alps but also with the mines of Linares in southern Spain (see Melheim et al., 2018a). Also, two other flange-hilted swords (10: Ke 5077 and NMK142: B2295) and a dagger (NMK 659: B3810) have LI ratios within the overlapping isotopic fields of the Italian Eastern Alpine deposits and ores in south Spain, but also with some ores of the French Massif Central (see Melheim et al., 2018a). While sources in southern Spain should also be considered as possible sources due to the overlapping lead isotope compositions, as discussed above, the Spanish are at present considered to be less likely.

The ores in the Italian Eastern Alpine deposits are well characterised isotopically, but detailed systematic elemental data of the ores are not as complete. However, sulphides and sulphosalts with presence of e.g. Ni, As, Sb and Bi are reported but not always quantified (Artioli et al., 2016a; Nimis et al., 2012). Metal produced from such ores may be expected to contain low levels of these elements. Some of the swords in the current study, however, have Ni at somewhat higher levels (close to 1%) than what might be expected from such ores. However, Ni are observed also in some of the Italian swords in the current study and other Italian artefacts that are isotopically consistent with Italian Eastern Alpine sources (Angelini et al., 2015; Canovaro, 2016) and therefore, the presence of Ni does not seem, currently, to exclude an origin from these deposits. Interestingly, it has recently been demonstrated that Trentino copper also circulated in the eastern Mediterranean world during this period (Jung and Mehofer, 2013; Mehofer and Jung, 2017).

Although ores from the Italian Eastern Alps seem to be of great importance 1500–1300 BCE as well as 1300–1100 BCE, neither the isotopic nor the elemental data are identical during this long time span. During the earlier period, the lead isotope data are consistent with ores from the Southalpine AATV. During the later period the isotopic data are, however, more consistent with slags from copper smelting that plot in a gap between known ore sources (Addis et al., 2016). This may very well be related to mixing of ores from both sides of the Valsugana Valley, producing both slags and metal with intermediate lead isotope ratios. Such a mixing of ores is potentially also reflected in the elemental signatures in the analysed metal, i.e. the swords. The general shift from higher towards slightly lower content of Ni and As from earlier to later phases may account for this. Although all ores in the region (Nimis et al., 2012; Artioli et al., 2016a) are not yet totally quantified in terms of trace elements, the general knowledge regarding the various ore types with more or few impurities are quite plausible for such a change in element concentrations. This will however not be further discussed within the topic of this paper.

4.5. Swords and potential recycling

Concerning the problem of recycling that was mentioned in the introduction, we have thoroughly discussed this aspect of lead isotope and chemical provenance identification in previous papers (Ling et al., 2014; Artioli et al., 2016a; Melheim et al., 2018a) also in relation to the expected depletion and enrichment of elements as suggested by Bray and Pollard (2012). If re-melting was the norm from 1500 to 1300 BCE to 1300–1100 BCE (both characterised by presence of As and Ni), according to their opinion one would expect an enrichment of Ni and a concomitant depletion of As due to different behavior of these elements.

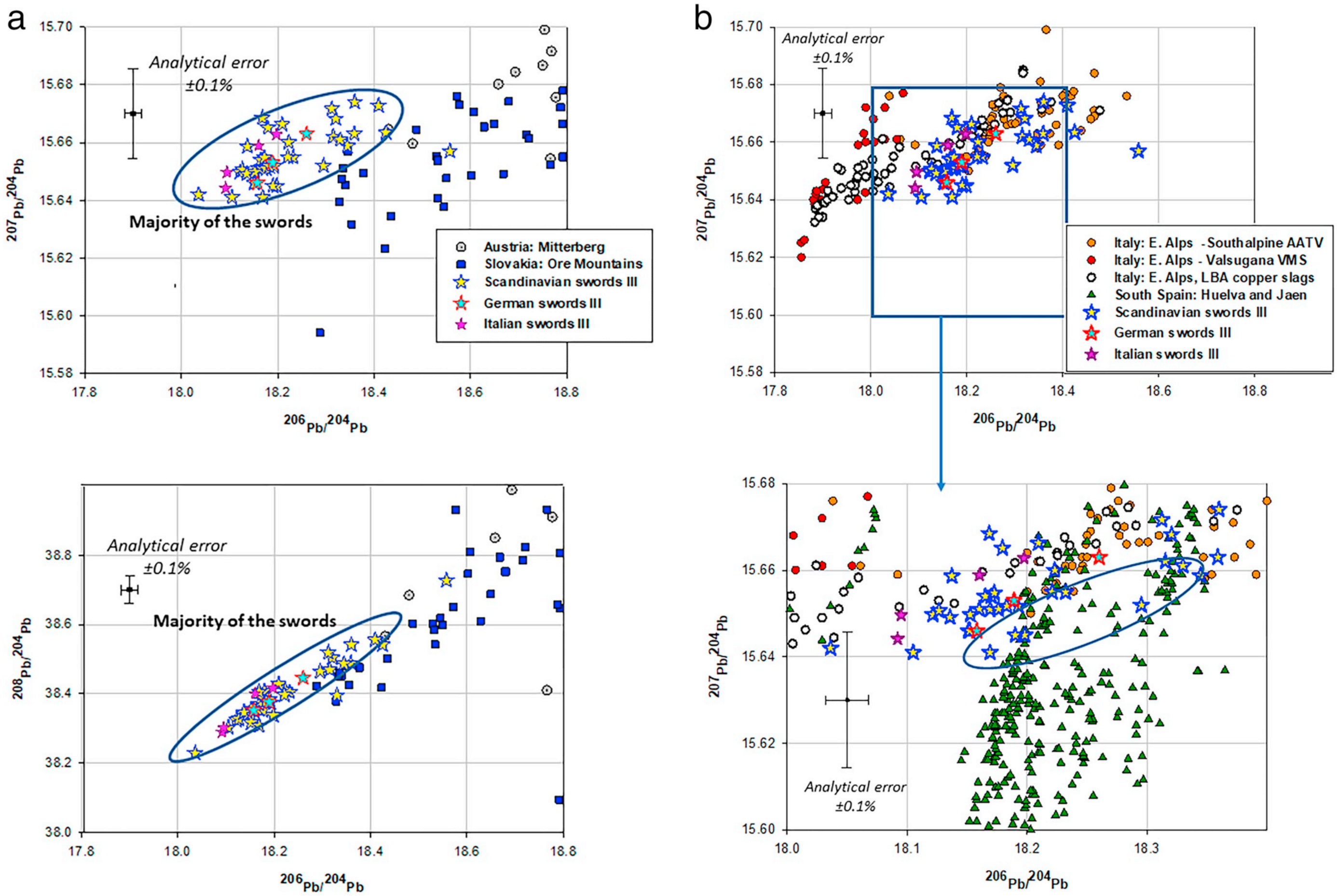

Fig. 14. a. Symmetrical comparative plots for the lead isotope ratios of the swords dated to 1300–1100 BCE (period III) compared with the ores from the Slovakian Ore Mountains and Mitterberg. The ellipse highlights the group of data for the swords that are definitely not consistent with these ores.
14. b. Comparative plot of the lead isotope ratios of the swords dated to 1300–1100 BCE (period III) with the ores from the Italian Alps. Lower plot is the enlarged section of the upper one showing the set of ratios of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ to demonstrate that some of the Scandinavian swords seem consistent with the lead isotope ratios of the copper ores from southern Spain (in the ellipse).

However, instead, a minor shift towards lower concentrations of both elements is found during the later period, i.e. not in support for this theory. Furthermore, the shift in Ni and As is contemporaneous with a shift in lead isotope ratios in the bulk of the swords. As discussed in Section 4.4 above, this is furthermore related to the differences noted in various ores within the Italian Alps.

4.6. Sword typologies and metal sources

The idea that certain types of swords were produced from the same copper sources, as presented in the introduction, is worth re-exploring in the light of the current results. Such hypothesis cannot, however, be supported by this study. Instead, the norm seems to be that different regions produced similar sword types on a local basis but were partly using copper from different ore sources. This can be demonstrated by the many subtypes of swords dated to 1500–1100 BCE, for which several sources can be identified for the same type of swords, from several different regions (Fig. 18, Table 3). For example, among the full-hilted swords found in Denmark, both the Nordic and octagonal types seem to be made of copper originating from Italian Alpine ore deposits (with a few samples with other origins). However, in Northern Germany, the majority of the octagonal-hilted swords seem to originate from copper sources in Slovakia (c.p Bunnefeld, 2016a, 2016b), but three may have Italian Alpine origin and two can be related to ores in the Austrian Alps. Although the data-set is too limited for a good statistical evaluation, it is clear that there is not a single source for either of the sword subtypes, neither in the Danish nor in the north German material. The observed differences suggest that Italian Alpine deposits to be more common in Danish swords and a Slovakian origin more common in North German swords, irrespective of whether the sword type is Nordic or octagonal (Fig. 18).

However, the flange-hilted swords show a somewhat different picture. Throughout their wide area of distribution, from central Europe to south Scandinavia, the same source seems to have supplied the copper (Table 4). All analysed samples, except two from North Germany (with Slovakian sources), are made from copper with a probable origin in the Italian eastern Alpine deposits. Similar results are seen for the full-hilted swords of Nordic type dated to 1300–1100 BCE, most probably also reflecting the general dominance of Italian Eastern Alpine deposits. Similar conclusions, that swords dated to 1300–1100 BCE, were based on copper from the Italian eastern Alps, have been presented by (Jung and Mehofer, 2013) and Bunnefeld (2016a, 2016b). Interestingly,

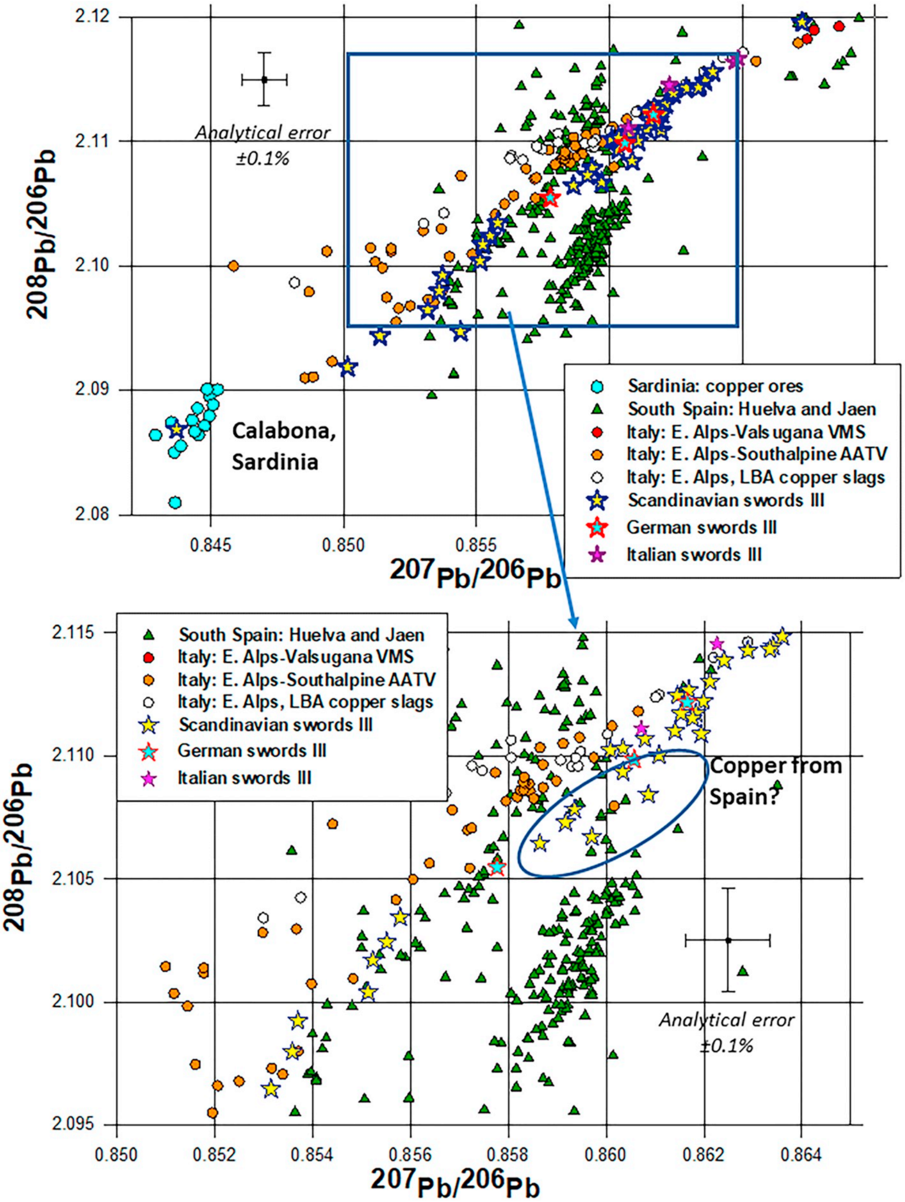

Fig. 15. The same sets of lead isotope data as on Fig. 14a and b presented for their $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ ratios. Additionally, on the upper plot there are included data for the ores from the mine of Calabona on Sardinia and the data for sword 5: Ke 5023 (A) from Denmark. The ellipse indicates the group of swords that seem consistent with the ores from south Spain.

Trentino copper is present even in flange-hilted swords of Naue II type found in the Mycenae and on Cyprus (Jung and Mehofer, 2013; Mehofer and Jung, 2017). Naue swords first occurred in Italy c. 1300 BCE, before they spread further north and east (Kristiansen and Suchowska-Ducke, 2015). One of the Danish swords which is consistent with slags from the Italian eastern Alps near Trento is a Naue II sword (Melheim et al., 2018a). In this case, a consistency between ore region and sword typology may be noted.

To conclude, the chronology and geography of the deposited swords indicate that the different regions relied on different metal supplies, that changed during the course of the Bronze Age. Furthermore, this changed from a disparate pattern in the earlier phases, to a more homogenous pattern in the later phase, with fewer suppliers covering larger areas. How can we explain these patterns in terms of trade routes?

5. Discussion

According to previous studies, most of the copper circulating 2000–1600/1500 BCE, was transferred to Scandinavia through Central European networks, probably via Elbe and Oder (Ling et al., 2014; Vandkilde, 2017). However, this scene changed around 1600/1500 BCE (Figs. 17, 19) (Vandkilde, 2017; Melheim et al., 2018a) when, as is also demonstrated in the current study, swords from Denmark were made of copper from British ore sources. This metal was probably transported by boat and through seagoing trade networks from the North Sea to Scandinavia. This does not come as a surprise, knowing that Scandinavia is the area outside British Isles with most finds of typical British flanged axes and spearheads dated to 1700–1500 BCE (Butler, 1963; Needham, 2009; Vandkilde, 1996, 2017). Another important cause for establishing more permanent exchange relations with the British Isles

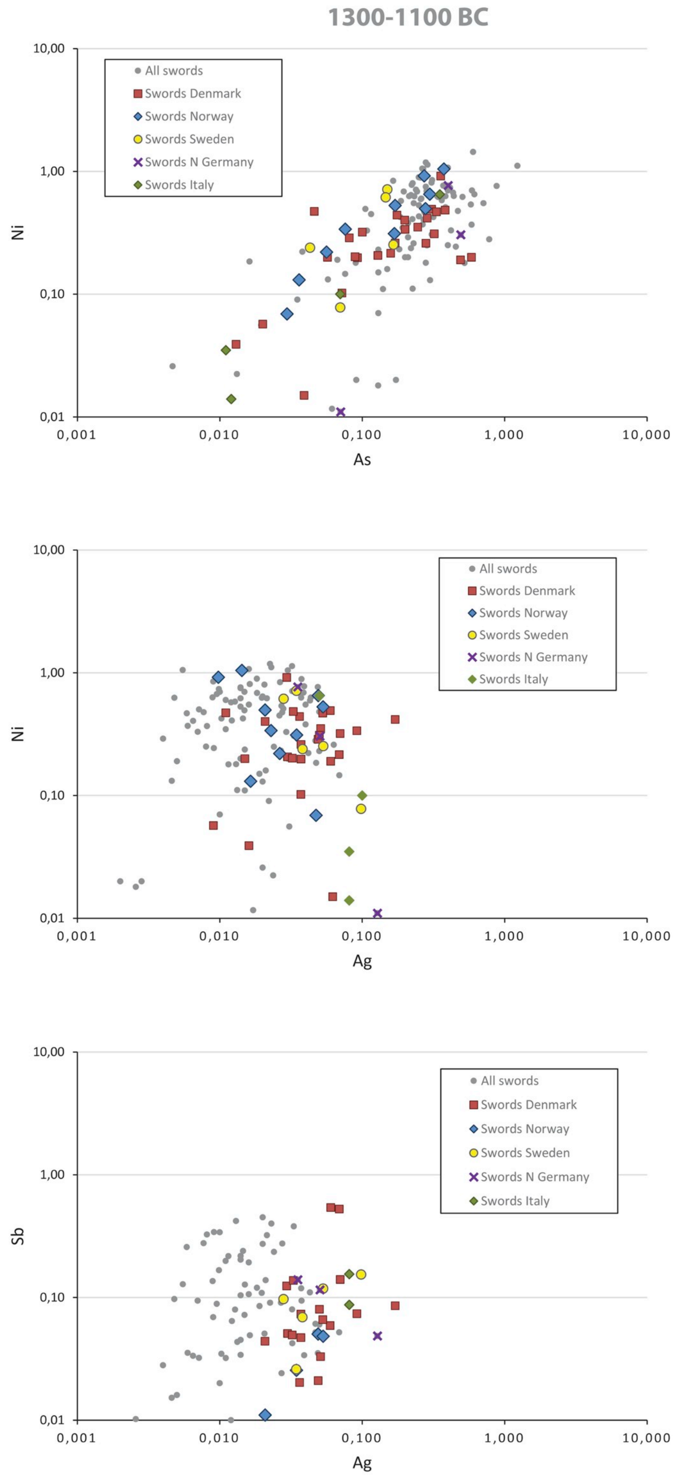

Fig. 16. Logarithmic plots of trace elements; Ni vs As, Ni vs Ag and Sb vs Ag for the sword samples dated to 1300–1100 BCE from various countries compared with the data for swords from all periods included in this project.

during this phase may have been the overall demand of tin, available e.g. through Cornish tin sources (O'Brien, 2015; see also Pernicka, 2010; Ling et al., 2014).

While the period 1600–1500 BCE saw the operation of several regional supply systems, the situation changed with the beginning of the Nordic Bronze Age period II, around 1500 BCE, when trade routes from Scandinavia were redirected towards the west and the south (Figs. 20–21). Archaeological evidence shows how trade network emerged between Jutland and the Tumulus culture during this phase (Randsborg, 1968). The most frequent copper source for Scandinavian groups appears to be the Italian Alps from which around 70% of the analysed swords derive, according to the current study, while North German groups seem to have obtained copper foremost from the copper sources in the Slovakian Ore Mountains and Mitterberg in Austria (Figs. 20–21, Table 3). We can explain this divergence through a scenario of three different riverine/maritime trade routes from the north to the south (or vice versa), that were potentially operated and controlled by different groups: one along the Weser to south Germany, another along the Rhine and a third from North Germany along the Elbe leading down to the Austrian Alps and Slovakia. An interesting difference can also be noted within the Scandinavian area since a non-negligible number of swords from Denmark were made of copper from Mitterberg and Slovakia, but in Sweden these sources seem to be comparatively rare, and copper from the Italian Alps predominates. A major part of the Elbe river was probably controlled by groups related to the Lüneburg culture in Northen Germany. The Elbe river has its source in the Karkonosze/Krkonoše mountains, located in the north of the Czech Republic and not far from the aforementioned copper sources in Slovakia. Moreover, the distance to the mines in Mitterberg in Austrian Alps is not long from where Elbe has its source. This may indicate that the North German groups primarily used the Elbe route, while the Scandinavian groups used Weser or Rhine. In this context it is intriguing that the mentioned two rivers were used by the Scandinavian Vikings; not the rivers of Elbe or Oder (Sawyer, 1983).

5.1. *Potential trade routes*

So far, we have pictured some potential routes, Weser, Rhine, Elbe, Oder, Vistula and the Atlantic seaway that could have been used to transfer copper from the Italian Alps, Slovakia, Austria and Iberia to Scandinavia (Fig. 20). Which riverine route was the most convenient to use, and which river has the most archaeological evidence for interaction and trade? For instance, the Rhine area holds more finds of swords and Baltic amber than the Weser area (Schauer, 1971; Laux, 2009; Woltermann, 2012, 2016; Kristiansen and Suchowska-Ducke, 2015). However, it must be stressed that the mouth of the Rhine is farther away than Weser for the Scandinavians; about 200 km southwest along the coast of the North Sea. If the Scandinavians travelled this far in the Bronze Age, it would take an additional 2–3 days with a Bronze Age boat to cover this distance (Ling, 2014). Hence, it is perhaps more logical to assume that copper from the Italian Alps was transferred by Tumulus middle men, at the southern branch of Weser, and from there they could have used the copper to trade Baltic amber with the riverine travelling Scandinavians. Another potential scenario was that Tumulus groups transported the copper to the river mouth of either Weser or Rhine for further exchange with other groups from Northern Europe.

One interesting problem with this scenario is that the copper in the analysed swords from the southern part of Germany, within the Tumulus culture, collectively interpreted here as being made of copper from Carinthia in the Eastern Austrian Alps could also be said to derive from three different sources; in the Italian Alps and the Slovakian Ore Mountains respectively. Since Carinthian ore sources are not identified in any of the Scandinavian swords, this would imply that Scandinavian travellers had access to other sources, although within the same cultural zone. If we consider the alternative scenario, a few ore regions have the potential of being sources to both, allowing for compositional differences. Thus, looking into the evidence of interaction and trade

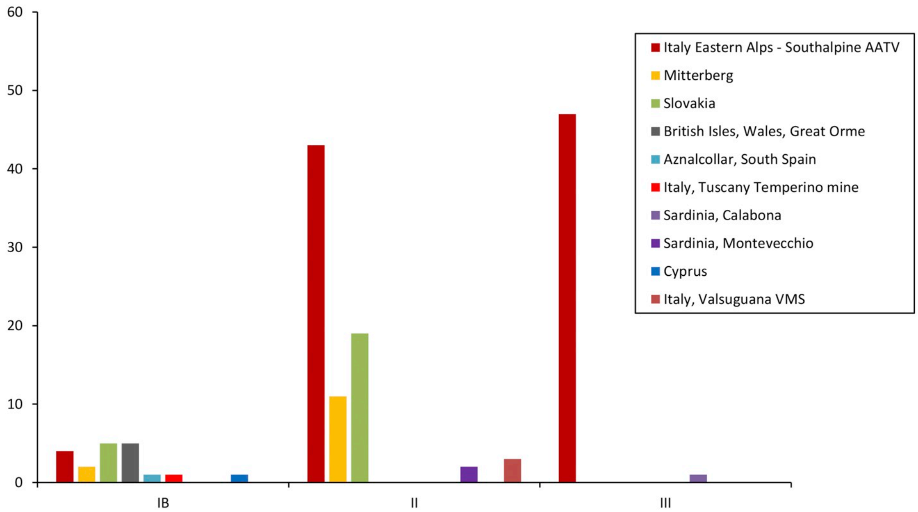

Fig. 17. Bar-chart overview of the suggested provenance areas for the sword samples from all countries, included in this research project according to their chronology. Several potential origins are discussed in the text for some of the swords; for simplicity, only the ones considered most plausible are presented here. A clear change in relation to chronology can be seen in the possible origin of copper for these swords, ranging from several potential sources during 1600–1500 BCE (period IB) to prevalence of copper from the Italian Eastern Alps during 1300–1100 BCE (period III).

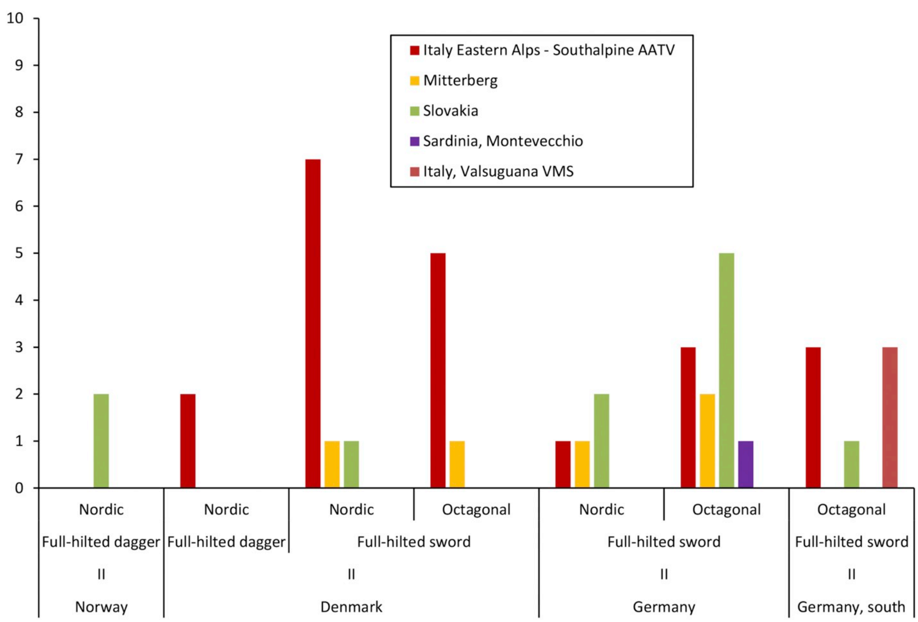

Fig. 18. Bar-chart illustrating that several copper sources are suggested for the same type of swords. As an example, this is demonstrated by samples of full-hilted swords dated to 1500–1300 BCE. Among those found in Denmark; the majority of the Nordic and Octagonal types were based on the Italian Alpine deposits as their copper source. However, in Northern Germany, the majority of the Octagonal swords originate from copper sources in Slovakia, although three samples may have Italian Alpine origin and two samples can be related to ores in the Austrian Alps.

1500–1300 BCE the second scenario seems after all to be the more plausible, i.e. that the south German swords originated from basically the same sources as swords in Scandinavia and Italy. Considering the many finds of Baltic amber in Tumulus graves in the southern part of the Weser region, dated to 1500–1300 BCE, we suggest here that Weser constituted one of the main routes for the Scandinavian travellers in the Bronze Age, like in the much later Viking Age. This route was probably already established by 1600 BCE (Fig. 19), as demonstrated by finds of swords and Baltic amber (Laux, 2009; Woltermann, 2012, 2016). Italian copper is identified not just in swords but also in other object categories in Scandinavia, e.g. jewellery (Melheim et al., 2018a). The results indicate that from 1500 BCE, the Scandinavian groups, relied mostly on copper from the Italian Alps, while northern Germany got copper from the Slovakian ore Mountains, with additional input from Mitterberg and Italy.

Thus, a new intriguing pattern of interaction and trade emerged between the regional groups in northern Germany and Scandinavia. This pattern of interaction corresponds to the culmination of the Tumulus culture, that had developed close commercial and political ties with south Scandinavia (Kristiansen and Larsson, 2005: Fig. 107), and at the time when the former influential Bronze Age tell cultures in the Carpathians were in decline. For the following centuries of 1300–1100 BCE copper from the Italian Alps seems to take over as the dominant source for nearly all Scandinavian swords. Thus, we can observe that within the Nordic zone, in particular before 1300 BCE, different regions selected different providers of copper. From northern Germany the Elbe route was connecting to Mitterberg and Slovakia, while Denmark and Sweden seem to have relied on the maritime trade along the North Sea to Weser or perhaps even the Rhine, leading directly to the south German Tumulus culture, which had connections to the Italian Alps (Mordant et al., 2007). The Weser versus the Elbe rivers thus represented two competing or parallel metal trade routes during the period 1500–1100 BCE, where the south German Tumulus culture traded copper with the Italian Alps in exchange for Baltic amber and other commodities from the north. But where does tin fit into this picture?

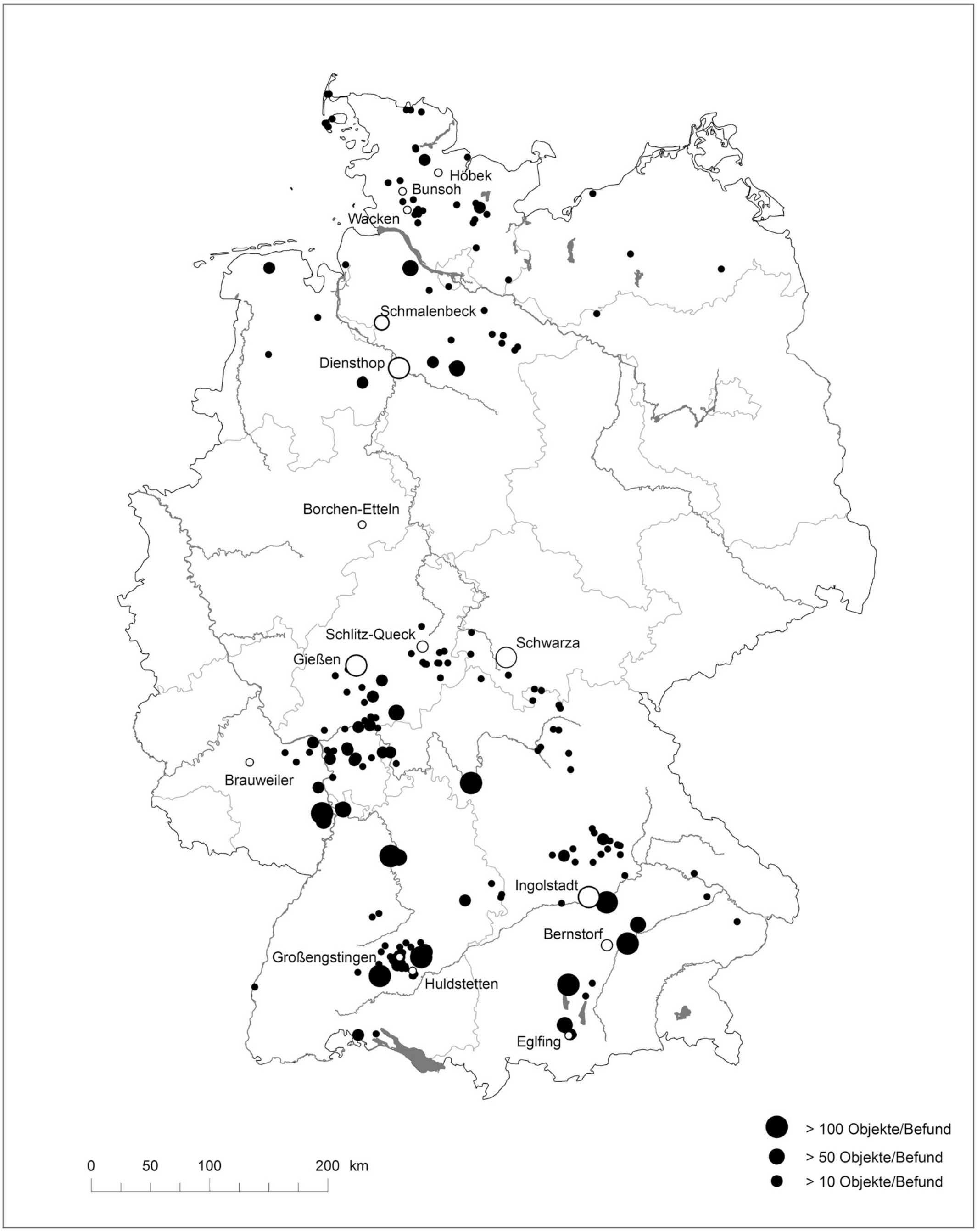

Fig. 19. The distribution of Baltic amber dated to 1500–1300 BCE (period II) adjacent to the southern parts of Weser, Main and the southern parts of the Rhine. Our hypothesis is that the Scandinavian traders used this route and traded amber against metals with the Tumulus groups in southern Germany. After Woltermann, 2012.

One possibility, discussed in previous papers, is that the British Isles acted as a hub of trade due to its comparative advantage of having tin and gold (Ling et al., 2014; Melheim et al., 2018b). In this scenario, the Rhine would lead more or less from the Alpine copper sources in the south to the tin sources in England. In light of this, we suggest that there was a triangular trade system in which amber was traded south by Nordic traders/warriors (Fig. 21). In south Germany they traded amber for copper, which they brought to the British Isles along the Rhine route, where they exchanged copper for tin, before returning home across the North Sea. Further support for the use of the Rhine route comes from the isotopic evidence showing that the traders in the British Isles also obtained some of their copper from the Italian Alps after 1500 BCE, even if copper from Great Orme was still being used (Rohl and Needham, 1998; OXALID, n.d.). Thus, out of 19 swords published by Rohl and Needham (1998) dated to 1400–1200 BCE, 15 are consistent with the ores from the Trentino-Alto Adige region in northern Italy (Fig. 22). These results suggest that the British Isles were involved in the continental and Scandinavian metal trade during these centuries.

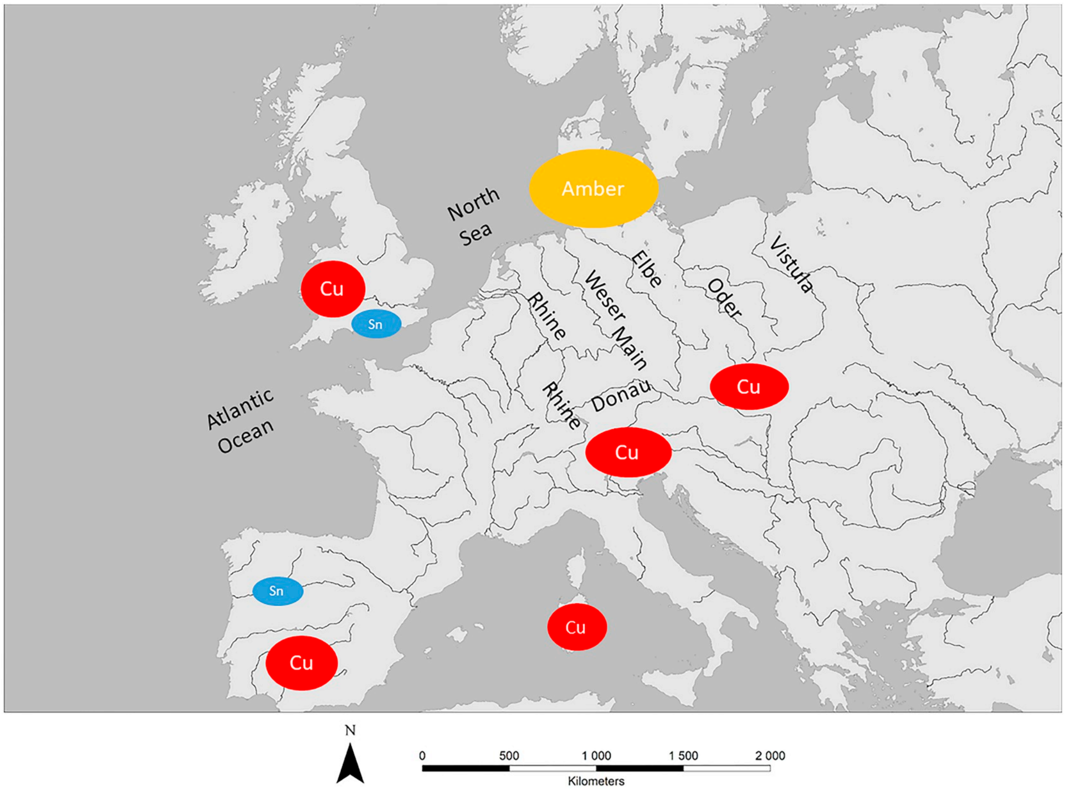

Fig. 20. Map showing the sources of raw material from different regions in Europe that could have been the subject for trade in 1600–1100 BCE between the regions mentioned in this study. The rivers listed here may have worked as potential trade routes between the regions as well as the oceans between.

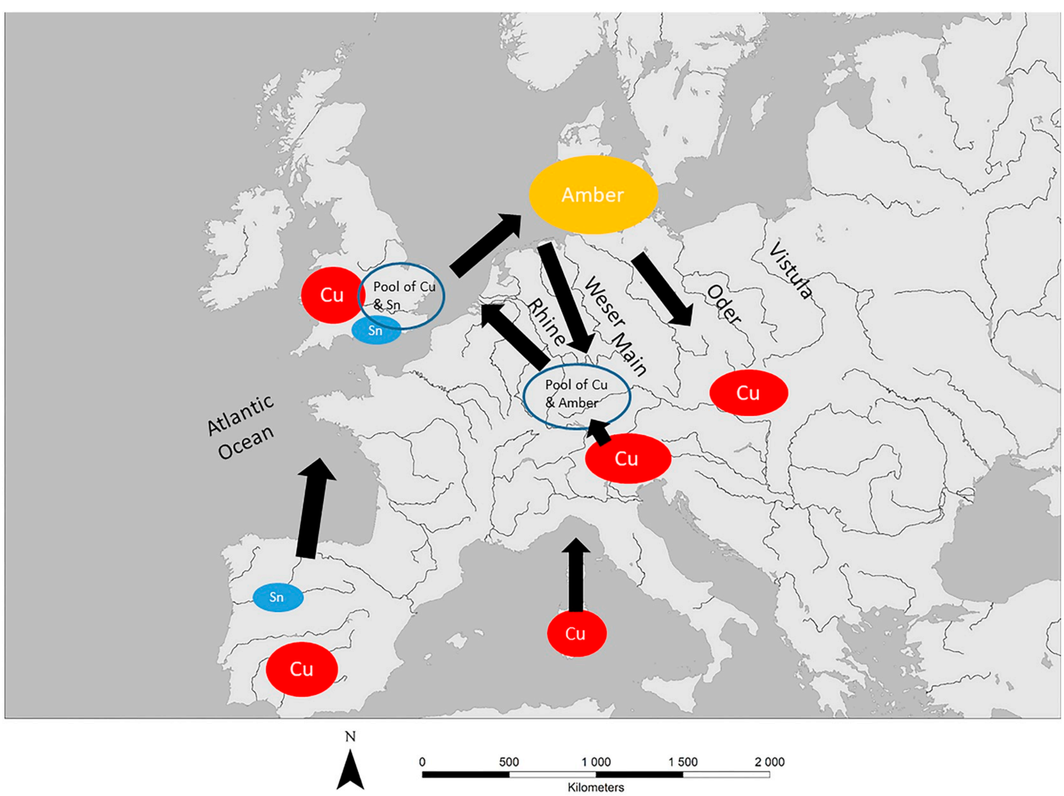

Fig. 21. Our model of a triangular trade system in which amber was traded south by Nordic traders. In south Germany they traded amber for copper, (illustrated by the ellipse; pool of copper and amber) which they brought to the British Isles along the Rhine route, where they exchanged copper for tin, (illustrated by the ellipse; pool of copper and tin), before returning home across the North Sea.

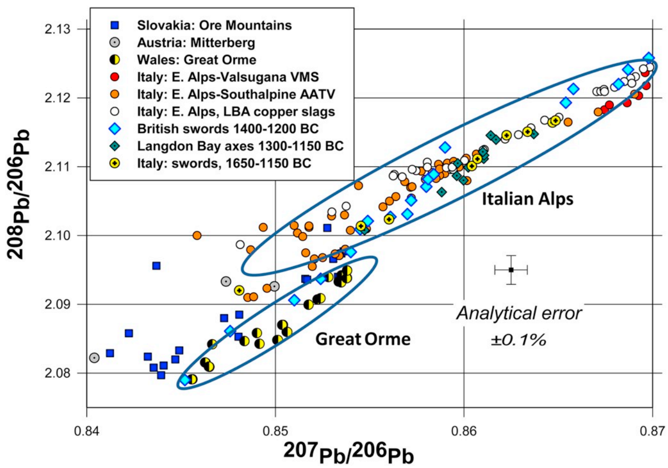

Fig. 22. Lead isotope plots for British swords dated to 1400–1200 BCE, British axes (palstaves) from the Langdon Bay hoard dated to 1300–1150 BCE and Italian swords dated to 1650–1150 BCE, compared with the copper ores from Wales, from the Italian Alps, Slovakia and Austria (the majority of the data for the two latter deposits plots outside the graph). These results suggest that the British Isles were fully included in the continental and Scandinavian metal trade during these centuries.

Considering that all metal was imported to Scandinavia during the Bronze Age, this, in turn, required a fairly driven trading organisation, perhaps a precursor to the trade organisation that took place later during the Viking Age (Fig. 23), notwithstanding obvious differences in the scale of trade, and other social and economic practices (Ling et al., 2018).

6. Conclusion

We have assembled and assessed the largest number of Middle Bronze Age sword analyses so far from northern and central Europe. Although there are still gaps, geographically and numerically, in the data-set, the hypothetical models about trade routes may be seen to increase the probability of the proposed interpretations. Most of the sampled and analysed swords derive from Scandinavia and Northern Europe. Many more samples from central Europe are now needed to provide a representative picture of production and trade in copper on the European continent. The conclusions from the current study are tentative and might change with an increased number of analyses. However, it seems likely that the general trends will remain valid, such as the shift in dominant mining areas after 1500 BCE, noted also by previous researchers (e.g. Liversage, 2000), which introduces the Italian Alps as a new large-scale supplier. Our current results also indicate that the supply situation changed around 1500 BCE as the supply of copper from Great Orme in Wales declined and supplies from ores in

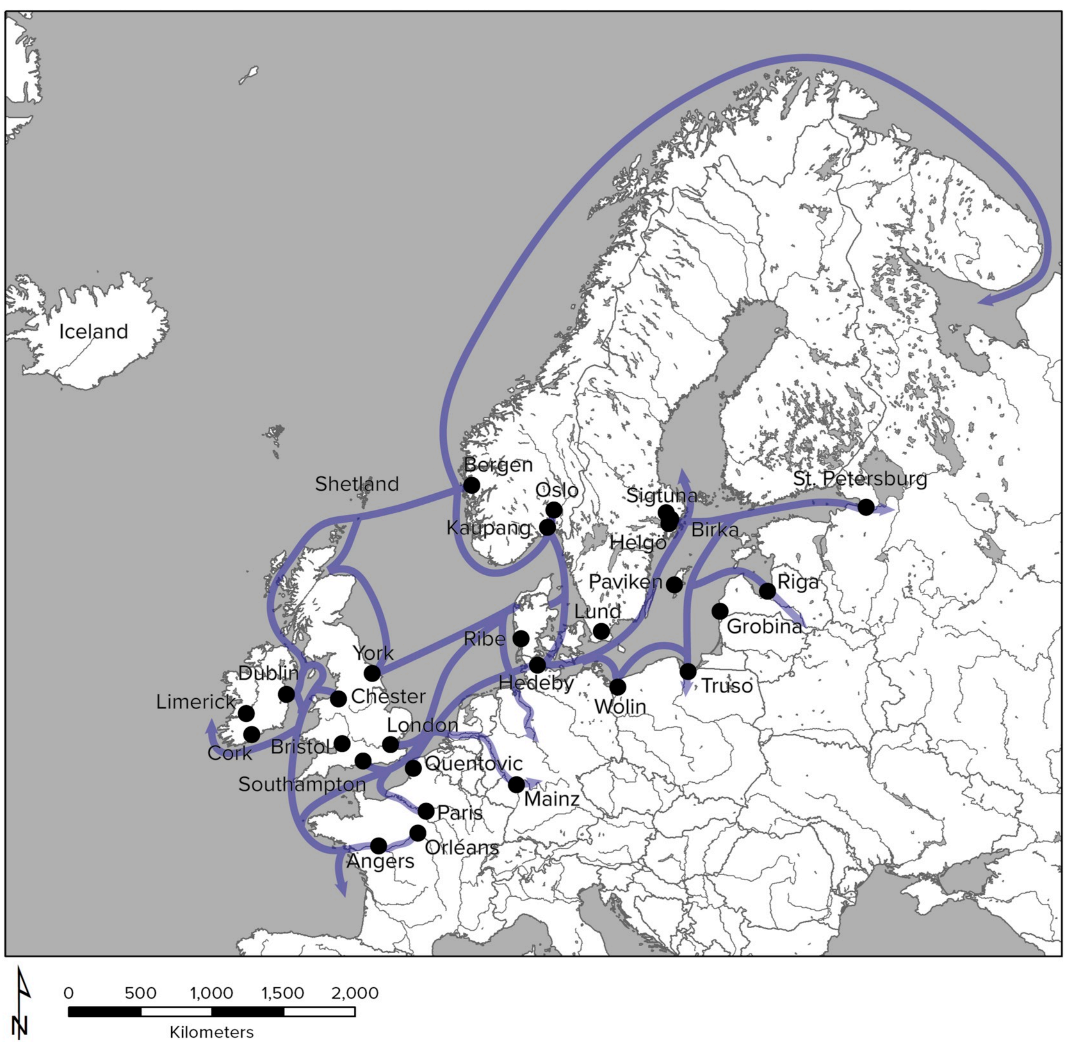

Fig. 23. Map showing the Viking Routes in Europe. We argue that the Scandinavian Bronze Age travellers also used some of these rivers (Rhine and Weser) as trade routes as trade routes. Modified after Brink and Price, 2008.

Austria and Slovakia increased in importance. Our new evidence from most of the Scandinavian swords, regardless of region, points to the Italian South-Eastern Alps (Tables 3–4, Figs. 21–22). Also, there is the possibility that copper from the rich mining regions of Jaen and Huelva in southern Spain makes its appearance in Sweden and Denmark during this period, as indicated by some of the swords in the current data-set. New sources of copper might also be related to the rich deposits of tin ore in the Iberian Peninsula, as an alternative to the Cornish tin.

The lack of copper from Austrian sources such as Mitterberg and ores in the Slovakian Ore Mountains in the sword data after 1300 BCE, may at least in part be due to the limitations of the data-set from north-eastern Germany and other parts of central Europe. Likewise, on a general level our data indicates that copper was supplied by a few dominant mining areas with a high output 1500–1100 BCE, since they were able to supply large regions in Europe.

On basis of the interpretation of the swords in this study, it seems as if only a few dominant sources contributed with copper at any given time. During the 16th century the Great Orme mine in Wales, the Mitterberg mines in Austria as well as mines in Slovakia constituted the major copper sources for the swords. Some major shifts in the production and distribution of copper took place around 1500 BCE, when mines in the Italian Alps became a main supplier to central and northern Europe. We may perhaps see this in connection with the decline of the tell cultures in the Carpathians and the rise of the Terramare culture in northern Italy, which now became a hub for the trade between the east and west Mediterranean, and northern Europe via the Tumulus culture network (Kristiansen and Suchowska-Ducke, 2015, Fig. 1). These networks were gradually shifting towards east central Europe after 1300 BCE, while at the same time an Atlantic network emerged to the west.

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