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Metal Analyses of the Skeldal Hoard and Aspects of Early Danish Metal Use

by HELLE VANDKILDE

An archaeological assessment of the Skeldal hoard has recently been published in this journal (Vandkilde 1990a). The hoard was found by Salten Langsø in the middle of Jutland, and it consisted of three low-flanged axes, the butt part of a fourth low-flanged axe, a nick-flanged double-edged chisel, a beehive-shaped box with lid, an open solid-cast ring, a spiral armring, a spiral bead, and two *Noppenringe*, all in copper or bronze; and a pair of golden *Noppenringe*. The objects were dated to the late part of the Late Neolithic Period (LN II) or c. 1950–1700 B.C. (cf. Vandkilde 1989, 29ff; 1990b, 175ff). It was argued that the flanged axes were produced in Denmark, with the possible exception of a trapezoidal axe in west European style, whereas the bronze ornaments and the chisel most probably came from the northern Únětice culture or its Baltic periphery, and it was suggested that the golden *Noppenringe* originated somewhere between the Erzgebirge and the Alps. The dating and the determination of the provenance was based purely on archaeological criteria. Already at this stage a metal analysis of the objects had been initiated in order to evaluate and supplement the archaeological evidence, and it is the results of this analysis that shall be reported on here (1).

The raw analysis data (appendix) will be classified according to different statistical procedures, and the results will be compared. The metal analyses of the Skeldal hoard will then be discussed in a local Danish and a wider European perspective. The analyses of the two golden *Noppenringe* will be treated in a separate chapter. The point of departure for the examination is a new chronological framework based largely on metal objects (Vandkilde 1986, 1989, 1990a, 1990b) (fig. 1).

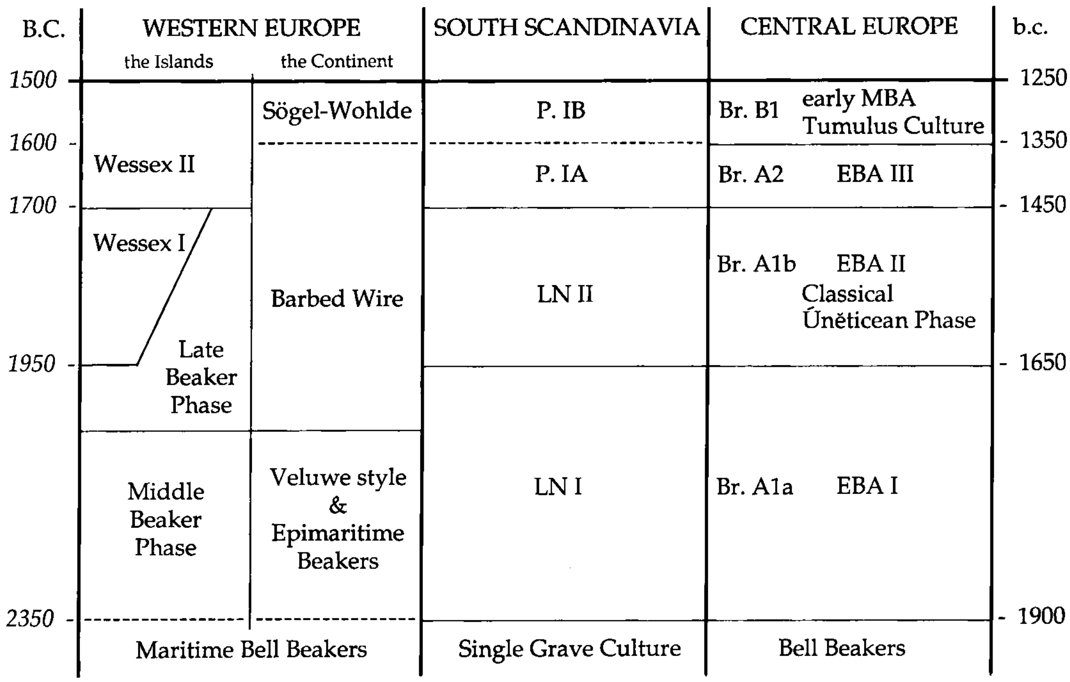


Fig. 1. Chronological table for the Danish Late Neolithic and earliest Bronze Age synchronized with central and west Europe.

STATISTICAL CLASSIFICATION OF THE SKELDAL METAL ANALYTICAL DATA

Most Danish copper and bronze objects prior to Period II of the south Scandinavian Bronze Age have been analysed quantitatively for the most important elements other than copper (Cu): tin (Sn), arsenic (As), lead (Pb), antimony (Sb), silver (Ag), nickel (Ni), bismuth (Bi), cobalt (Co), gold (Au), zinc (Zn), and iron (Fe) by the *Arbeitsgemeinschaft für Metallurgie des Altertums* based in Stuttgart/Mainz during the 1950's and 1960's. The results of this project have appeared in a series of publications abbreviated SAM. The analyses of the Danish material have been published in SAM 2 (Junghans, Sangmeister, and Schröder 1968–1974, SAM 2:3 and 2:4; cf. Cullberg 1968, 170ff). The appearance of the Skeldal hoard gave the opportunity to continue the metal analyses with regard to objects, which had been overlooked or which have appeared after the termination of the SAM analysis program (2).

The Skeldal metal objects were analysed by electron probe microanalysis (EPM), which requires only very small samples (3–4 mg); it is non-destructive, i.e. the samples are preserved for future analysis, and it is in general suitable for the analysis of ancient metal work (Northover 1980, 1982; Härke 1978, 249). All objects in the hoard, with the exception of the small spiral bead, which was too damaged and corroded, were analysed quantitatively for the same elements as in the SAM program, to facilitate comparison. Thirteen samples were examined, including two samples from the beehive-shaped box (appendix).

Cluster analysis has recently been much used for grouping metal analyses (Hodson 1969, 97ff; Ottaway 1974; Boomert 1975; Butler 1979; Pernicka 1984; Ryckner 1987, 22ff; Krause 1988, 192ff). Dealing with a limited number of objects, like the Skeldal hoard, there is, however, no need of multivariate methods. The Skeldal analyses will be classified according to three simple procedures: The Waterbolk-Butler graph method, a plot in a system of co-ordinates and the *Materialgruppen* of SAM 2.

The Waterbolk-Butler graph method was originally developed as an alternative to the SAM *Materialgruppen* (Waterbolk and Butler 1965, 234ff). Initially the grouping of the data was done by hand, the "impressionist way", using a so-called work-sheet graph, and the result was then illustrated in a corresponding histogram. Later, the work-sheet classification was partly replaced by an aver-

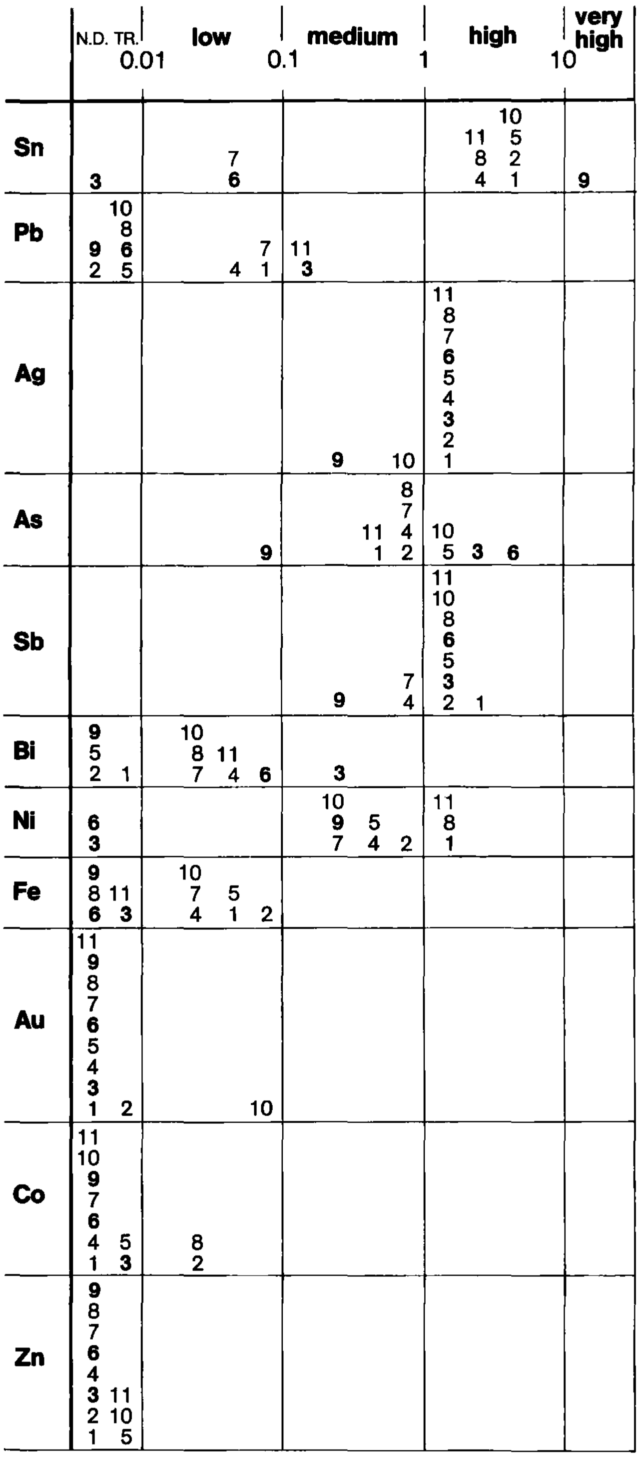
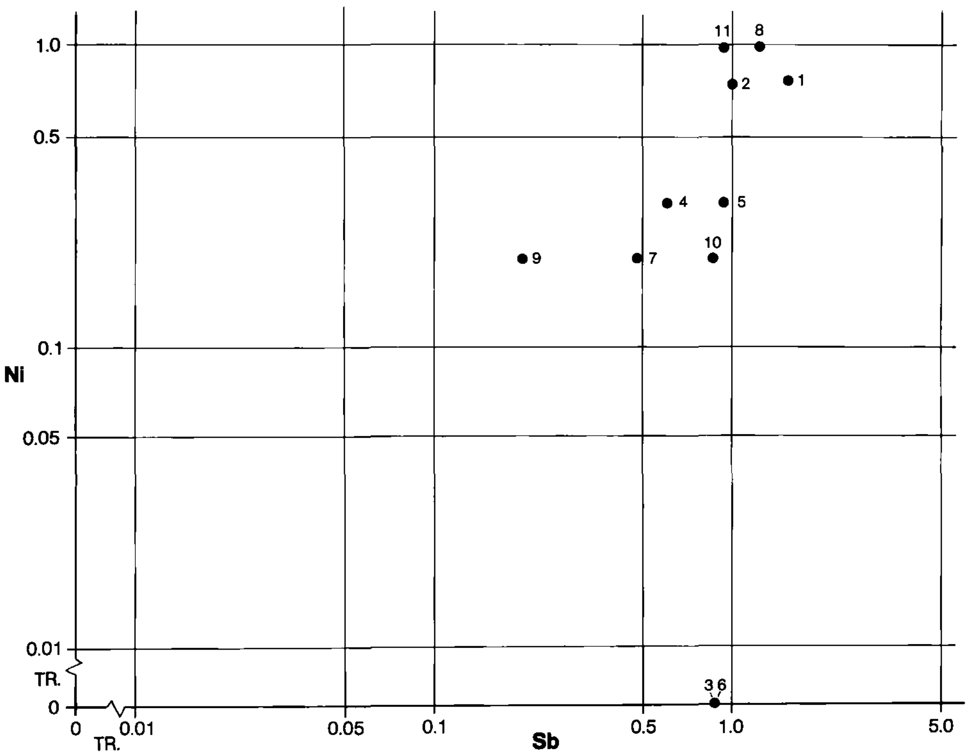


Fig. 2. Waterbolk-Butler work-sheet graph of the Skeldal hoard. Numbers of objects with deviating metal composition have been accentuated. See fig. 5 for the logarithmic scale of each range.

A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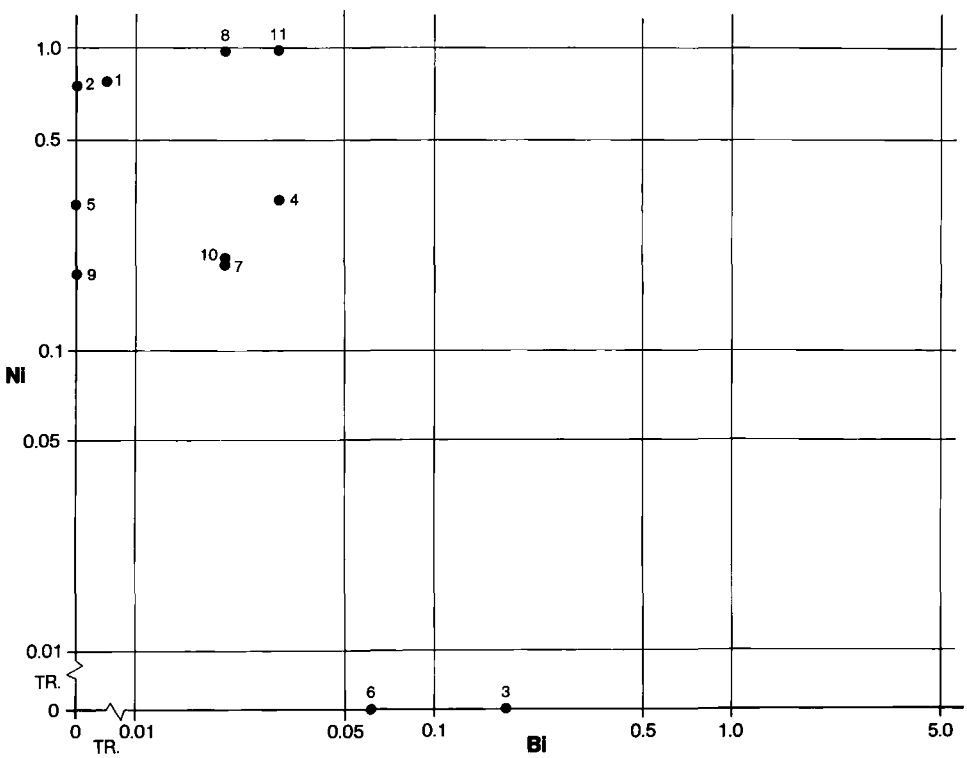
B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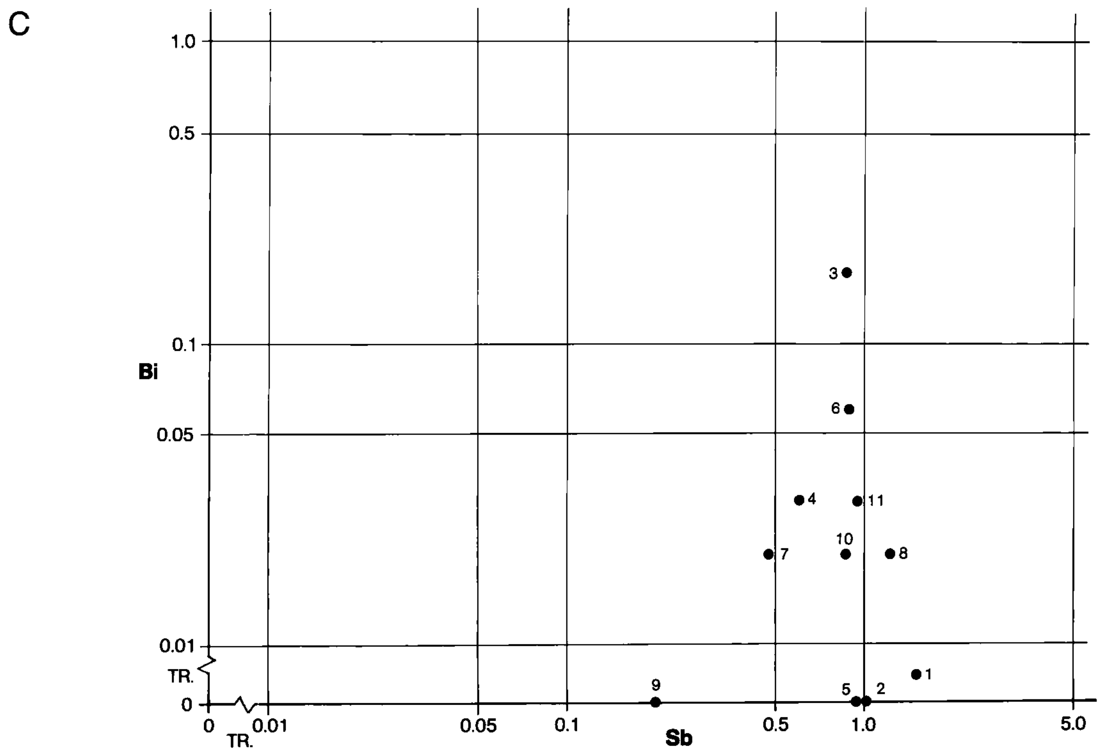

Fig. 3A–C. Bivariate plots of the relationship between selected elements: Sb, Ni, and Bi. A: The relationship between Ni and Sb. B: The relationship between Ni and Bi. C: The relationship between Bi and Sb.

age linkage cluster analysis by computer (Boomert 1975; Butler 1979), probably because it proved difficult to process large amounts of data on the basis of the work-sheet sorting. The representation of the results in histograms was, however, maintained.

Plotting the eleven Skeldal analyses into a Waterbolk-Butler work-sheet graph discloses a rather homogeneous impurity pattern with Ag, As, and Sb as the principal impurities in all objects (fig. 2). The metal of the Skeldal objects can be described as high impurity copper with a variable percentage of tin. Tin is an alloying addition in most of these objects (see below) and is therefore left out of consideration in this analysis. Pb, Bi, Ni, and Fe have differing values, while Au, Co, and Zn are, as is normally the case, present at a very low level or not present. It is immediately noticed that no. 9 falls outside the main distribution, but also no. 3 and no. 6 deviate from the main group, especially regarding the lack of Ni. This coincides with slightly higher contents of Bi and As than are found in the main group. Neither the Pb nor the Fe value seems to be of any significance.

This sorting procedure results in the following three groups:

Group I Medium to high Ag, As, Sb, and Ni: nos. 1, 2, 4, 5, 7, 8, 10, and 11.
Group II High Ag, Sb, and As; As higher than in group I; Ni not present: nos. 3 and 6.
Group III Medium Ag and Sb; rather low As: no. 9.

Liversage has recently advocated a computer-based use of the Waterbolk-Butler work-sheet sorting, on the basis of which he numerically defines four metal types in the Danish material (Liversage *et al.* 1989; Liversage 1989). His metal types agree quite well with the above metal groups. Group I corresponds roughly to the "Singen metal" of Liversage, however, with nos. 4, 5, and 7 at the border line between "Singen metal" and "*Ösenring* metal" (Liversage et al. 1989, 59, 64). Group II corresponds to Liversage's "Ösenring-metal", whereas Group III falls outside the system of Liversage.

The second statistical procedure is an attempt to classify the material by plotting impurity values of the main grouping indicators (cf. Northover 1982, 229) into a system of co-ordinates using logarithmic scales, thus illustrating the relationship between the elements. On the

Waterbolk-Butler work-sheet graph	System of co-ordinates	SAM-"Materialgruppe" classification
		A: no. 1, 2
GROUP I: no. 1, 2, 4, 5, 7, 8, 11	**GROUP IA:** no. 1, 2, 8, 11	**A1:** no. 8, 11
	GROUP IB: no. 4, 5, 7, 10	**B2:** no. 4, 5, 7, 10
GROUP II: no. 3, 6	**GROUP II:** no. 3, 6	**C2c:** no. 3, 6
GROUP III: no. 9	**GROUP III:** no. 9	**FG:** no. 9

Fig. 4. Comparative table with the metal groups achieved when using three different, bivariate statistical procedures.

basis of the work-sheet graph (fig. 2) only Ag, As, Sb, Ni, and possibly Bi are considered significant, and because of the nearly identical distribution of Sb, Ag and As, Sb was selected as representative of all three elements. Consequently, only the relationship between Sb, Ni, and Bi are examined (figs. 3A–C).

In all three logarithmic plots nos. 3 and 6 (Group II) deviate from the rest of the analyses. In the plots that relate Ni to Sb (fig. 3A) and Bi to Sb (fig. 3C), no. 9 (Group III) clearly falls outside the main distribution. A subdivision of Group I is indicated by the distribution of Ni (figs. 3A–B):

Group IA Medium to high Ag, Sb, and As; high Ni: nos. 1, 2, 8, and 11.

Group IB Medium to high Ag, Sb, and As; medium Ni: nos. 4, 5, 7, and 10.

Further subdivision cannot be inferred from this analysis (3).

The last procedure is the SAM *Materialgruppen* (Junghans *et al.* 1968, SAM 2:2, Tabelle 1, modified in Sangmeister 1973, 215). The SAM project has been the subject of much criticism (Butler & van der Waals 1964; Waterbolk & Butler 1965; Boomert 1975), with some recent attempts to rehabilitate aspects of this ambitious analysis programme (Härke 1978; Pernicka 1984) (4). Apart from being criticized for having a non-archaeological point of departure for the statistical classification of the raw analysis data (5), SAM is criticized for the statistical procedures, that resulted in no less than twenty-nine *Materialgruppen* and four residual groups. As admitted by Sangmeister (1973, 215) and further demonstrated by Boomert (1975, figs. 1–5) some of the *Materialgruppen* are so closely related that there is hardly any point in keeping them separate. This may particularly be the case where separation is due solely to differences in the content of Bi. The dispersion of Bi is, apparently, not constant within an object of copper or bronze (Slater & Charles 1970; Härke 1978, 194, but contradicted by Sangmeister & Otto 1973, 217ff; cf. Pernicka 1984, 522–524). Another problem appears to be some ten, less distinctly defined, mainly minor classes of copper (Boomert 1975, 137). On this background the classification of the Skeldal metal analyses into the *Materialgruppen* of SAM could be anticipated with scepticism.

However, the outcome (6) is quite in accordance with the results of the two preceding procedures. The only difference is that Group IA is subdivided into two groups, *Materialgruppe* A and A1 on the basis of a slight difference in the Bi value. As mentioned above the significance of minor variations in Bi has been questioned, and we shall therefore ignore this subdivision as recommended by Sangmeister (1973, 215).

It might have been expected that the use of three different statistical procedures would expose somewhat different metal groups, but the results have proved to be concordant to a very high degree (7) (fig. 4). There can, thus, be no doubt that the principal groups I, II, and III, and probably also the subgroups IA and IB, are significant. The result of the classification is displayed in a Waterbolk-Butler histogram (fig. 5).

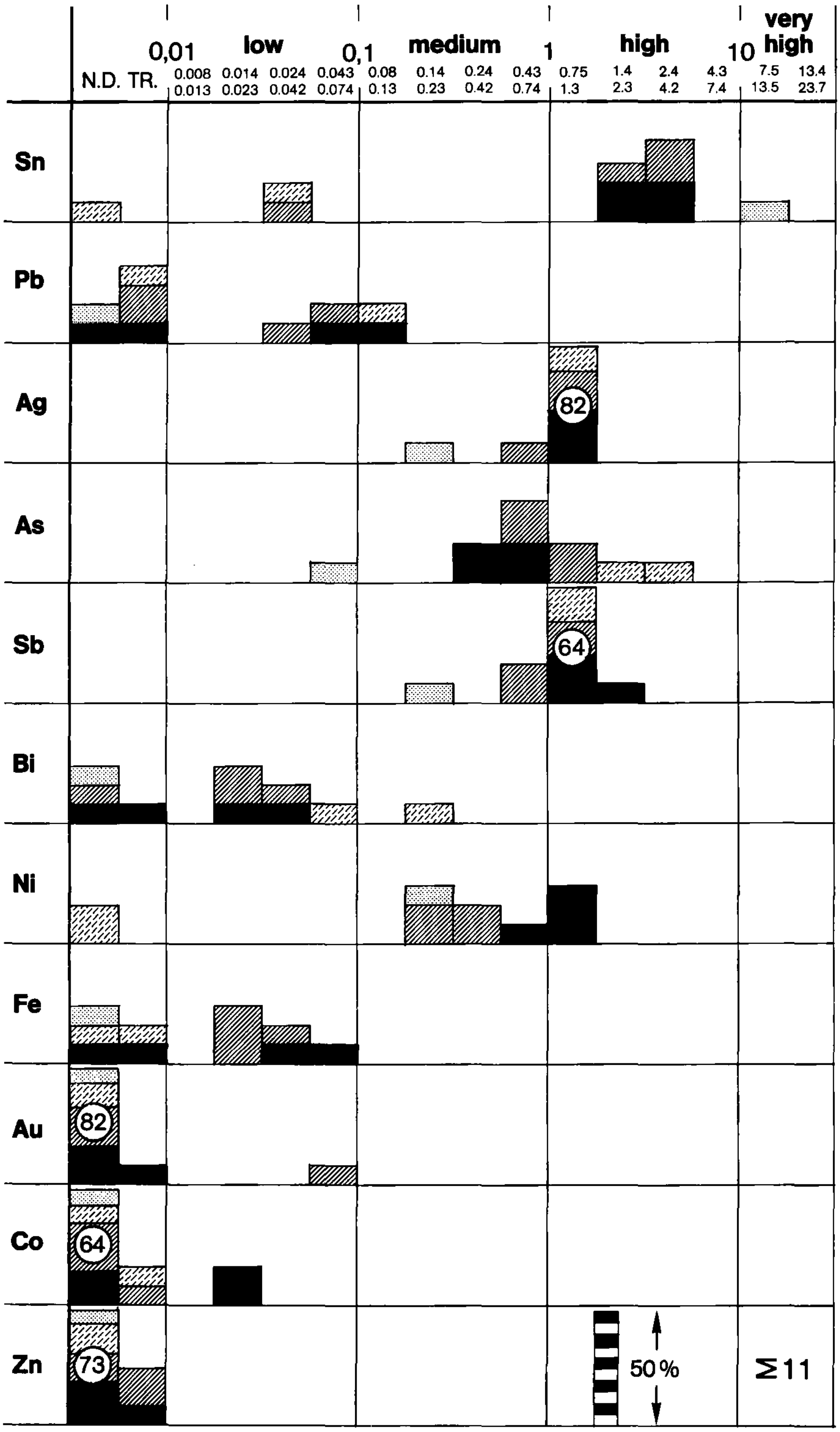

Fig. 5. The final four metal groups of the Skeldal hoard, illustrated in a Waterbolk-Butler histogram. Columns above 50% are marked. Symbols: black = Group IA, obliquely hatched = Group IB, oblique strokes = Group II, dots = Group III.

A modified version of the *Materialgruppen* of SAM 2 (cf. Sangmeister 1973, 215; Boomert 1975, figs. 1–5) will be employed in the remainder of this study, as they can be considered sufficiently reliable and accurate for a general survey. Besides, when comparing many different copper types in time and space the SAM *Materialgruppen* are extremely useful, due to their conciseness and brevity.

THE SKELDAL METAL ANALYSES IN A WIDER PERSPECTIVE

Even a superficial examination of the relationship between morphological types, metal types, and tin content in the Skeldal hoard demonstrates a high degree of correlation (fig. 6): The two *Noppenringe* fall into the same group, IA. The box and its lid have been made from the same type of metal, Group IB. The spiral armring and the open solid-cast ring are morphologically and functionally related, Úněticean imports, and they both belong to metal group II and contain little or no tin. The trapezoidal flanged axe, the only object of west European affinity in the hoard, falls in Group III and is the only medium tin bronze. These observations will now be discussed in a wider context, particularly in terms of chronology and intercultural relations, treating the copper types and the tin content separately.

analysis no.	type of object	group IA (Materialgruppe A)	group IB (Materialgruppe B2)	group II (Materialgruppe C2c)	group III (Materialgruppe FG)	tin class
1	Noppenring	●				4
2	Noppenring	●				4
8	small parallelsided-curved flanged axe	●				3
11	butt part of a flanged axe	●				3
4	beehive-shaped box		●			4
5	lid of the box		●			4
7	double-edged chisel		●			2
10	large parallelsided-curved flanged axe		●			4
3	spiral armring			●		1
6	open solid-cast ring			●		2
9	trapeze-shaped flanged axe				●	5

Fig. 6. The relationship between object types, metal groups, and tin content in the Skeldal hoard.

1. Copper types

The composition of early copper objects undergoes a general development from almost pure or relatively pure copper in the Neolithic periods to highly impure copper in the early Bronze Age (Butler & van der Waals 1967, 56, 57ff; Junghans *et al.* 1968, SAM 2:1, 32, SAM 2:2, Diagram 2). This most likely reflects a transition from native, oxide, and carbonate ores to sulphide ores, including the grey ores or *Fahlerz* (Sherratt 1976, 570, 577ff). In the central European *Materialgruppen* of SAM 2 (SAM 2:2, Diagram 2), there are systematic shifts through time, which are of obvious relevance for the study of the chronological development of copper and bronze objects. At the transition to Br.A1 the purer copper types like E00, E01a/E01, and E10 have been replaced by medium to high impurity copper like A/A1/A2, B2, C2D/C5, E11A–B, and C2/C2A–C, and these coppers give way to the medium impurity coppers FA and especially FB1–2 at the end of the early Bronze Age. A similar change in coppers occurs in the Danish material, a fact that has not been systematically exploited.

A brief description of the development of Danish metal types follows, based on the new chronology of early Danish metal objects (fig. 1).

In the Early and Middle Neolithic Periods (EN–MN) metal objects were manufactured in low impurity coppers, first and foremost E01/E01A, secondarily E00 and E10. In the early part of the Late Neolithic Period (LN I) the preferred metal types are medium to high impurity coppers like FA, FB1–2, A/A1/A2, and C2D/C5, relating the manufacture of metal objects to the succeeding periods rather than the preceding ones (Vandkilde 1989, 34ff; 1990b, 186ff). Whereas the separation between Periods EN–MN and LN I is due to a metal-analytical-typological classification of especially flat axes (Vandkilde 1989, 34ff), later periods have been separated on purely archaeological criteria. Thus, the metal analytical transition between the EN–MN and the LN I is possible not quite as clear-cut as indicated above.

In the LN II Period the local production is characterized by the high impurity coppers A/A1/A2, B2, and

C2D/C5, which constitute the three dominating *Materialgruppen* (fig. 7A).

In Period IA of the early Bronze Age the B2 group is still the most frequent, and the A groups are only reduced a little, whereas C2D/C5 has almost disappeared (fig. 7B). The mutually related medium impurity copper types FA, FC, and especially FB1–2 constitute a new and prominent group of coppers (8).

In Period IB of the early Bronze Age the FB1–2 copper has become absolutely dominant, and the only other metal of some importance is the FA group (fig. 7C). It is a general tendency that the use of copper types becomes increasingly standardized through time, particularly from Period IA to Period IB (figs. 7A–C). A similar development characterizes the alloying practices (see below).

Liversage arrives at a quite different picture of the changes in metal supply from the Late Neolithic Period to Period I of the Bronze Age (Liversage 1989, 52ff; Liversage *et al.*, 1989, 56ff). In the younger part of the Late Neolithic Period he defines two types of metals, "Singen metal", which approximately corresponds to *Materialgruppe* A/A1/A2 and B2 of the SAM system, and "Ösenring metal", which approximately corresponds to *Materialgruppe* C2/C2A–C and C2D/C5. According to Liversage, the "Singen-metal" and the "Ösenring-metal" are completely replaced by a new copper type, FAARDMET, approximately corresponding to *Materialgruppe* FB1–2, at the beginning of Period I. Liversage is, thus, in favour of a very clear-cut change instead of the gradual change, which is proposed here.

The gradual change with Period IA as a transitional, metallurgical phase is, however, supported by the evidence of all the metal analysed, closed finds, Virring, Tinsdahl, and Torsted (8a), and by the many singly found objects attached typologically to these key finds of Period IA. Whereas the coexistence of the two *Materialgruppen*, B2 and FB1–2, during Period IA can be considered certain, it is interesting to note that the Period IB hoard of Bagterp (cf. Vandkilde 1990b, 180) belongs exclusively to *Materialgruppe* FB1–2 (SAM 2:3, 8496–8499). The two analysed

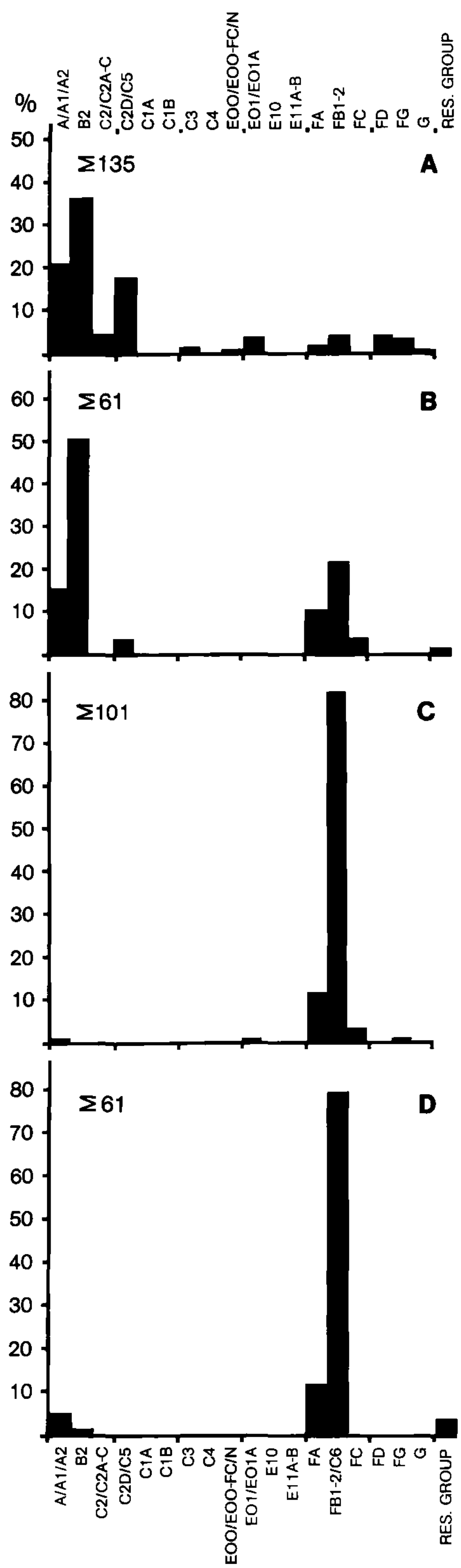

Fig. 7. The frequency of SAM 2 *Materialgruppen* within archaeologically defined periods and groups in Denmark. (Data primarily from Cullberg 1968, catalogue). A. Locally made metal objects (mainly flanged axes and halberds of south Scandinavian type) of the LN II Period. B. Locally made metal objects (mainly flanged axes) of Period IA. C. Locally made metal objects (mainly flanged axes) of Period IB. D. Locally made shafthole axes of type Fårdrup.

axes from Virring both belong to *Materialgruppe* B2 (SAM 2:3, 8500–8501), and three of the four recently analysed axes from Torsted belong to *Materialgruppe* B2, whereas the fourth belong to *Materialgruppe* FB1–2. The axe from Tinsdahl belong to *Materialgruppe* FB1–2 (Otto-Witter 1952: z1137).

A sample of 37 of the most typical of the flanged axes of type Torsted-Tinsdahl and Virring, which characterize Period IA, gives a similar result: 59% are assigned to *Materialgruppe* B2, 22% to FB1–2, and 19% to A/A1/A2 and FA. Moreover, it must be stressed that these Period IA objects are all full tin bronzes (see below), so that a typological and chronological mixture with LN II objects in the analysis is unlikely to have taken place.

If the closed finds and the singly found objects of Period IA are classified according to the metal groups of Liversage as first defined (Liversage 1989, 53), the results are identical. If his later definition is applied (Liversage *et al.* 1989, 67), the FAARDMET is a little more prominent than indicated above. One analysis from Virring and one from Torsted belong to "Singen metal", one analysis from Virring and three from Torsted and the one from Tinsdahl belong to FAARDMET. In the sample of 37 flanged axes of type Torsted-Tinsdahl and Virring, 51% join the "Singen metal", 43% FAARDMET, and the rest is ungrouped.

It is evident that the Danish development in metal types runs parallel to that of central Europe (compare fig. 7A to fig. 8A and 8B, fig. 7B to fig. 8C and 8D, and fig. 7C to fig. 8E).

This observation supports the recently published comparative chronology, which was based alone on archaeological data (fig. 1). Moreover, the parallel development indicates that the copper and bronze used in Denmark during these periods predominantly originated in central Europe. This suggestion is not contradicted by the Danish early metal objects, which are in general typologically tied to the current central European style.

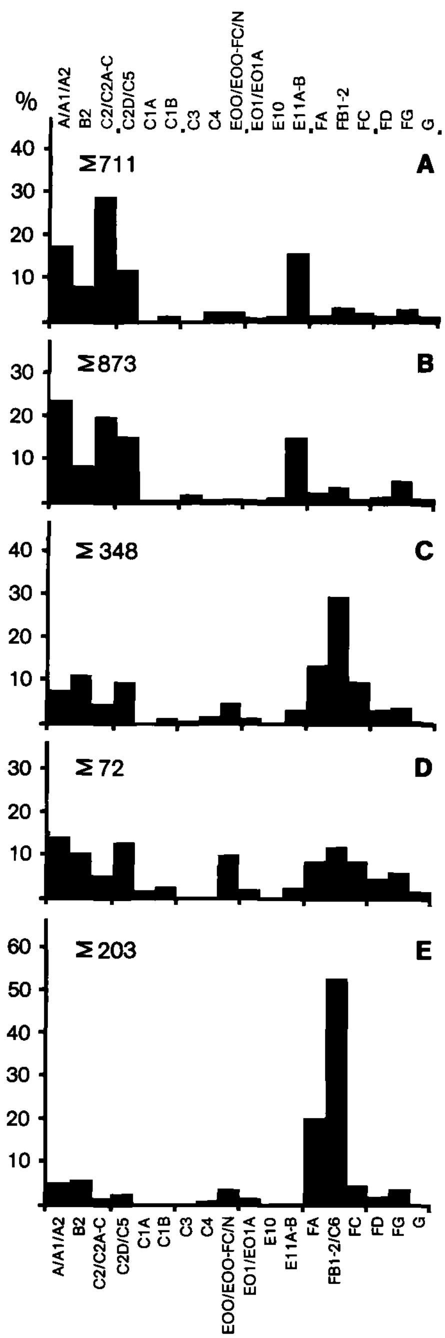

Fig. 8. The frequency of SAM 2 *Materialgruppen* within archaeologically defined periods and regions of central Europe. (Data from SAM 2,2: Tabelle 2, row no. 9a–b (excl. possible Úněticean objects), row no. 10b, 13, 14, and 17; Sangmeister 1966, Abb. 2, Tab. 2: phase 4). A. Southeast central Europe in the early and middle part of the early Bronze Age, Br.A1 (= approximately the LN Period in Denmark). B. The north Únětice culture and its Baltic periphery (north Bohemia, central Germany, Silesia, Brandenburg, Mecklenburg, Pomerania) in the classical phase of the Únětice culture, Br.A1b (= the LN II Period in Denmark). C. Southeast central Europe in the late part of the early Bronze Age, Br.A2 (= Period IA in Denmark). D. Central Germany and north Bohemia in the post-classical phase of the Únětice culture, Br.A2 (= Period IA in Denmark). E. Central Europe in the middle Bronze Age, mainly the early part of the Tumulus culture (= partly Period IB in Denmark).

In order to illustrate further the dating potential of metal analysis we shall look briefly at the locally manufactured shafthole axes of Fårdrup type. The find contexts of the Fårdrup axes do not allow a more accurate date than to period I in general (Lomborg 1969, 96ff; Vandkilde 1990b, 181), but on stylistic criteria Lomborg has dated them to early Period I, his "Fårdrup phase". The pattern of metal types of the Fårdrup axes is, however, almost identical to that of the local production of Period IB (figs. 7C and 7D), suggesting a position primarily within this period. It has been shown elsewhere, that Lomborg's Fårdrup phase is not confirmed by a study of the closed finds of period I of the Bronze Age (Vandkilde 1989, 29ff; 1990b, 178ff).

The metal analyses do not contradict the archaeological description of the *Skeldal hoard* as a chronologically homogeneous find, typologically related to the classical Únětice culture of central Europe. It fits perfectly into the pattern of metal groups that characterizes the LN II Period (figs. 6 and 7A). The presence of copper A/A1/A2 and B2 makes a position within the Period IA possible, but such a date is unlikely due to the *Materialgruppe* FG and C2/C2A–C, which are rarely found in later periods. C2/C2A–C is rather uncommon in the local production of the LN II Period, but it is frequently found in contemporary central Europe (figs. 8A–B), where it is sometimes called *Ösenring* copper, because around three fourth of all objects assigned to this metal group are neckrings and neckring ingots (cf. Butler 1979, 353, graph IV; Liversage *et al.* 1989, 60ff). In a general way the cultural attachment of the Skeldal hoard to the classical Únětice culture is confirmed by metal analysis, as the dominating metal types, A/A1/A2, B2, and C2/C2A–C, are the same (figs. 6 and 8B). Only the FG copper type of the trapezoidal axe occurs rarely in the Únětice culture (fig. 8B), and the FG-metal appears to be more common in the Anglo-Irish region than anywhere else (Junghans *et al.* 1968, SAM 2, 2, Diagram 11). Perhaps this allows for suggesting an Anglo-Irish origin for this metal type. At least it would be in harmony with the overall west European style of the axe and its high tin content, both of which set it apart from the rest of the objects in the hoard.

2. *Tin content*

The tin content of copper and bronze objects in the early European metal age undergoes a systematic change through time, as do the metal types. This development of tin content is illustrated in fig. 9. The six tin classes used here simplify the twelve tin classes of Spindler (1971, 207, 250f), with the addition of a tin-free class. The hardness (HV) of each class is given according to Tylecote (1986, table 16; 1987, table 7.1, fig. 7.4), and it pertains only to the effect of the tin, not to the various impurities (9).

Class 1: tin-free copper. The hardness of pure copper is in the cast condition c. 40, and when it has been worked and annealed c. 45. After having been work-hardened by 50% reduction in thickness, the hardness has risen to 120. Tin class 1 is associated mainly with pure and low impurity copper.

The succeeding tin classes 2–6 are typically associated with medium and high impurity coppers.

Class 2: copper with tin present as an impurity (trace-0.126%), either in the copper itself or in the arsenic that may have been added. Hardness approximately as class 1.

Class 3: tin copper (0.127–2.0%); the tin may not have been added, but may be present as a result of remelting and thus mixing of discarded copper and bronze objects as argued by Spindler (1971, 250f). He suggests, that this class will be found primarily in regions at some distance from naturally occurring ore (*op.cit.*) – at least in the initial period of tin bronze technology, where tin bronze has not yet become standard. Each remelting means c. 0.5% reduction in the tin content (J. P. Northover pers. comm.). An object with 2% tin has a hardness of 50 in the worked and annealed state and of 140 when work-hardened by 50% reduction in thickness. The effect of 2% tin is, thus, relatively limited compared to copper of class 1 and 2.

Class 4: low tin bronze (2.01–4.00%) may likewise be a result of mixing objects of copper and bronze, or the tin may be an addition. A tin value of 4% will raise the hardness of a worked and annealed object to 60, and to 165 when work-hardened. It is, thus, within this tin class, that the functional advantage of tin bronze becomes clear.

Class 5: medium tin bronze (4.01–7.95%) is mainly copper with tin as an alloying addition. A tin value of 6–8% will raise the hardness to 65–70, when worked and annealed, and to as much as 185–210 after work-hardening. The effect is thus very clear.

Class 6: high tin bronze (7.96–>10%), where tin has been added to the copper. A tin percent of 10% results in a hardness of 80 before work-hardening and 230 after work-hardening. When around 16% tin is added, the metal becomes brittle when cold-worked.

In the Danish LN I Period the copper objects belong primarily to tin class 1 and 2, whereas earlier copper objects are predominantly attached to class 1 (Vandkilde 1989 and 1990b, Figs. 10B–C). In the Danish LN II Period the tin classes 2 and 3 dominate the local production, but also class 4 and especially 5 are quite important (fig. 9A) (10). In general, the tin pattern of the LN II

Period is comparable to that of contemporary central Europe (figs. 10A–B), with the closest resemblance to areas where tin does not occur naturally. In Period IA the picture has changed completely (fig. 9C); now medium and high tin bronzes are absolutely dominant, and this is even more true in Period IB (fig. 9D). This reflects the central European situation, where tin bronze has become standard from Br.A2 onwards (Spindler 1971, Diagram 1, 3 and 5).

Compared to the Late Neolithic Period we are in Period IA dealing with a standardized alloying practice, which agrees well with the tendency to less variation in metal

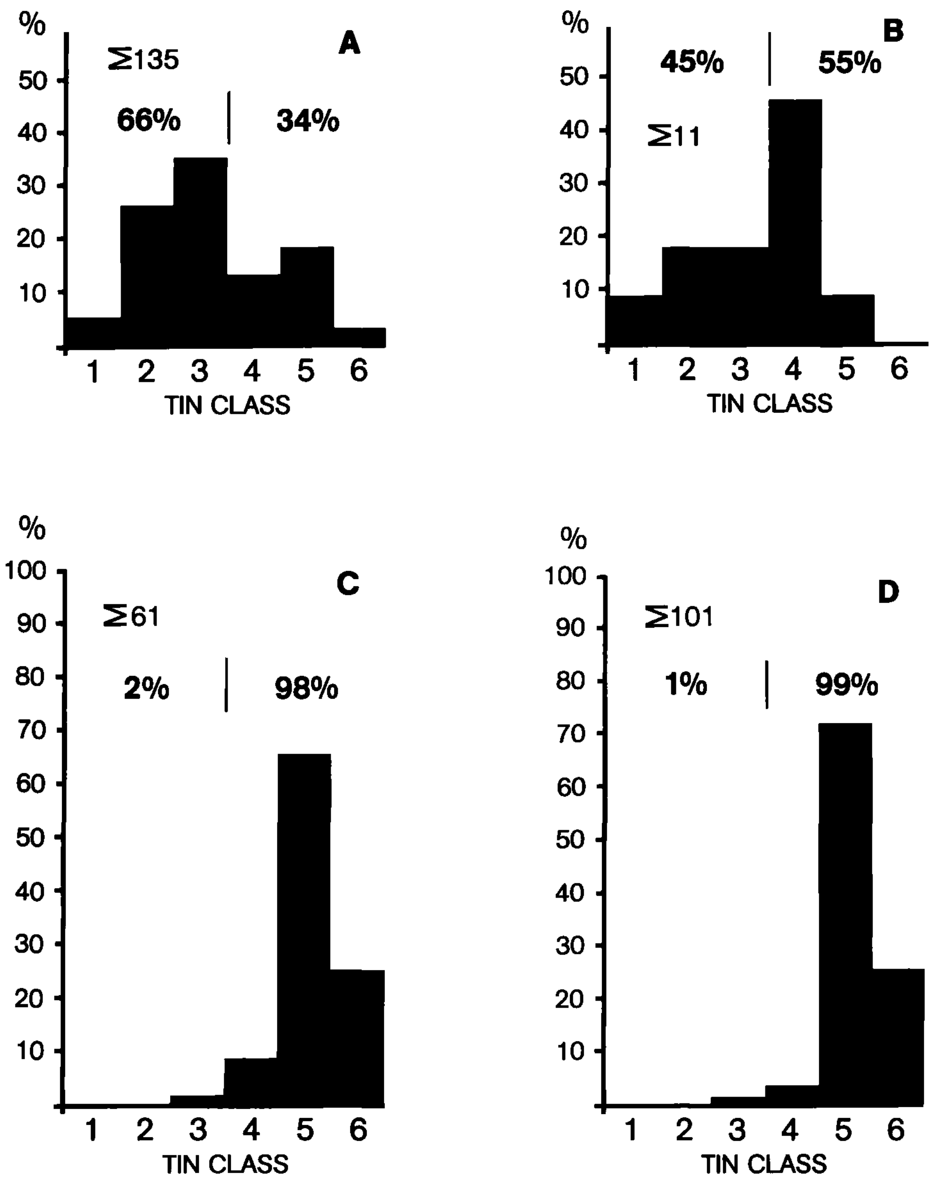

Fig. 9. The distribution of tin in Danish metal objects within archaeologically defined periods and groups. (Data from SAM 2,3 and 2,4; Cullberg 1968, Catalogue; Appendix). A. Locally made metal objects (mainly flanged axes and halberds of south Scandinavian type) of the LN II Period. B. The bronze and copper objects of the Skeldal hoard. C. Locally made metal objects (mainly flanged axes) of Period IA. D. Locally made metal objects (mainly flanged axes) of Period IB.

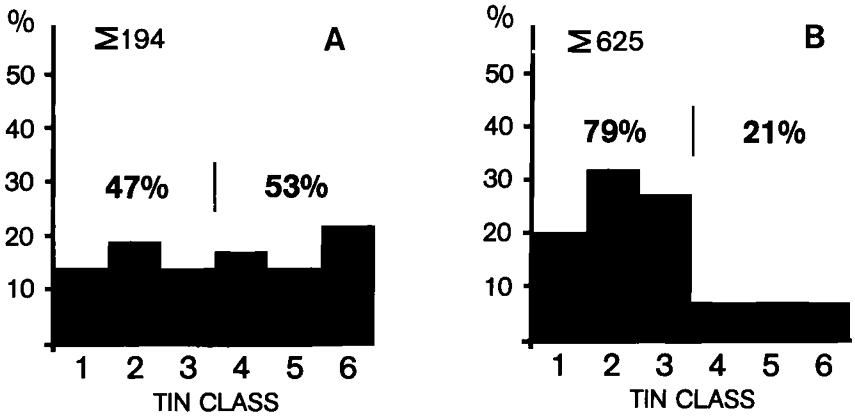

Fig. 10. The distribution of tin in Úněticean metal objects. A. The classical Úněticean centre at the Unstrutt-Saale in Thuringia. B. The periphery of the Unstrutt-Saale classical Úněticean centre, i.e. the regions of north Bohemia, Spree-Neisse, Riesa-Dresden-Bautzen, Berlin-Brandenburg, and Mecklenburg-Pomerania (data from SAM 2,3 and 2,4; Otto & Witter 1952 and Breddin 1969).

composition, that becomes evident in Period IB (figs. 7B–C). It is still an open question whether the Danish local production of bronze objects in Period I is based on separately imported tin and copper, or the result of remelting tin bronze objects of central European origin. Till now, specialized ingots are unknown in the Danish material from the earliest Bronze Age. A comparison of the tin patterns in Denmark and central Europe may, however, throw some light on this problem. In central Europe the high tin bronze (7.96>10%) is more common than medium tin bronze (4.01–7.95%) – in contemporary Denmark it is the opposite. As the concentration of tin is reduced during the process of remelting, this might perhaps suggest that the Danish local production depends on remelting of imported, tin bronze objects rather than importing ingots of copper and tin.

The introduction of the FB1–2 copper type at the beginning of Br.A2, c. 1700 B.C. coincides with a standardized use of medium and high tin bronze in most areas. According to Waniczek (1986, 130) a homogeneous tin level indicates that metallic tin was used. With reference to archaeological finds Roden (1985, 50–57) also suggests the use of metallic tin. This is in agreement with Tylecote (1987, 143), who maintains, that the close control exercised in tin composition in the Bronze Age suggests the use of metallic tin rather than cementation with tin oxide under reducing conditions. Charles (1975, 22f), however, believes, that the latter method was used throughout the Bronze Age, as tin appears to be difficult to refine. Further analysis should examine these two methods more carefully and consider whether there is a transition from tin oxide cementation to addition of metallic tin around the beginning of Br.A2, as may be indicated by the development from a highly variable tin content to a standardized high tin level.

The tin values of the *Skeldal hoard* are given in fig. 9B, and they show a good resemblance to the tin level of the LN II Period (fig. 9A), whereas there is no similarity to Period IA. The date achieved archaeologically of the Skeldal hoard is thus confirmed by the tin analysis as well as by the composition of its copper. Correspondingly there is good correlation with the tin level of the Únětice culture (figs. 10A–B).

METAL ANALYSIS OF THE SKELDAL GOLD RINGS

Most Danish Bronze Age gold has been analysed and published by Hartmann in SAM 3 and 5 (1970, 1982; cf. Thrane 1985 and Hartmann 1987). The analysis method is the same as used in the SAM analysis program of copper and bronze objects, i.e. optical emission spectroscopy. The two golden *Noppenringe* from Skeldal were analysed by the Oxford laboratory using electron probe microanalysis. Additional comparative material from Great Britain, Ireland, and France is found in Taylor 1980 and Eluère 1982.

From a Danish point of view the closest gold resources are found in the Erzgebirge between Saxony and Bohemia and in Great Britain and Ireland. More distant, there is gold in the southern part of Bohemia, Slovakia, Siebenbürgen, France, and Switzerland (Tylecote 1987, fig. 3.6; Coles & Harding 1979, fig. 3). Gold occurs mainly in the native state and is easy to locate because of its lustrous appearance. It does not demand the same technological skills of the smiths as copper and copper-base alloys, because it can be hammered into shape without annealing, and it was presumably the first metal known to man (Coles 1981, 96f; Tylecote 1986, 1f). Consequently gold working may be found in societies that do not yet master copper technology or are in the process of developing a copper technology. This is probably how we should understand the group of Danish gold sheet ornaments, lunulae and the closely related ornaments with oar-shaped ends (11). They most likely belong to the LN I Period and may have been made in Denmark (Vandkilde 1989, 38, fig. 12; 1990b, 190f, Abb. 12), probably from different sources of west and central European gold (Vandkilde in preparation). In the LN II Period and Period IA less gold is in circulation, and none of the objects, all Noppenringe, seem to be locally manufactured. In Period IB the first "ring gold" appears with other kinds of gold ornaments, for instance the *Lochhalsnadel* from Buddinge, County of Copenhagen (Lomborg 1969, 101ff, 107). The pin from Buddinge has presumably come from the Danubian region in the earliest part of the Tumulus Period. A Tumulus culture origin for the bulk of the "ring gold" of the Danish early Bronze Age does not seem unlikely.

Neolithic and early Bronze Age gold is close to natural gold in composition and was less frequently than later gold alloyed with other materials. Occasionally copper seems to have been added to the EBA gold, probably to counter the whitening effect of the silver content (Tylecote 1986, 2ff; 1987, 72ff), or to make the precious gold last longer. Technologically this would offer no difficulty, as we are now well within the age of copper. Hammering is more frequent than casting in the early production of gold objects, implying that mixing of gold of various origins may have been practised less often than is the case with contemporary copper. On the other hand, the composition of the elements present in gold apparently varies less than in copper. There is nevertheless some variation in regard to time as well as space, as demonstrated by Hartmann, Taylor, and Eluère, which may be of use archaeologically.

Apart from the Skeldal *Noppenringe*, four other gold *Noppenringe* are known from Denmark. Of the six gold rings, four constitute pairs. Archaeologically they cover

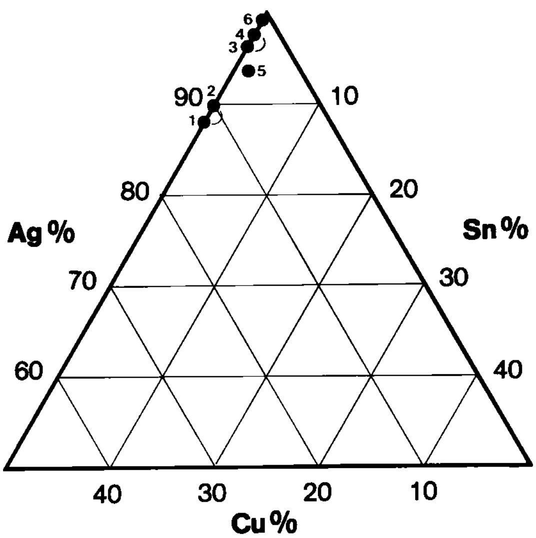

Fig. 11. Triangular proportional plot of Danish gold *Noppenringe*. Those found together have been connected. (Data from Hartmann 1970 and 1982) (12).

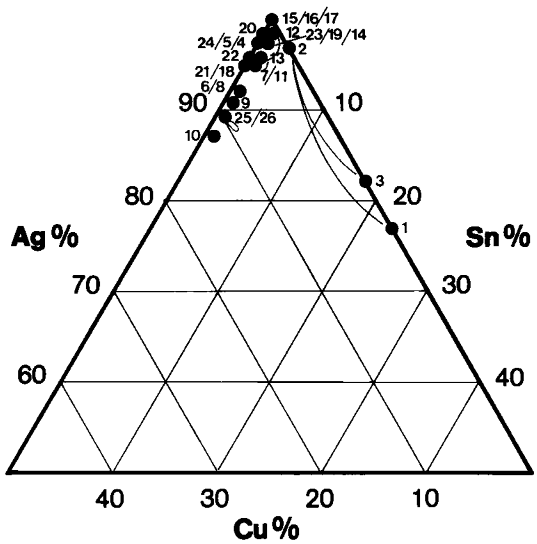

Fig. 12. Triangular proportional plot of central European EBA gold objects, primarily *Noppenringe*. Those found together have been connected. (Data from Hartmann 1970 and 1982: nos. 5, 24 from central DDR, nos. 6–10, 19–20, 23, 25–26 from north Bohemia, nos. 14–18 from southwest Slovakia, nos. 1–4, 11–13 from Bavaria and no. 21 from Siebenbürgen) (14).

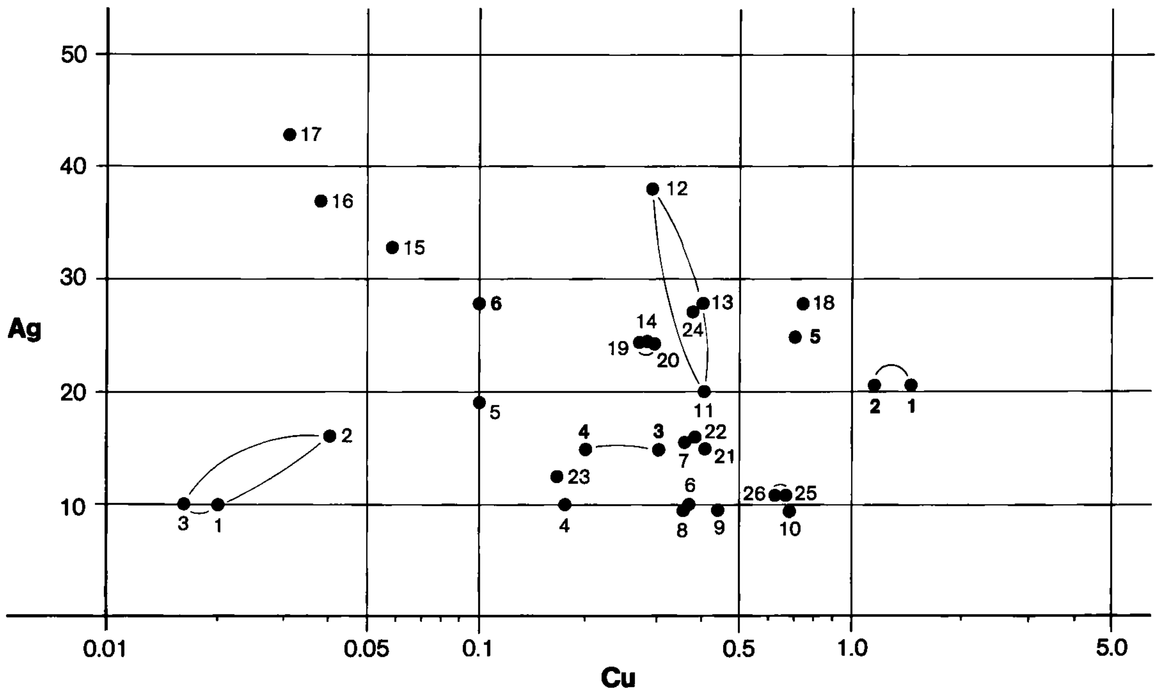

Fig. 13. Semi-logarithmic plot of Danish gold *Noppenringe* (bold numbers 1–6) and central European EBA gold objects, primarily *Noppenringe* (weak numbers 1–26). Objects found together have been connected. See fig. 11–12 for the corresponding triangular plots. (Data from Hartmann 1970 and 1982) (12), (14).

the timespan LN II – Period IA, and they belong to two different types. The large, simple ring with one end twisted, found in the Skeldal hoard, has been described earlier (Vandkilde 1990a, 120f). The other type is much smaller, more complicated, and contrary to all other types of *Noppenringe* it is open in front (cf. Lomborg 1973, fig. 84B). Quite possibly the Skeldal type of *Noppenringe* belongs primarily in the LN II Period, whereas the small frontal type may belong to Period IA (12). Both types of *Noppenringe* have exact counterparts in the central European early Bronze Age, and doubtlessly they were manufactured there. They are different from later gold rings, though the large *Noppenring* may be confused with the "ring gold" of later periods. The latter ring type, however, is always without twisted end.

In order to see if the archaeological evidence was supported by metal analysis, the analytical data (from Hartmann 1970 and 1982) of different archaeological groups were plotted into two kinds of diagrams, introduced by Taylor to describe the British, Scottish, and Irish gold (1980, 17). Whereas the triangular proportional plot describes the relative proportions of the three main elements of prehistoric gold, Ag, Cu, and Sn (13), the corresponding semi-logarithmic plot includes the absolute values of Ag against Cu, as a control of the triangular plot. Such diagrams are easier to read than the statistical system employed by Hartmann (1970, Diagram 3 ff; 1982, Diagram 1ff).

To judge from the triangular proportional plots (figs. 11–12) the composition of the six Danish *Noppenringe* is very similar to the composition of central European *Noppenringe*. The silver content is high, the copper value low, and tin is absent or nearly so. In a general way, the distributions confirm the archaeological evidence concerning location in time and space. The affinity between the two diagrams (figs. 11–12) is in fact surprising as the central European gold rings come from many different regions and therefore presumably many different sources of gold. The more scattered picture appearing on the corresponding semi-logarithmic plot (fig. 13) probably reflects these geographical differences. The amount of analysed gold from the central European early Bronze Age is, however, too limited to infer the exact place of origin for the Danish rings. The scattered appearance of

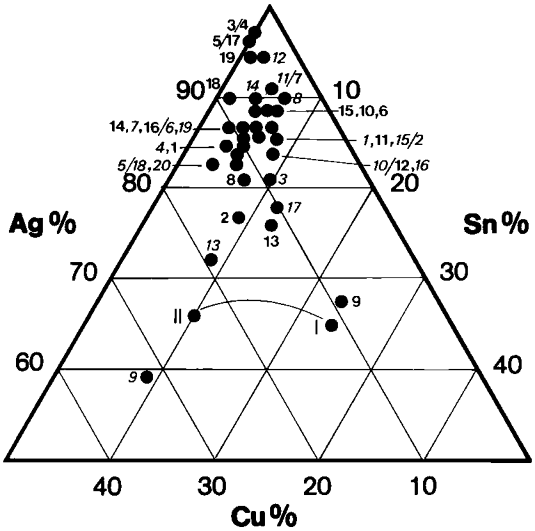

Fig. 14. Triangular proportional plot of Danish spiral rings of doubled-up gold wire, "ring gold" of Period II (bold numbers 1–19) and Period III (weak numbers 1–20) of the early Bronze Age. The spiral and the pin (I–II, connected) from the Period IB burial at Buddinge are included. (Data from Hartmann 1970 and 1982) (15).

the latter diagram indicates that they originate in different parts rather than one part of central Europe. Pairs of rings are very close to each other in the plots, suggesting that they are produced in pairs of exactly the same raw material.

An origin for the gold in the Anglo-Irish region is excluded by the absence of tin or extremely low tin level in the six Danish *Noppenringe*. Apparently this is typical of central European EBA gold (fig. 12), whereas tin is present in most contemporary British, Scottish, and Irish gold (Taylor 1980, figs. 14–15, figs. 22–23). Tin in gold indicates, that the gold was collected from tin-bearing areas (Tylecote 1987, 79), which are much more numerous in Great Britain than on the Continent. In regard to later central European gold, the presence of tin in the gold may be due to alloying with copper containing tin, or to the collection of gold in tin-bearing areas, first and foremost the Erzgebirge.

The copper content of the Skeldal rings is above the level found in the other central European EBA ornaments (fig. 13). According to Tylecote (1987, 74) natural gold rarely has values exceeding 1% Cu. Thus the Skeldal rings could have been made from alloyed gold.

The composition of "ring gold" from the Danish early Bronze Age is distinctly different from the *Noppenringe*. Around forty spiral rings made of doubled-up gold wire have been included in a triangular plot, fig. 14. They have either loops in both ends, or one end is open. The rings are very closely distributed in the uppermost part of the triangle, but the distribution is different from that of the *Noppenringe* (figs. 11–12), due to the tin value being markedly higher. It should indeed be possible to separate gold rings of a LN II-Period IA date from later rings solely by their metal composition.

Rings of Period II and Period III were entered into the diagram (fig. 14) separately, but there is no difference in

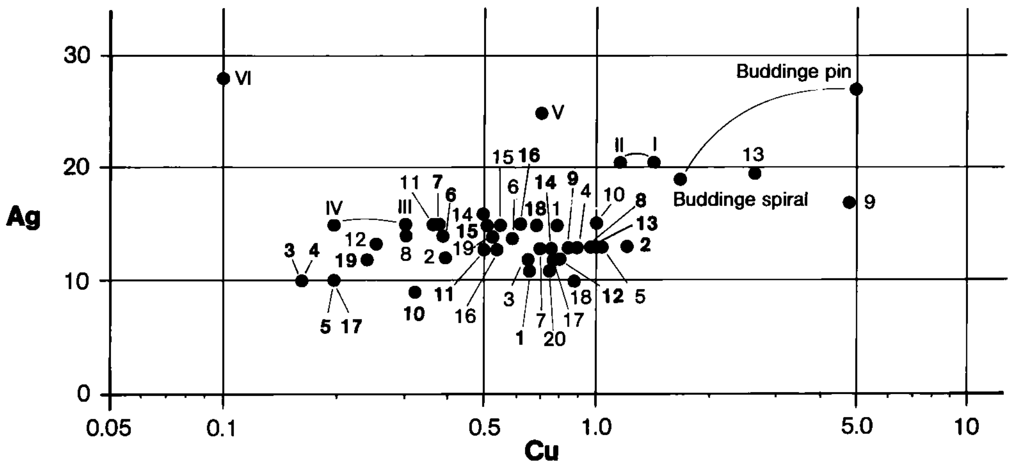

Fig. 15. Semi-logarithmic plot of Danish spiral rings of doubled-up gold wire ("ring gold") of Period II (bold numbers 1–19) and Period III (weak numbers 1–20) of the early Bronze Age. The spiral and the pin (connected) from the Period IB burial at Buddinge are included, as well as the six Danish gold Noppenrings (I-VI, pairs connected). See fig. 11 and fig. 14 for the corresponding triangular plots. (Data from Hartmann 1970 and 1982). (15).

the distribution. The *Lochhalsnadel* and its spiral from the burial at Buddinge have also been included. The deviating position in the plot compared to "ring gold" as well as *Nopperinge* (fig. 11) emphasizes the outstanding position of the Buddinge gold. Its supposed origin in the region of the middle Danube (Lomborg 1969, 101ff, 107) should be further examined by compositional comparisons with central European gold of Br.B1.

The corresponding semi-logarithmic plot (fig. 15) supports the above evidence. The "ring gold" is found within a small area of the diagram with a silver content between 9 and 18 and a copper value between 0.15 and 1.2, implying that the "ring gold" is made from natural, non-alloyed gold, with a few possible exceptions. There is no difference between the "ring gold" of Period II and Period III. The compositional homogeneity of the "ring gold" suggests, that it originates from a single resource, or at least related sources of gold within the same region. The presence of tin in the "ring gold" (fig. 14) may suggest, that the gold has been collected in the Erzgebirge near the tin deposits. The *Noppenringe* and the Buddinge gold have also been included in the plot (fig. 15), and the difference already noted repeats itself. The *Noppenringe* fringe the upper periphery of the "ring gold", whereas the *Lochhalsnadel* and the spiral from Buddinge are located towards the upper right. The latter gold has clearly been alloyed with copper, and the rather high tin value of the gold may imply that the added copper contained some tin. After all, these ornaments belong in the age of tin bronze.

In conclusion, the archaeological evidence is indeed reflected in the gold analysis, which besides chronology and origin may also be informative regarding the technique of early gold manufacture.

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APPENDIX

The Raw Metal Analyses of the Skeldal Hoard

An.no. NM.	object	Sn	As	Sb	Pb	Co	Ni	Fe	Ag	Au	Zn	Bi
1 B17061/1	*Noppenring*	3.51	0.39	1.39	0.05	–	0.76	0.03	0.92	–	–	tr.
2 B17061/2	*Noppenring*	2.92	0.59	1.08	–	0.02	0.73	0.05	0.79	tr.	–	–
3 B1762	armring	–	1.89	0.88	0.08	tr.	–	tr.	1.14	–	–	0.16
4 B1763	box	2.13	0.49	0.60	0.04	–	0.31	0.02	1.16	–	–	0.03
5 B1763	lid	2.76	0.79	0.93	tr.	tr.	0.31	0.03	1.07	–	tr.	–
6 B1764	solid ring	0.03	2.61	0.90	tr.	–	–	–	1.09	–	–	0.06
7 B1765	chisel	0.04	0.43	0.47	0.07	–	0.19	0.02	0.86	–	–	0.02
8 B1766	small axe	1.55	0.50	1.17	tr.	0.02	0.96	–	0.86	–	–	0.02
9 B1767	trapez axe	7.66	0.05	0.20	–	–	0.17	–	0.14	–	–	–
10 B1768	large axe	3.13	0.77	0.87	tr.	–	0.21	0.02	0.70	0.05	tr.	0.02
11 B1769	axe butt	1.38	0.41	0.94	0.08	–	0.98	tr.	0.88	–	tr.	0.03

The gold analyses	FE	Co	Ni	Cu	Zn	Bi	Sb	Sn	Ag	Pb	Au
1 *Noppenring* NM19/82	0.02	0.02	0.02	1.05	–	–	tr.	–	20.53	–	78.32
2 *Noppenring* NM19/82	0.03	tr.	0.02	0.90	–	–	0.02	–	20.54	–	78.48

NOTES

1. The Danish Research Council for the Humanities financed the metal analyses of the objects, which were carried out by Dr. J.P.Northover from The Department of Metallurgy and Science of Materials, University of Oxford. I am much indebted to D.Liversage and P.O.Nielsen, *Nationalmuseets 1. Afdeling* for support during the investigation, to J.P.Northover for advice in regard to alloying practices, to D.Liversage and T.Rehren for a critical review of an earlier draft of this paper, and to J.Kirkeby, who drew the diagrams and the tables. A complete publication of the chronology, on which this article is based, is being prepared. The manuscript was completed October 1990.
2. Apart from the Skeldal objects, a dagger and a flanged axe from the contemporary Vigerslev hoard (see this volume), sixteen copper flat axes, four halberds, one tanged copper dagger, and one early, presumably, Anglo-Irish axehead were analysed by the Department of Metallurgy and Science of Materials, University of Oxford, using electron probe microanalysis (EPM). In addition, the same group of objects, except those from the Skeldal hoard, were analysed by *Risø National Laboratory*, some of them twice, using energy-dispersive X-ray fluorescence (EDXRF) and induction-coupled plasma-mass spectroscopy (ICP-MS). A few of these objects had already been analysed by SAM, by optical emission spectroscopy (OES). This represents a rare opportunity to compare and evaluate a number of different methods and to discuss the problems of combining metal analyses from different laboratories (in preparation by J.P.Northover).
3. A triangular proportional plot of the relationship between Ni, Bi, and Sb was also attempted. Only the deviation of nos. 3 and 6 was clearly indicated. Since the proportional plot illustrates the relationship in percentages and not the real values, low impurity copper may actually group with high impurity copper!
4. See Boomert (1975, 134ff) for a summary of the critique of the SAM programme and Härke (1978, 226–241) for an evaluation of the classification methods of SAM and Waterbolk-Butler.
5. Härke (1978, 238) has pointed out that departing from an archaeologically defined group, as advocated by Waterbolk and Butler (1965, 230) gives similar results as a non-archaeological departure.
6. Nos. 1, 3, 5, 7, 8, and 11 could be classified directly, however, without being identical with the *Materialgruppen, nach den tatsächlichen Maxima der Verteilung* (Junghans *et al.* 1968, SAM 2.2, Tab. 1: lower horizontal column). Nos. 4 and 9 appeared to be slightly deviating in relation to the groups into which they were classified. Exact counterparts do, however, not exist to these analyses anywhere in the SAM system. These minor divergences are probably due to the fact that two different analysis methods are involved, OES and EPM (2).
7. Also Härke has pointed out that the classification systems of SAM and Waterbolk-Butler arrive at similar results. This appears to be due to the fact, that they belong to the same statistical family, the former being a mathematical analysis of frequency, the latter a graphical analysis of frequency (1978, 234ff, 236).
8. The heterogeneous assemblage of copper types in Period IA is not a simple reflection of contemporary central European conditions in Br.A2 (figs. 7B, 8C, and 8D). The arrival of the FB1–2 copper to Denmark may reflect a major shift in the supply of raw materials from the Úněticean to Alpine and Transsylvanian copper ores. This is in accordance with the archaeological evidence of increased contact with the east Alpine-Danubean-Transsylvanian region in Period I. The continued importance of *Materialgruppe* A/A1/A2 and B2 in Period IA may then reflect re-cycling of LN II metal, or a weakened flow of metal from the mines of the north Únětice culture, which is now rapidly loosing its former importance. In the mining areas the increasing importance of FB1–2 copper from Br.A2 onwards could possibly also reflect the development of new technical abilities to process uniformly a particular kind or related kinds of copper ore.

8a Also the hoard from Underåre has been metal analysed (SAM 2, 4: 11989–11991; FB1–2). Its exact chronological position within Period I is at present uncertain, and it has therefore been left out of consideration. The four metal analyses of axes from the Torsted hoard have recently been carried out by J.P.Northover from Department of Metallurgy and Science of Materials in Oxford, and they are unpublished.

9. Future examinations of early Danish alloying practice should consider other elements than tin. The impurities in the copper may together increase the hardness. The so-called "Singen metal" (Waterbolk & Butler 1965, graph 8–9; Butler & van der Waals 1967, fig. 27; Liversage 1989, graph 7), which is equivalent to *Materialgruppe* A/A1/A2 and a frequently used copper type during the main part of Br.A, is most often associated with tin class 2 and 3. However, this copper type and related types of coppers, for instance the frequent B2 copper, may be quite good natural alloys because of the high values of As, Sb, Ni, and Ag. In Danish metal objects the value of As very seldom exceeds 2%, and most objects contain between 0.5% and 1% As. This means, that arsenic is unlikely to have been added to the copper, but is present in the copper as an impurity (Tylecote 1987, 43). An As value of 0.25–2%, which is representative for the great majority of Danish early metal objects, will raise the hardness of a worked and annealed object to 68–85 and to 122–140 after work-hardening (Tylecote 1986, table 16; 1987, fig. 7.4). The effect is thus almost like the effect of tin, and the reason for preferring tin bronze may be that it is easier to control during the process of production.
10. The great variation in the Danish LN II tin levels raises more questions than can at the moment be answered: Does it reflect an unsatisfied demand for tin bronze, or does it reveal a lack of awareness in regard to the technical and functional advantages of different tin levels? Were other alloys, e.g. with As, able to compete with tin bronze? Was copper used primarily for prestige objects and tin bronze for tools? Or perhaps the other way around, because of the attractive, golden colour of tin bronze?
11. Some of the Danish gold sheet ornaments have evidently been made from gold alloyed with copper. These alloys could have been made anytime during the lifetime of the gold, and thus not necessarily in Denmark. Some of the Irish lunulae are also made from alloyed gold (Tylecote 1987, 79).
12. Danish gold *Noppenringe* referred to firstly by their numbers in the diagrams of this text (figs. 11, 13, and 15) and secondly by their Au-numbers in SAM 3 and 5: *1–2, OX/EPM:* the two Skeldal rings of the LN II Period. *3–4, Au 3291 and 4967:* A pair of small rings of the open, frontal type. Found with flint daggers of type I and IV, below a stone heap at the bottom of a mound, Tvillingegård near Nørre Snede, County of Skanderborg; there is no information on the

relationship between the objects (Broholm 1943 I, 23). *5, Au 4968:* Small ring of the open, frontal type from the latest burial in Brønhøj *Jættestuen*, County of Randers. The ring was associated with a pin with spherical, obliquely perforated head of an early type, datable to Br.A2. This burial superimposes burials containing flint daggers of type IV and V (cf. Lomborg 1973, 145–147). The gold ring is thus clearly datable to Period IA. Another ring of this type, but of bronze, is known from a cist burial at Søsum, County of Frederiksborg (*op. cit.*, fig. 85). This ring is associated with other metal objects of a general *Frühbronzezeit* character, and the burial superimposes a burial with flint daggers of type VA and VI, a combination that implies a date within Period IA for the daggers. Although stratigraphically later, the burial with the *Noppenring* probably also belongs to Period IA. The latest appearance of the frontal, open *Noppenring* in central Europe is a Br.B1 burial (Kibbert 1980, Taf. 68J), but this is most likely an exception. *6, Au 3431:* Small ring of the simple type with one end twisted. Single find from Hjelm, County of Præstø. Found close to a burial mound. The ring is smaller than the Skeldal rings, but belong to the same type.

13. The elements of the Skeldal gold included in appendix are weight percent of the total weight of the alloy. The SAM gold analysis, however, presents the values of Cu and Sn as weight percent of Au (= 100), a system used also by Taylor (1980). In order to make the data comparable, the Skeldal values of Cu and Sn were, therefore, changed according to the formula of Hartmann (1970, 20, note 23).
14. Central European EBA gold objects included in figs. 12–13: 1 = Au 3333, 2 = Au 3335, 3 = Au 3336, 4 = Au 5030, 5 = Au 4574, 6 = Au 182, 7 = Au 183, 8 = Au 184, 9 = Au 185, 10 = Au 186, 11 = Au 1330, 12 = Au 1331, 13 = Au 1338, 14 = Au 150, 15 = Au 151, 16 = Au 152, 17 = Au 153, 18 = Au 158, 19 = Au 189, 20 = Au 190, 21 = Au 261, 22 = Au 157, 23 = Au 188, 24 = Au 1814, 25 = Au 1487, and 26 = Au 1488.
15. Danish "Ring gold" from Period II-III of the early Bronze Age included in figs. 14–15. Period II (bold numbers 1–19): 1 = Au 3340, 2 = Au 3422, 3 = Au 3876, 4 = Au 3874, 5 = Au 3879, 6 = Au 3893, 7 = Au 3892, 8 = Au 3994, 9 = Au 3990, 10 = Au 4081, 11 = Au 4063, 12 = Au 4144, 13 = Au 4312, 14 = Au 3275, 15 = Au 3282, 16 = Au 3283, 17 = Au 3262, 18 = Au 3397, 19 = Au 3320. Period III (weak numbers 1–20): 1 = Au 3303, 2 = Au 3306, 3 = Au 3307, 4 = Au 3315, 5 = Au 3317, 6 = Au 3311, 7 = Au 3321, 8 = Au 3324, 9 = Au 3348, 10 = Au 3340, 11 = Au 3363, 12 = Au 3401, 13 = 3412, 14 = Au 3421, 15 = Au 3424, 16 = Au 3469, 17 = Au 3468, 18 = Au 3491, 19 = Au 3488, and 20 = Au 3489. Period IB gold from Buddinge: I = Au 3258 (the spiral), II = Au 3257 (the pin).

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