The Oedt sword: a note on brass and fire-gilding in the European Bronze Age

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ABSTRACT: The Oedt sword is one of three exceptional but disputed examples of fire-gilded metal objects in Europe dated to the Bronze Age. The sword has been re-investigated to determine its chemical composition and its method of manufacture. Metal analyses and X-ray computer tomography revealed a peculiar construction of the hilt, which is obviously a modern addition to the blade which is most likely of Bronze Age date.

Introduction

The history of gilding and especially of fire-gilding has been documented in numerous papers and books (*eg* Oddy 1993; Anheuser 1999; Oddy 2000; Wolters 2006). The technique of fire-gilding metals in Europe is well established from the Roman period onwards and there are also a few late Iron Age objects from different parts of western Europe which indicate that fire-gilding was practised then too (*eg* Oddy 1993, 180; Anheuser 1999, 15–16; Northover and Anheuser 2000, 111–112; Oddy 2000, 6; Wolters 2006). Examples of gilding from the European Bronze Age were made by mechanical inlays or by various coating techniques, but in all cases where the application of fire-gilding has been suggested, it is disputed.

At present there are two objects known in Europe with scientifically confirmed fire-gilded surfaces which are believed to date to the Bronze Age. These are a disc from Rathgall in Ireland and the metal-hilted sword discussed here (Fig 1). Both are clearly fire-gilded but their origins are unclear (Anheuser 1999, 15). Another Late Bronze Age sword from Rothenmoor in Mecklenburg-Western Pomerania (Germany) is reported to be fire-gilded, but the publications do not described how it was investigated (Driehaus 1968, 354; Wüstemann 2004, 242). The sword of the present study was reportedly recovered from the river Niers near Oedt in Westphalia (Germany), not far from the frontier with the Netherlands. The date of the discovery is uncertain but it must have been before 1947, when the sword came into a private collection. At that time the technique of fire-gilding was unknown on Bronze Age artefacts, and the story of the discovery of the sword seemed even more doubtful as other Bronze Age weapons, allegedly Nazi-replicas, appeared in the vicinity at the same time (Driehaus 1968, 329–330; Joachim 1977; Joachim and Weber 2002–3, 3).

Figure 1: The sword from Oedt. Overall length 440mm. CT measurements show the blade is 385mm long and 41mm wide.

Driehaus (1968) published a detailed description of the sword with photographs, radiographs, a drawing and semi-quantitative X-ray fluorescence (XRF) surface

Figure 2: The fire-gilded hilt is 99mm long. On both sides is a pattern of hatched triangles and ring-and-dot designs.

analyses of the gilded hilt (Fig 2). Emission spectroscopy and additional XRF analyses were apparently in progress when the paper appeared (*ibid*, 346). The detection of mercury seemed to indicate fire-gilding (*ibid*, 352) but the analytical results for the blade and the handle were never published, though Driehaus (1968) said that the first analyses suggested that the blade and the hilt were made of two different alloys. This fact did not seem unusual, as one might expect, because previous investigations (Driehaus 1961, 25–27) had indicated that composite swords with parts of different compositions were made during the Bronze Age. Since it was not possible to reconstruct the find circumstances, Driehaus (1968) discussed the possibility that the sword was a fake in some detail, but finally settled for a date for the sword in the early Middle Bronze Age. His dating of the sword was based on the decoration of the hilt with hatched triangles and a ring-and-dot pattern that resembles the 'Spatzenhausen' type and was accepted by several contemporary scholars, and has recently been confirmed (Joachim and Weber 2002–3, 13). However, both authors remarked that the Oedt sword was typologically only distantly related to other swords of this period and that the blade would fit better with earlier swords and daggers.

In fact the sword was, and still is in its published configuration, without any typological or technological parallel. Driehaus' main argument was based on the authenticity of the blade and assumed a simultaneous production of blade and hilt. A further but less important argument was the supposed fire-gilding on the hilt of the Late Bronze Age sword from Rothenmoor (Driehaus 1968, 354). However, in concluding that fire-gilding was applied to that object, Wüstemann (2004, 242) has recently referred to the Oedt sword as supporting evidence – a circular argument.

Today the Oedt sword is in the Rheinisches Landesmuseum in Bonn in North Rhine-Westphalia, Germany (Inv No 73.0570) as one of the highlights of the museum. In the archaeological literature it is not regularly referred to, though it does appear in more recent articles (Joachim and Weber 2002–3, 24; Wüstemann 2004, 242; Wolters 2006, 187).

The results presented by Driehaus were disputed by Oddy *et al* (1978, 230) and then ignored by him in his numerous papers on gilding in antiquity. Only in a more recent paper did Oddy (2000, 6) finally comment that European Bronze Age mercury gilding should be treated with caution.

Anheuser (1999, 15) re-investigated the hilt of the sword with an optical microscope and again suggested the application of fire-gilding. A more recent analysis by Hans Mommsen (nd), using PIXE, confirmed the presence of mercury in the gold. The fire-gilding of the hilt seems to be confirmed beyond doubt but this does not solve the principal problem which is the uncertain origin and consequently the dating of the sword.

The sword was in Mannheim in 2006 for an exhibition of the Sky Disc of Nebra and its setting in the Early Bronze Age. This offered the opportunity to sample the object and re-determine the composition of its components. After the exhibition new attempts were made to obtain more information about the origin of the sword.

Analytical methods

Three drilled samples were taken from the blade (FG-051081), the hilt (FG-051082) and the one gold rivet which was visible on the underside of the pommel (FG-051083) and thus thought to be a later addition

Figure 3: The pommel has seven rivets, one in the centre and six evenly spaced near the edge. One of these six rivets emerges on the underside and was therefore interpreted as a later addition. Sample FG-051083 was taken from this rivet.

(Fig 3; Driehaus 1968, 337 fig 10). The metal compositions were determined by energy-dispersive X-ray fluorescence analysis (EDXRF) as described by Lutz and Pernicka (1996).

To determine whether the hilt was made of recently-smelted metal the activity of ^{210}Pb was detected by α-spectrometry, using the α-emission of ^{210}Po ($t_{1/2}$ = 138.4 d) after separation of ^{210}Po by spontaneous deposition on nickel plates. Smelting disturbs the radiochemical equilibrium of the ^{238}U decay-chain. The ^{210}Pb nuclide decays with a half-life of 22.3 years after the removal of its lithophile parent nuclides U, Th and Ra. This means usually no radioactivity is measurable in metals older than about 110 years. The basic principles of this method are presented by Pernicka *et al* (2008).

The radiographs published by Driehaus (1968, 348–353) leave many details unclear and their technological interpretation casts even more doubts on the authenticity of the sword (see below). One of the radiographs (Driehaus 1968, 351) revealed that there are two small strips between the grip and the tang, made of a material with higher absorption than the metal of the hilt. New radiographs revealed some details but did not resolve all the questions, so it was decided to use X-ray computer tomography (CT) which was performed at the BAM Bundesanstalt für Materialforschung und -prüfung in Berlin (Goebbels *et al* 2004).

The tomograph that was used works with a micro focal X-ray tube (Feinfocus, 225kV, focal spot less than 10μm) and an amorphous silicon flat panel detector (2048x2048 pixels at (200μm)^2). The sword was turned in the conical beam of the X-ray tube and a multiplicity of slices could be measured using an area detector. The advantage is a homogenous spatial resolution for all three dimensions and a saving of time compared with conventional tomography which only measures single slices. Each matrix element of the three-dimensional image matrix is equivalent to a volume element (voxel). CT yields a measure for the absorbed X-rays averaged over one voxel, the material-dependent linear attenuation coefficient μ (cm^{-1}). These values are normalized to 250 values on a grey scale. Three different parts of the sword were imaged with the X-ray tube at 210 kV, 100 μA with a pre-filtering of 1mm of silver. Altogether1800 images (shadow graphs) over 360° were taken for one measurement. The integration time for each image was 12s for the pommel, 22s for the guard and 24s for the grip. Depending on the object diameter the spatial resolution (side length of a voxel) was 20–30μm.

Using the information obtained by CT some further samples were taken. They were analysed with EDXRF using the same method as before and a measurement of the ^{210}Pb activity was also made on another sample. Further analyses of some of the samples were performed by inductively coupled plasma mass spectrometry (ICP-MS) of sample solutions.

Results and discussion

Composition of the copper alloys

Table 1 shows the blade (FG-051081) and the hilt (FG-051082) were two different alloys, as Driehaus (1968)

Table 1: Chemical composition (wt%) of the Oedt sword determined by EDXRF.

Object	Sample No	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Sn	Sb	Te	Au	Pb	Bi
Blade	FG-051081	0.11	0.01	<0.01	91	0.2	1.50	0.022	<0.003	7.20	0.04	<0.005	<0.01	0.06	0.01
Hilt	FG-051082	0.14	<0.01	0.11	85	4.5	0.01	1.800	0.008	6.10	0.09	<0.005	<0.01	1.50	0.03
Rivet	FG-051083	<0.05	<0.01	<0.01	13	<0.1	0.05	14.00	<0.03	<0.05	0.01	0.010	73.00	<0.01	<0.01

Note: Elements below the limits of detection are not included: (Al <0.1, Mn <0.01, Co <0.1 and Se <0.01).

had noted. The composition of the blade is consistent with a typical Bronze Age alloy, but the hilt is a lightly-leaded red brass or gunmetal which is quite unusual in pre-Roman times in Europe and unknown in the European Bronze Age.

There is a large body of analyses of Bronze Age metal objects, and Bronze Age brasses are known from the eastern Mediterranean and the Near East (*eg* Caley 1964; Craddock and Eckstein 2003; Thornton and Ehlers 2003). Caley's (1964) compilation of brass objects from the European Bronze Age contained analyses by Otto and Witter and other early researchers that are probably of modern copies as Craddock (1978, 3) has noted. One of the largest systematic studies of prehistoric metal objects was performed by Junghans *et al* (1960–1974). In this study Bronze Age analyses that showed zinc contents above 5% were omitted from the publications, because they were considered to be modern replicas (H Schickler, pers comm). However, the original database does contain a substantial number of brasses. Werner (1980) also called attention to 19th-century replicas of medieval and also Bronze Age objects in German museums, which are occasionally identified by chemical analysis (*eg* Riederer 2004). Most of these replicas were acquired from private collections and became 'authentic' during their time in the museums (Werner 1980). It would be desirable, but probably difficult and unrewarding, to screen all museum collections for the origin of Bronze Age metal objects and their authenticity.

According to current research, the first brass objects that are not culturally Roman appear west of the Rhine in the region of the Moselle and the Eifel Massif just before but mainly after the Gallic Wars in the mid 1st century BC (Schwab in press). Regardless of ongoing speculations about Iron Age mining for calamine at Stolberg near Aachen, there is no evidence for pre-Roman brass production in this area at present. The probability is therefore high that the metal of the hilt does not date to the Bronze Age.

More significant in considering its origin is the observation that the concentrations of the major components in the metal are similar to copper-based alloys with a golden appearance used in modern commercial foundries. Such alloys were used in the jewellery industry to imitate gold or as base metal for gilding and are known under various historic names such as French Tombak, Bristol Brass, Talmigold, Mannheimer or Nürnberger Gold among others (Karmarsch 1851, 48; Pritzlaff 1922, 241). Most of them are red brasses, occasionally with additions of tin or lead and sometimes with low concentrations of gold, iron and later also aluminium. Their golden appearance is useful when gilding in order to reduce the required thickness of the actual gold layer and also for concealing small flaws in the gilding. Only the high silver concentration of the hilt is unusual in these alloys and none of the mixtures published by authors like Karmarsch (1851, 49–50) or Pritzlaff (1922, 241) correspond with the alloy composition of the hilt. However, Pritzlaff (1922, 242) also wrote that every jeweller had his own recipe and Karmarsch (1851, 464) commented on the beneficial use of scrap metal to introduce a little lead and tin, which would be useful for gilding brasses. It should be remembered that Driehaus (1968, 352) used the lead content to argue against the hilt being a modern replica. If one assumes that scrap metal was used, then there are several possibilities for how the composition of the hilt could have been produced. Silver solders are commonly brasses containing silver, and from the beginning of the 20th century silver-bearing copper was produced for the electrical and automobile industry because of its high conductivity (Butts 1954).

Internal structure of the hilt

The CT shows the hilt is composed of four castings which are clearly joined by a solder of higher atomic number (Fig 4f) and hollowed in the area of the tang (Fig 4b). No vertical joints are visible. Two of the segments were also pinned by two pegs before soldering. These pegs fit into drill holes obviously made by modern drill bits (Fig 4b). The CT also revealed that the drill hole to sample the metal of the hilt (MA-051082) cut into the solder which had flowed along the hole drilled to take one of the pegs (Fig 4c and 4d); the metal sample must therefore have been contaminated with solder. Eight of the larger rivets and one of the smaller rivets which are visible on both sides of the hilt are only for decoration and do not penetrate the grip (Fig 4a, 4c and 4e). The other rivets fix the blade to the hilt (4d–4f).

Composition of the brazing metal

We did not expect to find any indications of the authenticity of the hilt but the questions remain, when was it made, and why it was made in this peculiar manner? Since Bronze Age swords composed from individual segments are known (Schwenzer 2004), some original parts could have been used to make this pastiche. However, original parts should be hollow as organic materials were used to make hilts. Because of this and because of the solder contamination, new samples were taken. Their locations were chosen in the light of the structural information from the CT images. Drilled samples were taken from the brazed joints, the four main castings, and

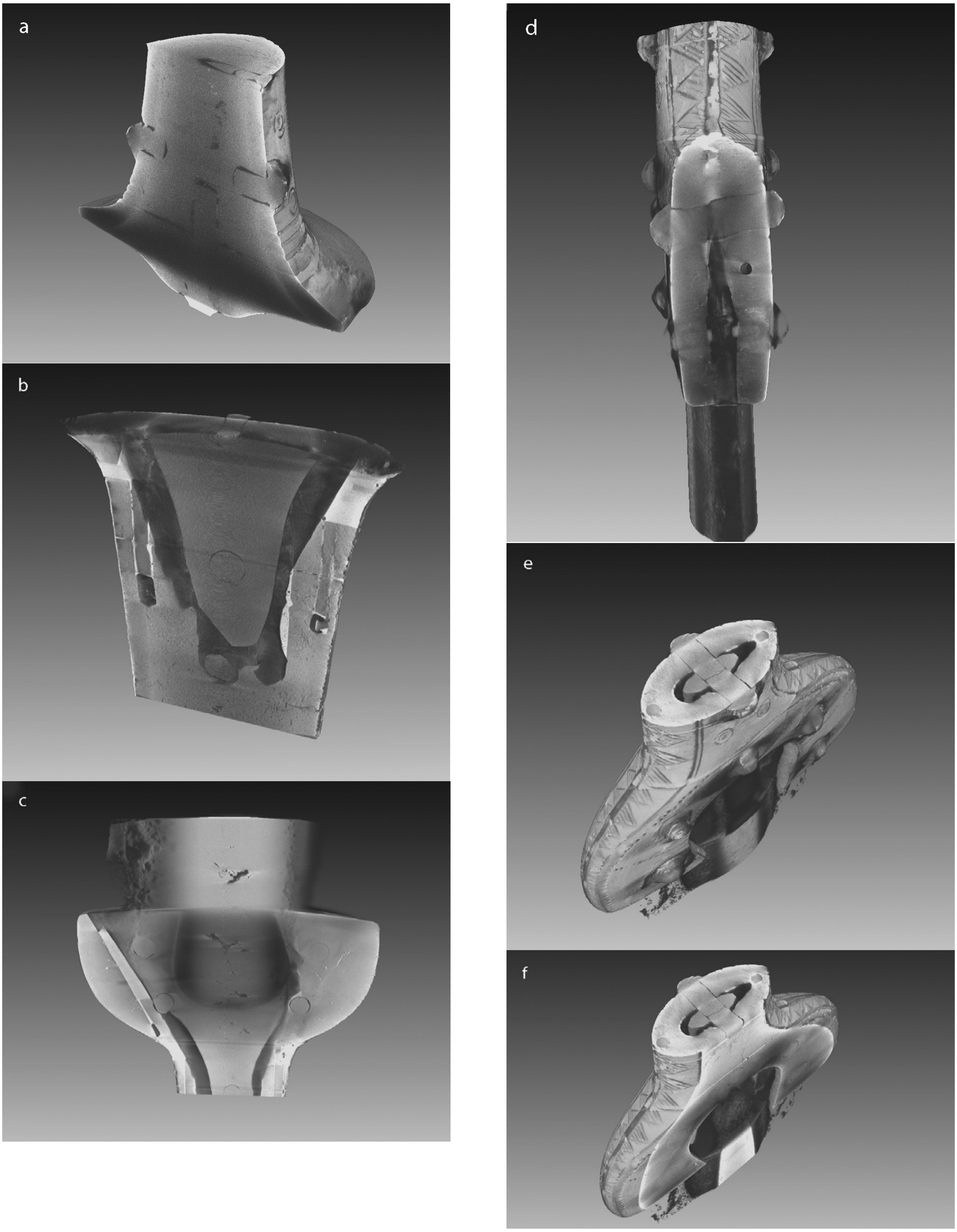

Figure 4: CT sections of the hilt. In images a–c the blade is pointing upwards, in d–f downwards. a) Vertical section through the pommel at the top of the hilt shows the central rivet and three rivets running across the hilt. b) Vertical section of the hilt nearer the blade reveals the pegs soldered into drilled holes; the solder shows as a lighter tone. The hollow around the tang of the blade also has marks of the conical end of a drill bit. c) Traces of solder within casting flaws in the lower part of the hilt show as lighter areas. d) Vertical section of the guard (at right angles to 4a–c) showing a deformed rivet and below it the small drill hole for sample FG-051082. e) Cross section through the hilt showing a cracked rivet and the cross section of the pegs seen in 4b. f) Same view as 4e with a vertical section through the hilt cut away to shows two brazed joints (lighter-coloured lines), from which solder samples (MA-103211 and MA-103213) were taken.

Figure 5: Drill hole for a solder sample (MA-103214) from the join between the pommel and upper part of the grip (arrowed).

one of the pegs locating the two segments of the grip seen in Figure 4b. The brazed joints are narrower than the drill bit (Fig 5) and the peg could only be sampled after drilling through the metal casting, so these samples are contaminated with metal from the main castings. The results are given in Table 2.

The contamination of the solder samples with metal from the castings, and vice versa, is significant. There is a correlation between silver and zinc concentrations and also a negative correlation between zinc and tin. As a result, zinc contents increase and tin contents decrease with solder contamination. Sample MA-103216 from the cast metal and Sample MA-103214 from the solder are probably most representative of the original compositions. Note that the composition of the first solder sample (MA-103210) suggests a second hard solder was used (Table 2). As zinc content increases and silver decreases the melting point of the solder is reduced. One can expect that the hilt was made in several steps and therefore probably contains a number of different hard solders with different melting points. Cadmium is not an intentional addition to the solders and the cadmium contents seem independant of the degree of contamination of the sample.

Most modern brasses were developed after the First World War and were in regular use until the middle of the 20th century (Pernicka *et al* 2008). From the beginning of the 20th century aluminium, manganese, nickel, iron and silicon were commonly added. Aluminium is one of the most common minor components in commercial brasses, but neither aluminium nor manganese was detected in the samples. It should be noted, however, that EDXRF is not a very sensitive method for detecting aluminium.

It is commonly thought that cadmium was a minor component in modern solders from the later 19th century and thus a good indicator for modern alloys. Meeks and Craddock (1991) suggested that the presence of cadmium in gold should be taken as evidence of modern work but this is disputed (Demortier 1992). Riederer (2008, 149) suggested that a concentration above 20ppm of cadmium in brass may be used to identify modern manufacture. He analysed a large series of Benin castings that consisted largely of brass and showed that cadmium is only present in 19th-century castings and modern replicas (*ibid*), but has also published a late 16th century brass ingot from the river Elbe which contains 90ppm of cadmium (Riederer and Forkl 2002, 232). Several 19th century African manillas with cadmium concentrations of more than 100ppm are known (Craddock 1985), though Weirong and Xiagxi (1994) have shown that ancient Chinese brasses can contain up to 70ppm of cadmium. Since zinc minerals like sphalerite usually contain cadmium, it is frequently present in small amounts in metallic zinc; cadmium should therefore be expected in brasses which are not exclusively made by the cementation process.

Table 2: Chemical composition (wt%) of samples taken from the hilt determined by EDXRF.

Ohject	Sample no	Fe	Ni	Cu	Zn	As	Ag	Cd	Sn	Sb	Pb	Bi	*Al (ppm)	*Cd (ppm)
Solder between blade & hilt	MA-103210	0.14	0.03	66	6.2	0.06	24.0	0.007	2.30	0.038	0.73	<0.01	88	49
Solder between two parts of grip	MA-103211	0.53	<0.01	76	7.2	0.01	14.0	0.004	1.70	0.019	0.70	<0.01		
Solder between two parts of grip	MA-103213	0.29	0.02	82	5.3	<0.01	8.1	0.005	3.30	0.030	0.78	<0.01		
Solder between pommel & grip	MA-103214	0.73	0.05	66	11.0	<0.01	21.0	0.005	0.93	0.018	0.35	<0.01		
Guard	MA-103215	0.21	0.07	88	4.2	<0.01	0.46	0.007	5.50	0.084	1.70	0.01	32	86
Grip, large part	MA-103216	0.19	0.04	87	3.8	<0.01	0.03	0.008	6.70	0.040	2.00	0.01		
Pommel	MA-103217	0.17	0.11	86	3.6	<0.01	2.00	0.005	6.30	0.105	1.40	<0.01	5	47
Grip, small part	MA-103218	0.17	0.11	88	3.6	<0.01	0.14	0.003	6.20	0.097	1.40	<0.01	23	43
Peg between two parts of grip	MA-103212	0.14	<0.01	91	1.6	<0.01	5.00	<0.003	0.30	0.003	0.25	<0.01		

Notes: Elements below the EDXRF limits of detection are not included: (Al <0.1, Mn <0.01, Co <0.01, Se <0.01, Te <0.005 and Au <0.01).
* The values in the box to the right were determined by ICP-MS.
For details of positions of the samples see Figures 4–6.

We therefore re-analysed more than fifty brass objects of different ages and provenances for comparison. The objects included several late Iron Age and Roman brooches, late medieval and early modern religious items and statuettes, early modern Benin castings and diverse modern replicas. The result was that only a modern brass replica of a Hellenistic bar and a 19th-century statuette, both from private collections, contained 100ppm and 90ppm cadmium respectively. This is close to the maximum value of 80ppm in the hilt of the Oedt sword (Tables 1 and 2) but is nevertheless rather weak and uncertain evidence for the date of the metal.

When using EDXRF the detection limit for cadmium in copper alloys without silver as a major constituent is better than 30ppm. It rises by an order of magnitude in silver alloys and the radiation from tin, an element of adjacent atomic number, further reduces the sensitivity for cadmium in bronzes and gunmetals. Many energy-dispersive X-ray detectors have thin aluminium layers sputtered onto the X-ray entrance windows, causing internal fluorescence peaks, which make the quantitative analysis of low aluminium concentrations rather uncertain. The cadmium and the aluminium contents in a few samples were therefore checked by ICP-MS (Table 2).

The slightly elevated cadmium concentrations in the hilt were confirmed by ICP-MS while the aluminium concentrations are probably not significant. Indeed aluminium is one of the most common constituents in modern industrial brasses, but usually in the range of 0.2–0.7% or even higher (Pernicka *et al* 2008).

As the reported date of discovery of the sword was before 1947, the date of production must have been earlier. In the first α-spectra of samples MA-051801 and MA-051802 there was no signal from ^{210}Pb detectable either in the blade or in the hilt. It is possible that the hilt was made before or just at the beginning of the 20th century. In this case the radioactivity with a half-life of roughly 22 years would have decayed below the detection limit. If electrolytically refined metals were used then the initial radioactivity would already have been relatively low so that 80 or so years later it can no longer be detected. In the end a new measurement of ^{210}Pb revealed a small (5.4 mBq g^{-1}) but measurable activity in sample MA-103216 of the cast metal.

Conclusions

The results from X-ray CT and the analyses of chemical composition shows the hilt is composed of 23 different pieces (Fig 6), and that five or more different alloys were used for the whole sword:

bronze for the blade
red brass or gunmetal for the hilt
red brasses containing silver for the solders
copper for the pegs and probably also for the rivets
gold alloy for the rivets on the pommel

Following Driehaus' and our investigations, the authenticity of the blade is beyond doubt but contrary to his suggestion, hilt and blade were not made at the same time. As already mentioned, the blade suggests an earlier date, whereas the hilt is without direct parallels.

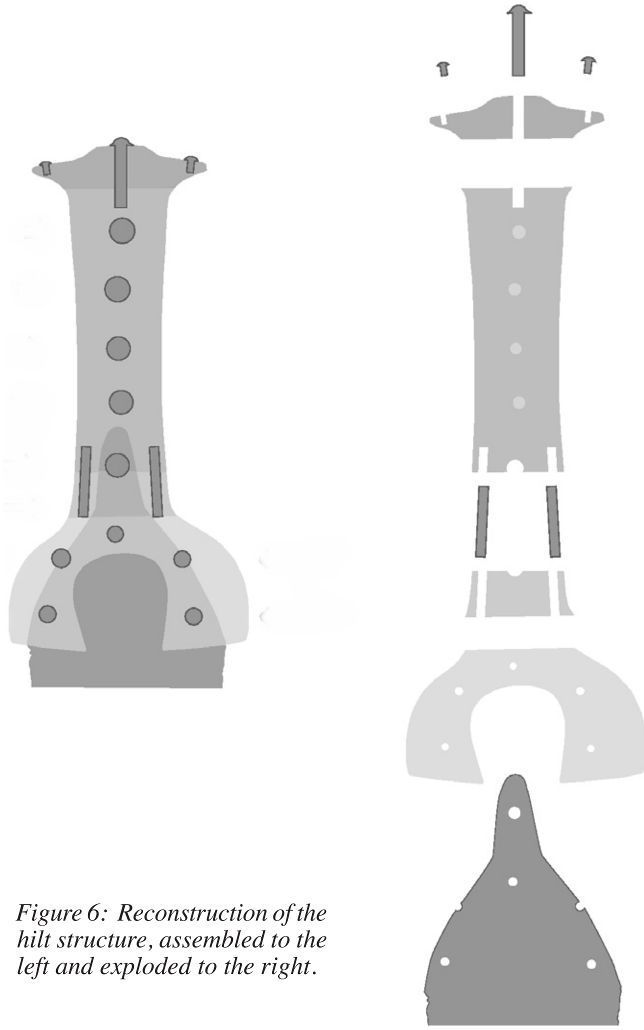

Figure 6: Reconstruction of the hilt structure, assembled to the left and exploded to the right.

The main arguments against a Bronze Age date for the fire-gilded hilt are the high zinc concentrations in the metal of the hilt and the solders, the brazing itself, and of course the technique of fire-gilding. None of these materials or techniques are known from objects securely dated to the European Bronze Age. Furthermore, the composition of the hilt is similar to modern commercial foundry alloys imitating gold! A pastiche with parts of a Bronze Age hilt can be excluded as we analysed all the relevant parts, which were made of the same alloy.

If we summarize all features we found and also those that Driehaus (1968) noted, then the unavoidable conclusion is that the hilt is a fanciful creation of a modern craftsman assisted by someone interested in archaeology. We can narrow down the time window within which it must have been made. The latest date is 1947, when the sword came into a private collection, and the earliest the 16th century AD, when brass-bearing silver solders came into use (Wolters 1983, 64). The limit at the early end must probably be moved to 1818 when metallic cadmium was discovered. Although cadmium can be present in objects made before then (see above), it is unusual (Riederer and Forkl 2002). It has been added to solders from the end of the 19th century onwards (Pritzlaff 1922, 128–9; Wolters 1983, 62), however, the origin of the cadmium in the solder cannot be identified. As it does not seem to have been added intentionally, either to the solder or to the copper alloy, it may be the result of inefficient refining of scrap which can allow traces of cadmium to occur as oxides (Butts 1954, 415). Even though cadmium is probably not an intentional addition, its presence suggests a manufacturing date for the hilt between the end of the 19th century and the Second World War. This dating is supported by the low activity of ^{210}Pb, which suggests the metal is less than about 100 years old.

Another indirect but very important indicator of the likely date is a call for producing 'high quality' replicas of Bronze Age weapons for education in the first issue of *Germanen-Erbe* (Rothert 1936). Advertisements for replicas of Bronze Age weapons available from a company producing teaching material in Cologne appeared in this national socialist journal from 1938 (Joachim 1977). In addition, several other replicas appeared after the Second World War in the vicinity of the find location of the Oedt sword, one of them also from the river Niers (Joachim 1977; Joachim and Weber 2002–3, 3). Finally, Driehaus (1968, 334) reported only slight corrosion of the hilt. Due to the quite different reactivities of the associated metals (zinc, tin, lead, copper, silver and gold), we can assume that the sword can only have been buried in the river for a short time. Probably only a few years!

At present the disc from Rathgall in Ireland and the sword from Rothenmoor in Germany remain as the only suppossedly fire-gilded Bronze Age objects. However, they are of uncertain date in the case of Rathgall and of an uncertain technique in the case of Rothenmoor. Both finds certainly need to be re-investigated to clarify their find circumstances and their gilding technique. The evidence presented above concerning the hilt on the Oedt sword makes it absolutely clear that it cannot be dated to the Bronze Age, and therefore no reliable evidence remains for fire-gilding in the Bronze Age.

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