A Unique Case of 'Counting Marks' Revealed by Tomography on a Middle Bronze Age Sword from Champagneux (France, Savoie)

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ABSTRACT

In the 1960s, a solid-hilted sword dating to the second half of the Middle Bronze Age (1450–1300 BC) was dredged up in a gravel quarry in the Rhône river at the village of Champagneux (Savoie, France). The sword belongs to the octagonal-hilted swords (German: *Achtkantschwerter*). This type, mainly found in the northern Alpine region and southern Scandinavia, was until then unknown in France. X-ray fluorescence (XRF) analyses and high-resolution X-ray computed tomography (µCT) of the hilt were carried out to understand how the hilt was cast and fixed to the blade. Thanks to the opportunities offered by these techniques, we were able to reconstruct the *chaîne opératoire* of this sword with a close inspection of the inter-nal structure of the hilt. Furthermore, we visualised the surface of the sword's tang located inside the hilt, which shows a series of five vertically arranged marks. Until now, similar symbols were only known on Late Bronze Age bracelets and tools, predominantly in the eastern part of the Alpine region. Although their exact function remains enigmatic, these marks are believed to be markers left by craftsmen on the object during their manufacture. On the solid-hilted sword from Champagneux, these marks could be linked to a way for the craftsman to remember which blade and hilt were supposed to be joined together, shedding light on the organisation of the production process behind this kind of weapon.

RÉSUMÉ

Dans les années 1960, une épée à poignée métallique datant de la seconde moitié du Bronze moyen (1450-1300 av. J.-C.) fut draguée dans une gravière du Rhône à Champagneux (Savoie). Il s'agit d'une épée à fusée octogonale (en allemand : *Achtkantschwert*). Ce type, caractéristique de la région nord-alpine et du sud de la Scandinavie, était jusqu'alors inconnu en France. Des analyses par spectroscopie de fluorescence X (XRF) et tomographie haute résolution par rayons X ont été réalisées afin de comprendre comment la poignée a été coulée puis fixée à la lame. Ces méthodes nous ont ainsi permis de reconstituer la chaîne opératoire de cette épée en réalisant une inspection minutieuse de la structure interne de sa poignée. Nous avons par ailleurs été en mesure de visualiser la surface de la languette de la lame, insérée à l'intérieur du manche, qui présente une série de cinq marques disposées verticalement. Des éléments similaires n'étaient jusqu'à présent connus uniquement sur des outils et parures de du Bronze final, essentiellement dans la partie orientale de l'arc alpin. Bien que leur fonction exacte demeure inconnue, ces marques pourraient être des marqueurs laissés sur les objets au moment de leur fabrication. Dans le cas de l'épée de Champagneux, il pourrait s'agir d'un moyen pour l'artisan d'identifier rapidement dans son atelier la lame et la poignée devant être assemblées. Ces marques nous permettent ainsi d'obtenir de nouvelles informations l'organisation de la production de ce type d'arme.

Keywords: Middle Bronze Age, France, Octagonal-hilted swords, Counting marks, CT-scan, XRF, Metallurgy, Craftsmanship.

INTRODUCTION

Although Bronze Age solid-hilted swords have been studied since the end of the 19th century, very little is known about the workshops they were produced in and the organisation of their production. Except for the very end of the Bronze Age (9th century BC), there are no archaeological remains of the manufacturing sites of these swords (Dumont 2021). Remains of a workshop's location have never been found, nor the moulds used to cast the different parts of these artefacts. Our knowledge concerning the Bronze Age solid-hilted swords' *chaîne opératoire*, and the organisation of their production, is therefore only indirect and comes from the study of the swords themselves. The case of such a sword found in the Rhône river in Champagneux (France, Savoie) in the 1960s is particularly noteworthy concerning this topic. In the frame of the BOF-funded (Bijzonder Onderzoeksfonds, Ghent University) project 'Production and distribution of Bronze Age solid-hilted swords in Western Europe' (2018–2022), it was investigated using high-resolution computed-tomography (µCT) in order to study the hilt and the blade and their respective layouts. This technique also revealed the unexpected presence of five so-called 'counting marks' on the part of the blade inserted within the handle. This feature allows us to discuss several hypotheses concerning the production organisation of this kind of weapon. After thoroughly presenting the Champagneux sword and the techniques used to study it, we will try to reconstruct the different steps of its production and determine what was (or were) the role(s) of the marks observed inside the handle.

THE CHAMPAGNEUX SWORD (FRANCE, SAVOIE)

The sword from Champagneux (France, Savoie) was dredged up in a gravel quarry by Mr François Debauge in the Rhône river in the 1960s, upstream of its confluence with the Guiers river. It was given to the Escale Haut-Rhône museum in Brégnier-Cordon (France, Ain) in January 2011 by Mrs Françoise Bousculat. The museum still curates the sword, which has inventory number 2011.1.1. A few studies on the sword were published by A. Bocquet (Bocquet & Haussmann 2001, 305–307; Bocquet 2006), but no detailed technical examination has been conducted so far.

Although the blade is broken into two fragments, the 51.2 cm long Champagneux sword is completely preserved (Fig. 1). The visible section of the bl

ade is 40.5 cm long from the bottom of the hilt to the tip, with a maximum width of 2.8 cm and an average thickness of 0.7 cm. The blade presents a lenticular-shaped section with a light recess located a few millimetres from the cutting edges. It was found covered with a blackish patina verging on green, which now has been partly removed, exposing the underlying uncorroded golden bronze. The slight deformations of the cutting edges, visible in some places, are associated with alterations of the corrosion layer, indicating that this probably happened after the sword was deposited, for example, when it was taken out of the Rhône river. The hilt is 10.7 cm long and has a 4.5 cm wide oval pommel. Its surface is riddled with small craters, and on its top sits a truncated cone-shaped protuberance. The pommel's edge is flattened on one side. The presence of corrosion and the smooth edge suggests that this happened before the object was deposited in the river, i.e., during its production or period of use. The grip has a convex outline and a circular-shaped cross-section. A series of straight lines carved in the bronze highlights the transition to the pommel. The grip's surface was subject to substantial erosion, especially in its centre, judging from the almost total absence of corrosion on this spot. The erosion may have been caused by the current of the river where the sword remained for more than three millennia or by manual abrasion of the sword's surface after its discovery. The grip ornaments were thereby almost totally erased, except for a circular pattern or a spiral that remains barely visible on the bottom part of the grip, close to the guard (Fig. 1). Finally, the kite-shaped guard is 5.3 cm wide with a semi-circular notch in its centre and two rivets on either side.

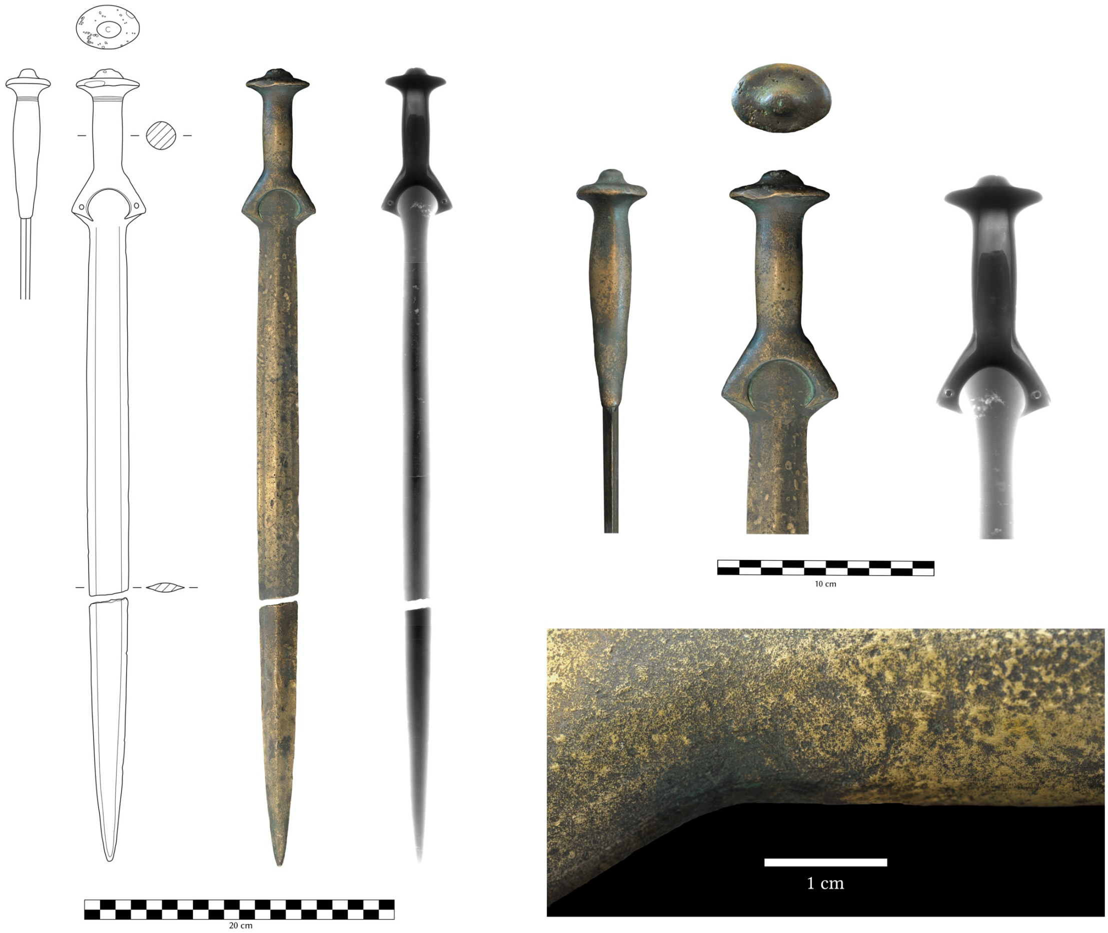

Figure 1. General view, details, and radiography of the Champagneux sword (Musée Escale Haut-Rhône, Brégnier-Cordon, Ain, France, no. 2011.1.1). © L. Dumont, UGCT.

TYPOLOGY AND CHRONOLOGY

The Champagneux sword presents singular formal features, making it difficult to fit in the traditional typological framework of Bronze Age solid-hilted swords. It evokes two different types. First of all, the kite-shaped guard, the slightly convex outline of the grip, and the quite massive pommel are typical features of the octagonal-hilted swords (German: *Achtkantschwerter*). These swords, typical for the second part of the Middle Bronze Age (Bronze C, mid-15th–14th century BC), are equipped with a very distinctive hilt sharing common features with the Champagneux sword, with the addition of an octagonal hilt cross-section that gave them their name (Holste 1953, 16–25; Quillfeldt 1995, 45–94). The patterns of circles or spirals still visible on the hilt of the Champagneux sword is also an element widely found on octagonal hilted swords (Holste 1953, 16–18). However, the circular cross-section of this sword is a feature that only appears at the beginning of the Late Bronze Age (Bronze D, 13th century BC) among Central-European solid-hilted swords. It is then occasionally found on swords belonging to the Riegsee type, such as the one from Král (Slovakia) (Novotná 2014, 33, pl. 5, 24), or on other swords isolated from a typological point of view, as in the case of a sword from Bad Staffelstein (Bayern, Germany) (Quillfeldt 1995, 97, pl. 26, 80).

Despite the lack of features perfectly matching one specific type, the Champagneux sword appears to be related to the octagonal-hilted swords. Although the octagonal cross-section of

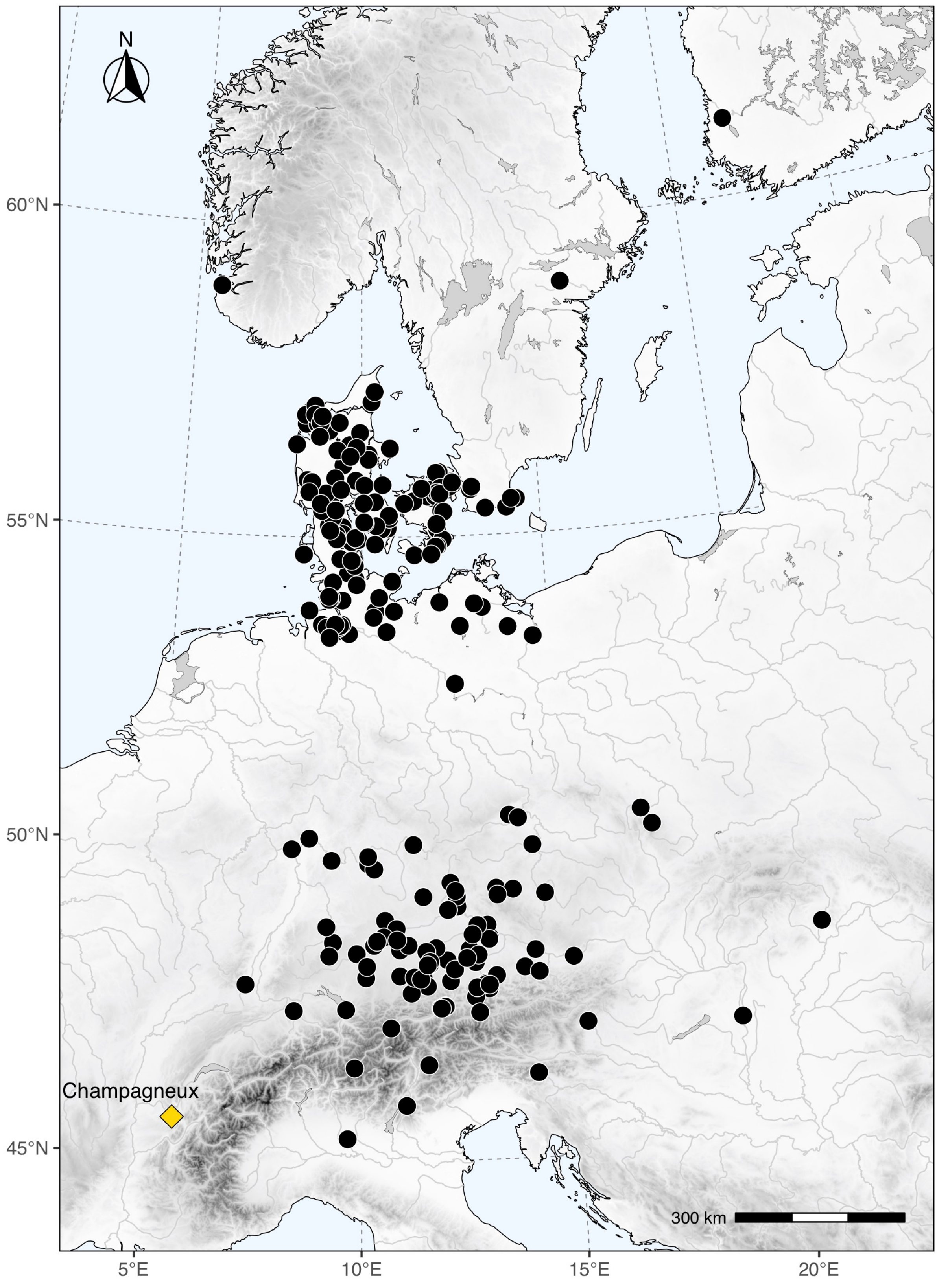

Figure 2. Distribution of Middle Bronze Age octagonal-hilted swords in Europe (after Holste 1953; Bianco Peroni 1970; Krämer 1985; Kemenczei 1991; Quillfeldt 1995; Wüstemann 2004; Laux 2009; Winiker 2015; Bunnefeld 2016). © L. Dumont.

the hilt is missing, all the other features, such as the thick, stocky pommel and the kite-shaped guard, belong to the octagonal-hilted swords' characteristics. Furthermore, as mentioned earlier, this sword likely used to have an octagonal cross-section that was altered by its three millennia-long rest in the Rhône river. It is then possible to propose a dating of the Champagneux sword in the second half of the Middle Bronze Age (Bronze C, ca. 1450–1300 BC).

The octagonal-hilted swords are distributed across Europe in two main clusters: one around the Alpine region, especially between the Alps and the Main river; another in Southern Scandinavia, mainly in present-day Denmark and Schleswig-Holstein (Fig. 2). Accepting the affiliation of the sword from Champagneux with this type would make it the most western find from this group. All octagonal-hilted swords are made the same way. Since no hilts are identical to one another and given their rich ornamentation, they are very likely to be produced using the lost-wax casting technique with individually made wax models on clay cores (Hundt 1962, 38). The hollow-cast hilts were then fixed to the blade using a combination of two techniques. First of all, the hilt is put on the tang located at the top part of the blade. This tang, inserted inside the hilt beyond the guard, is adjusted by the craftsman in charge of the manufacture of both parts so that it can be in contact with the inner walls of the hilt. By doing so, both elements are locked together. The fixation is then strengthened by adding two rivets on the guard piece on either side of the central notch. This technique, which combines the locking of the hilt with the blade and the riveting, is an invention of the Middle Bronze Age that appears with the octagonal-hilted swords and is designated after this type as the 'octagonal-hilted sword principle' (*Achtkantschwert-Prinzip*) (Hundt 1965, 54). These octagonal-hilted swords form a very consistent group, technically speaking. Examinations performed on this type of sword using X-ray-based imaging techniques such as radiography and computed tomography indicate that almost all are produced the same way, wherever they are found in Europe (Hundt 1965; Bunnefeld 2016, 122–125). This technical normalisation and homogeneity suggest that these swords may have been produced in a limited number of workshops whose products were designed for users in the north-Alpine region and in southern Scandinavia, where imitations were also manufactured, probably locally (Bunnefeld 2014).

METHODS AND RESULTS

HIGH-RESOLUTION COMPUTED TOMOGRAPHY (μCT)

A new examination of the Champagneux sword was possible in 2019 and 2020. After a first macroscopic inspection, the sword was brought to the Ghent University Centre for X-ray Tomography (UGCT) in October 2020 for further analysis. Whereas radiography has been used to investigate Bronze Age solid-hilted swords since the 1950s (Drescher 1958; Driehaus 1959; 1961; Hundt 1962; 1965), the use of digital radiography and computed tomography is much more recent and enables significant advances in the visualisation of the swords' construction due to increased precision and the opportunity to investigate in 3D the inner structure of the artefacts (Mödlinger 2008; Bunnefeld & Schwenzer 2011; Bunnefeld 2016; Dumont et al. 2020a; 2020b).

Radiography and high-resolution computed tomography (μCT) were used to investigate the production process of the object. UGCT's HECTOR (High Energy CT Optimised for Research) setup was used (Masschaele et al. 2013), suitable for both larger samples and samples with a high X-ray attenuation like the case of this bronze sword. We used an X-RAY WorX XWT 240-SE microfocus source operating at 220 kV and 60 W. The source was equipped with a 1 mm Cu sheet to filter low energy X-rays. Images were acquired with a PerkinElmer 1620 CN3 CS flat panel detector where the 2024 × 2024 0.2 mm pixel range was cropped to fit the sword projection. For the scan of the hilt, the Champagneux sword was placed on a rotary base, and 1501 projections were acquired around the sword's hilt, each with 1 second acquisition time. As for the digital radiography, projections were acquired over different vertical steps to cover the sword's length. The images were averaged over 100 normalised images, each with 1 s acquisition time.

The digital radiography of the whole sword enables us to assess the global quality of the casting of both parts. Whereas the handle is made of a very homogenous metal, the blade shows inner flaws within the bronze from the upper third (Fig. 1). Thanks to the scan of the hilt area, it is possible to realise a much more precise examination of the hilt structure and the organisation of the different elements. Several sections were made through the reconstructed volume following the axial, coronal and sagittal planes using the 3D Slicer software (Fedorov et al. 2012), showing precisely the layout of the blade inserted within the handle (Fig. 3). With the help of the 3D model of the hilt resulting from the μCT, it was also possible to virtually visualise the tang's surface, which is the part of the blade inserted in the hilt, revealing the five marks that were made on it (Fig. 4).

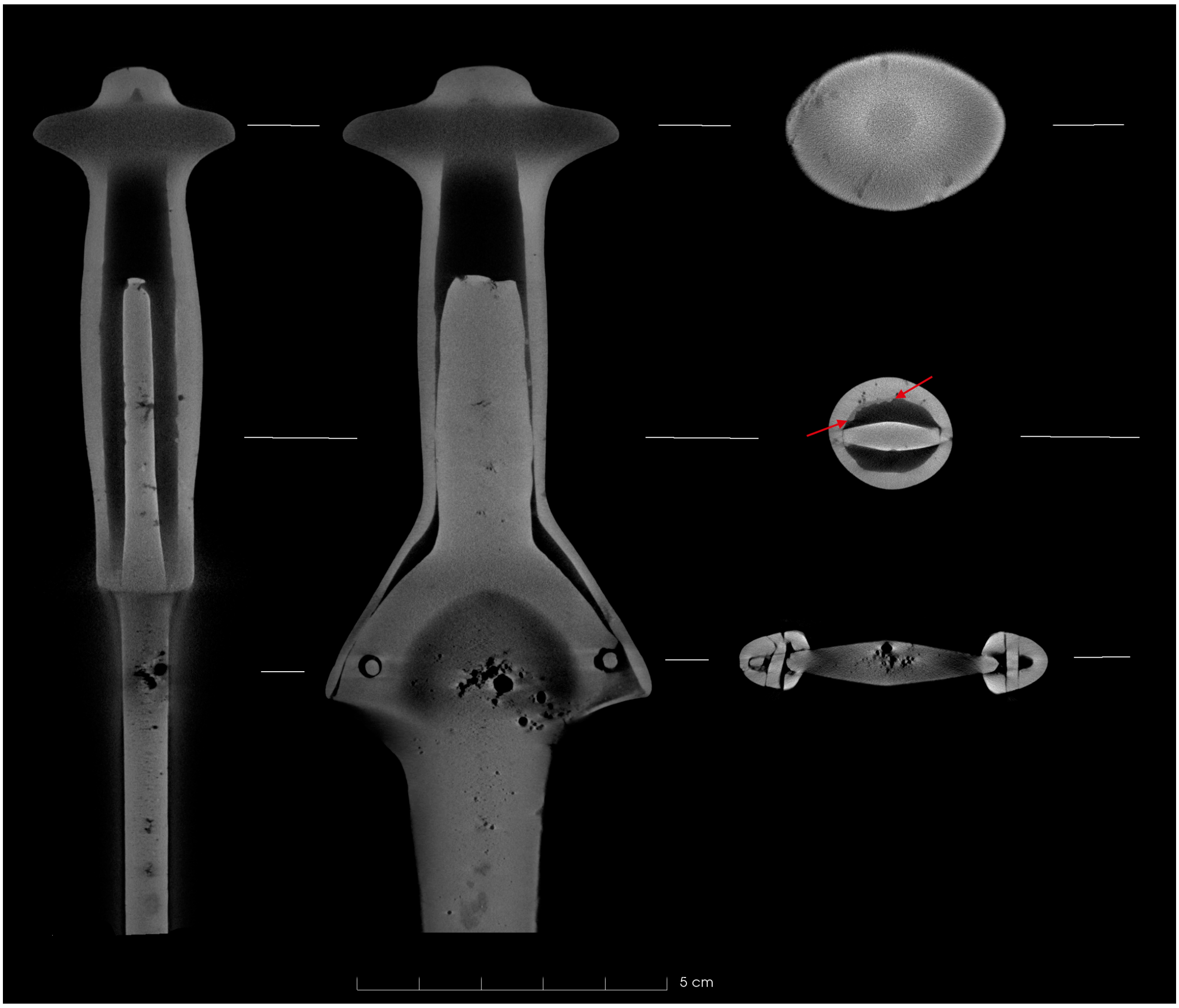

Figure 3. Different sections through the Champagneux sword's hilt produced by μCT scanning. The red arrows show the limits of the core residue deposited on the hilt's inner wall. © UGCT.

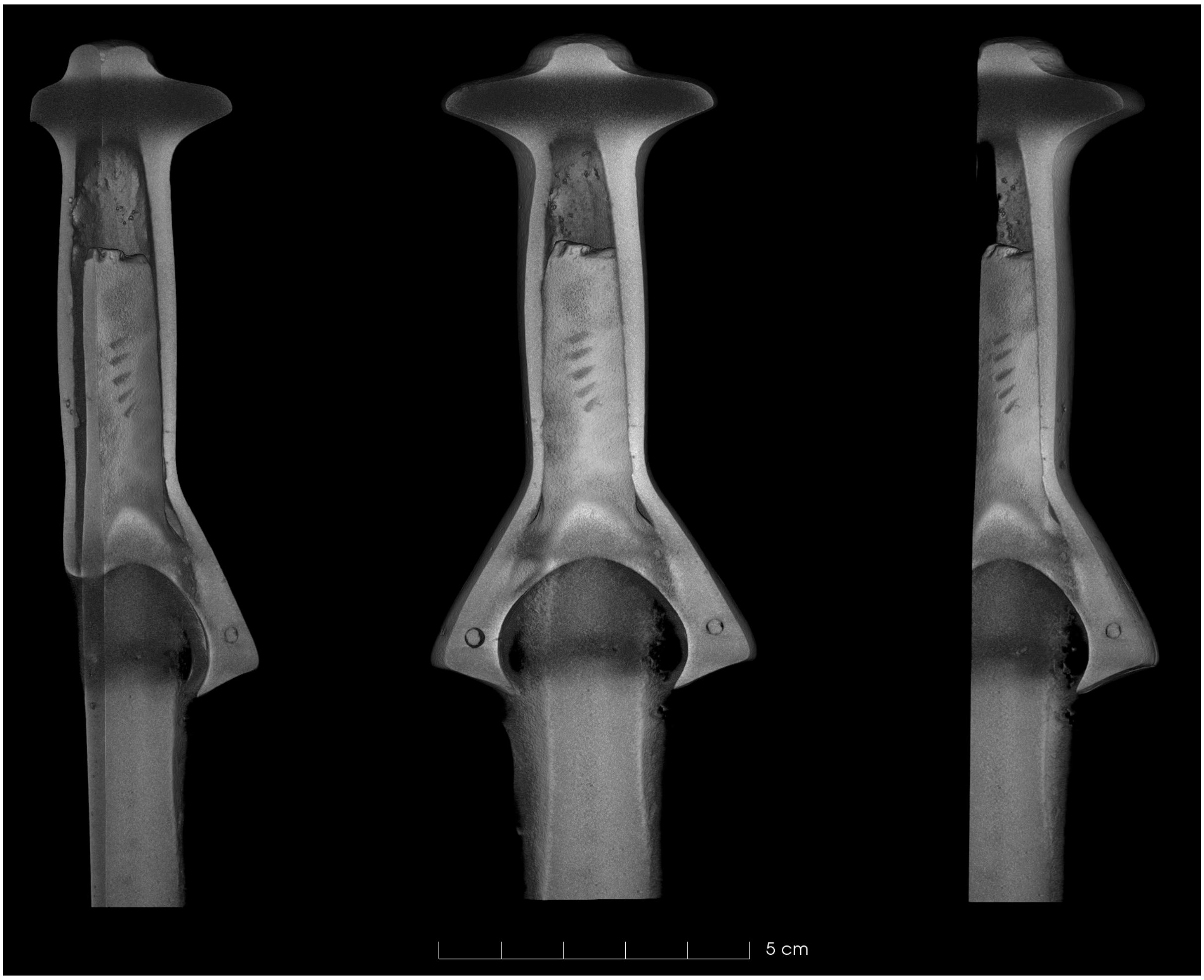

Figure 4. Different views of the cropped reconstructed volume of the Champagneux sword's hilt. The tang carries a series of five carved marks which are vertically arranged. © UGCT.

HAND-HELD X-RAY FLUORESCENCE SPECTROSCOPY (HXRF)

When the sword was in Ghent University, non-invasive surface handheld XRF analyses were also conducted. This method allows us to determine the concentration of the element on the sword's surface in a non-invasive way. Although these analyses are limited in precision, not all elements can be detected and the corrosion layer can alter the results (Nørgaard 2017), the impossibility to sample the Champagneux sword and the presence of uncorroded areas on the sword's surface prompted us to use this technique to determine if the blade and the hilt were made from the same type of alloy or not.

The measurements were performed with a commercial instrument, i.e., an Olympus Innov X Delta Premium unit. It is equipped with rhodium (Rh) based X-ray tube and a silicon drift detector (SDD). An aluminium (Al) filter was applied for measuring the higher Z-elements (from Al onwards) with a voltage of 40 kV and a current of 38.7 µA. The measurements were performed in the air for 300 seconds (real-time) with an uncollimated polychromatic X-ray beam for excitation (5 × 5 mm2). The instrument was set on the Geochem mode. As any invasive operations on the Champagneux sword were prohibited by the museum curating it, the measurements were conducted on its surface without any preliminary treatment. Areas where the corrosion layer was missing were targeted (Fig. 5).

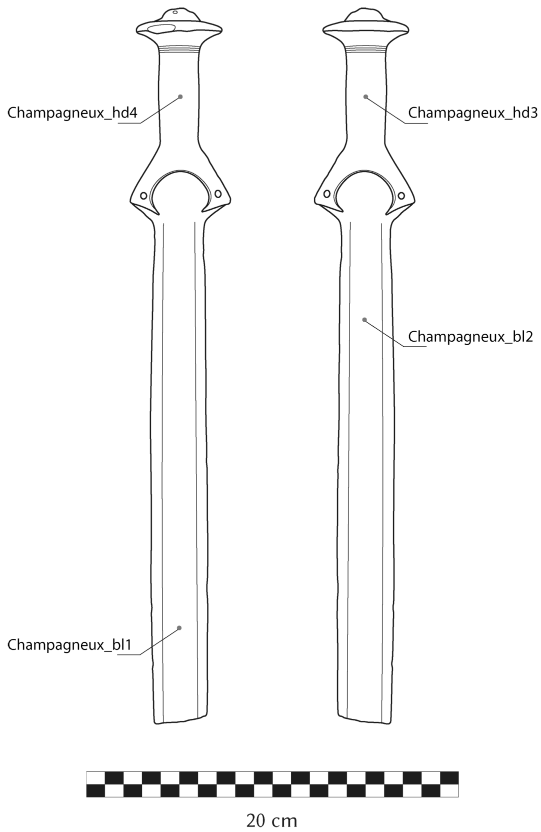

Figure 5. Locations of the measured points using hand-held XRF. © S. Lycke & L. Dumont.

The collected spectral data were processed using the dedicated XRF spectrum evaluation software AXIL (Analysis of X-ray spectra by iterative least squares) (Vekemans et al. 1994). The XRF results were quantified using references MBH-32x-lg10g, MBH-32x-pb14e, MBH-32x-sn6b, MBH-32x-sn7b and MBH-33x-gm21b based quantification method. The elemental yield was determined for each certified element in the reference materials by dividing the XRF net peak intensity by the corresponding certified concentration after normalising for measurement time and illuminated mass by division of the Compton scatter intensity. Where an element is present in multiple reference materials, the average elemental yield and its standard deviation were used as a resulting error. For elements not present in any of the used reference materials, the elemental yield was determined by interpolating the closest neighbouring elements by the atomic number – present in the reference materials. Four points were measured on the surface of the Champagneux sword: two on the handle and two on the blade (Fig. 5). The composition of both parts is similar. They are both made out of a binary alloy with copper (Cu) and tin (Sn) with low traces of lead (Pb) (Table 1).

It should be noted that the sum of concentrations listed in Table 1 does not equal 100 – this is because the quantification method used provides concentration values only for the detectable elements, excluding, for instance, the detection of low energetic photons originating from oxygen, carbon, and other elements. Additionally, due to the inability to remove corrosion from the sword in a non-destructive manner, it was opted to measure the sample on the least corroded parts. Corrosion products can partially modify the resulting quantitative information on top of the sword alloy. However, these are expected to be limited due to the limited corrosion layer thickness and relatively lower density than the sample bulk. In any case the corrosion layer thickness is expected to be similar for all measured points, thus providing reliable information on the alloy composition from different measurement locations.

	Champagneux_bl1		Champagneux_bl2		Champagneux_hd3		Champagneux_hd4	
	C[w%]	C_err[w%]	C[w%]	C_err[w%]	C[w%]	C_err[w%]	C[w%]	C_err[w%]
Cu	74,6	7,42	79,47	7,9	80,19	7,98	77,83	7,74
Sn	13,48	1,62	14,44	1,73	16,22	1,95	14,82	1,78
Pb	0,21	0,05	0,22	0,06	0,22	0,06	0,25	0,07
Mn	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Fe	0,01	0,02	0,01	0,02	0,01	0,03	0,02	0,03
Co	0,02	0,02	0,02	0,02	0,02	0,03	0,02	0,02
Ni	0,06	0,02	0,06	0,02	0,06	0,02	0,06	0,02
Zn	0,12	0,08	0,13	0,09	0,13	0,09	0,12	0,09
As	0,05	0,01	0,04	0,01	0,05	0,01	0,04	0,01
Ag	0,03	0,06	0,05	0,09	0,01	0,01	0,08	0,16
Bi	0,03	0,01	0,04	0,01	0,03	0,01	0,04	0,01

Table 1. Concentrations of the elements measured by hand-held XRF. © S. Lycke & P. Tack.

RECONTRUCTING THE PRODUCTION PROCESS OF THE SWORD CASTING

the study of two types of features revealed by the radiography and µCT scanning: blows and shrinkage porosity. Both are two kinds of defects that can occur during the casting and under different conditions. Blows correspond to gas trapped inside the metal during the casting process. They can be caused by insufficient mould ventilation or by too rapid solidification of the bronze, not allowing the gas sufficient time to evacuate. Their almost circular or pear-shaped form can easily be identified on the radiographs or the section resulting from the computed tomography. As the gas is lighter than the bronze cast inside the mould, they move upwards while the metal is in a liquid state. The distribution of this kind of fault inside the sword can therefore give us information about the position of the mould and the introduction point of the metal. Shrinkage porosity is another kind of defect inside the casted metallic mass. The retraction of the bronze causes shrinkage while it is cooling, and the drop in temperature is not homogenous everywhere around the casted objects. The drop is, for example, much faster around the introduction point of the melted metal inside the mould, which is where the bronze comes in contact with the air. This kind of fault is different from blows. It takes the shapes of a series of rims with irregular outlines associated with small uneven cavities. Concentrations of shrinkage porosity and blows are known to be an indication of where the metal introduction point of the mould was located (Wirth 2003, 126–127; Mödlinger 2008; 2011, 32; Mödlinger & Trnka 2009, 31).

The Champagneux sword's blade has significant inner defects. They are primarily concentrated in the upper quarter of the blade. The flaws are scattered in the central part and almost absent at its tip (Fig. 1). We see a concentration of blows and shrinkage porosity located just below the handle, within the notch of the guard (Figs. 1, 3). It suggests that the sword's hilt was cast from its upper extremity, where the tang is located, as most of the swords dating back to the Bronze C period are (Mödlinger & Trnka 2009, 31–32). However, the metal of the tang itself is much more homogeneous than the blade below the hilt. Only very small blows and porosity are visible on this part of the blade inserted in the handle (Fig. 3). The mould used to cast this blade was likely slightly tilted to allow a better pouring and flow of the melted bronze plus a better evacuation of the gas (Mödlinger 2008). It is clear from this data that this did not give the expected results. It is difficult to evaluate the impact of these flaws on the solidity of the blade and on its ability to be used in combat. This blade was prepared as a fully functional sword. The cutting edges are not raw and were sharpened. This operation usually involves a series of hammering and heating operations aiming to increase the edges' hardness (Mödlinger 2011, 35–36).

Reconstructing the casting process of the hilt of this sword is much more complicated. It is indeed made of a much more homogeneous metal in which radiography and µCT scanning only revealed a very limited amount of porosity (Figs. 1, 3). Except for a few blows located in the grip, most flaws are concentrated within the pommel. Some are visible on its surface (Fig. 1), which is consistent with a casting made from the upper part of the hilt, especially from the side of the pommel as it was documented on later swords, such as the broken cup-shaped pommel sword from St. Pölten (Austria) (Pola et al. 2015), as well as on Late Bronze Age moulds for Mörigen type hilts at Erlingshofen (Bayern, Germany) (Wirth 2003, 119–128; Overbeck 2018, pl. 10, 20) and Grésine (Lac du Bourget, Savoie, France) (Perrin 1871). The flattened edge of the Champagneux sword's pommel might indicate the removal of the metal excess located at the mould pouring gate. The manufacture of a hollow handle means to be cast over a core. This piece was probably made out of clay, which is the most probable option for producing this kind of hilt (Hundt 1965, 43; Quillfeldt 1995, 75–76; Wüstemann 2004, 122– 123; Berger 2014, 229; Bunnefeld 2016, 122). The use of a permanent and reusable core, for example, made out of bronze as in the Erlingshofen mould (Overbeck 2018, pl. 10, 20), is to be ruled out. As the hilt's inner room is wider in its centre than at the guard's base (Fig. 3), it would not be possible to take a metallic core out of the hilt after the casting.

On the contrary, a clay core could have been destroyed after the handle was melted down over it. The µCT data reveal the presence of residues on the hilt inner surface (Fig. 3). The residues are likely to come from the core, and since the deposit shows a lower density than the rest of the handle on the tomography, we are confident the core was made out of a different material. Its adhesion to the hilt's inner wall suggests it might be clay. Another exciting feature concerning the production of this hilt is the hollow canal within the pommel connecting the inner room with the outside. There has been much debate concerning these canals, often observed on Bronze Age swords' hilts. First, it has been proposed that this hollow part originated from the gas produced during the casting making its way through the pommel while the bronze was still liquid (Driehaus 1961, 26; Berger 2014, 227). J. Driehaus later suggested that the craftsman may have turned the mould over after casting the bronze in order to remove excess metal, thereby creating at the same time this open room within the pommel (Driehaus 1968, 356–357).

Meanwhile, H.-J. Hundt proposed another explanation, stating that this element could correspond to a vent used for evacuating the gas produced during the casting (Hundt 1965, 42–44). A much more probable hypothesis comes from the study of Early Bronze Age solid-hilted daggers. This feature may originate from using a stand designed to go through the core, the wax model, and the clay mantel to hold the clay core in place during the entire casting process (Schwenzer 2004, 147; Mödlinger 2011, 32). However, this technique would produce only very regular canals, which is not always the case, hence the possibility that some canals and pommel openings could be caused by the combination of the presence of porosity in the bronze and its retraction during the cooling process (Bunnefeld & Schwenzer 2011, 216–217). In the case of the Champagneux sword, the outline of the pommel canal is unmistakable but is not straight: it becomes narrower in the middle of the pommel before it slightly extends just before it reaches the surface, visible on the profile section of the hilt (Fig. 3). It may have been caused by two combining factors: the presence of a stand during the casting and the metal retraction. The regularity of the canal indicates it may not be related to porosity. After the casting, the opening remaining at the centre of the pommel was closed using a small bronze shaft.

ASSEMBLY

After both the hilt and the blade were cast, the two parts needed to be joined together. The fixation was made using two techniques. First, the blade was inserted inside the hilt through the opening located at the guard's base. The contact points between the tang and the inner wall of the handle on the bottom part of the grip show that the blade was forced inside the hilt to block the two elements together. The tang and the guard fit the hilt's inner room, perfectly matching the guard opening and the grip width (Fig. 3). Because we do not know any moulds for casting octagonal-hilted swords' hilts and blades, we are probably dealing with individually made objects and no serial production. Consequently, the blade tang must have been worked after it was cast to fit this specific hilt, such as by hammering to expand it slightly.

Once the blade and the handle were both locked together, the rivets were added to the guard, on either side of the notch in its centre. The role of these two small bronze rods in the fixation of both parts seems somewhat limited. First of all, the µCT data shows that the rivet holes are larger than the shafts inserted in them. Secondly, one of the hole's outlines is broken, making it more like a notch than a real rivet hole. We also see that the two holes in each side of the guard and the perforation made in the tang are not perfectly aligned on one side of the guard, hence a twisted rivet (Fig. 3).

Consequently, it is questionable what the rivets' purposes are. We here propose two hypotheses to this question. The rivets can be seen as a security if the blocking of the hilt and blade fails, for example, following a violent impact. Although there would be a play between the two parts, they would remain joined together. The presence of the rivets might also be considered a cultural remain more than an effective way to bind the handle to the blade. Before the emergence of octagonal-hilted swords in Bronze C, other sword types, such as the Spatzenhausen type, were equipped with a short-tanged blade only fixed to the hilt using rivets (Hundt 1965, 43–44).

The development of the fixation technique mentioned above, blocking and riveting, is indeed a fundamental breakthrough in the swords' conception. As we already saw earlier (see section 'Typology and chronology'), this so-called 'octagonal-hilted swords principle' appeared in the Bronze C period, when craftsmen followed it to produce most of the swords found between the Alpine region and the Carpathian basin from the mid-15th to the 10th century BC. Although this technique has been widely documented through the use of imaging techniques since the 1960s (Hundt 1965; Ankner 1977; Wüstemann 2004; Bunnefeld & Schwenzer 2011; Mödlinger 2011; Berger 2014), the organisation of the crafting process remains undocumented mainly due to the absence of workshops in the archaeological record. The computed tomography performed on the hilt area of the Champagneux sword, besides producing valuable documentation of the sword's casting and assembly, also enabled us to visualise the surface of the tang, which appears to carry a series of five vertically arranged carved marks (Fig. 4). They are believed to come from the craftsman who made the blade. They may be connected to the fixation process of the blade and therefore give us information about how the *chaîne opératoire* was organised and possibly divided between several individuals.

THE “COUNTING MARKS”: MAKING AND FUNCTION(S)

Computed tomography not only allows visualisation of sections of the scanned artefact. It also enables us to virtually reconstruct the object’s volume, both from the outer surface and inside. It is thus possible to ‘cut’ through this numerical model to get a sight of the inner surfaces, which are impossible to visualise using traditional radiography or CT-scan sections. Thanks to this opportunity, it was possible to glimpse the inside of the Champagneux sword. The most important feature of this examination are five vertically arranged marks on the centre of one side of the blade’s tang. They measure 4to5mmlongforawidthbetween2and3mmanda depth of about 1 mm (Figs. 3–4). They have the shape of an almond, with one sharp edge and a curved one. Each one is slightly tilted and forms an angle between 30 and 45° compared to the blade axis. Each of them shows a thin bulge (Fig. 4), and, with their shallow depth and this thin bulge in mind, it seems clear that these marks were probably made directly on the bronze after it was cast rather than on the wax model (assuming that the lost-wax process was used for the casting). According to the almond shape and the small size of the marks, they were likely made using the corner of a chisel blade. Their shallow depth and width suggest they were realised with a rather blunt blade. Otherwise, using a sharper edge, the marks would have been deeper and thinner.

Although this kind of feature has, to our knowledge, never been observed on a Bronze Age solid-hilted sword, elements of comparison are known on other kinds of bronze artefacts. Armrings are the best-known case, with several examples dating back to the Late Bronze Age, mainly from the north and east Alpine regions (Thrane 1962; Müller-Karpe 1974; Weidmann 1983; Janssen 1989– 1990; Primas 2008, 192–193; Windholz-Konrad 2008). Two kinds of marks are known on bracelets: thin, long and engraved marks (German: *Strichmarken*) and more extensive, deeper and shorter chiselled marks (German: *Schlagmarken*) (Windholz-Konrad 2008, 385–386). Armrings with such signs are more commonly found in hoards than graves (Janssens 1989–1990, 88). Usually, the bracelets with marks form sets where each bracelet wears a unique number mark. It was first proposed that they were made in the framework of intense exchanges to enable the ‘tradesman’ to ‘keep account of his rings’ or for the user to check if a set was complete (Thrane 1962, 99). In the case of the rings found in the Late Bronze Age Bleibeskopf settlement (Bad Homburg, Hesse, Germany), the number of marks can be related to the size of the bracelets: the more marks there are, the smaller the circumference of the armring is. As the use-wear marks show, the bracelets were probably used together as a unique set, and the marks were probably made by the craftsman for the user, indicating the place of each ring within this set and the order they should be worn (Müller-Karpe 1974, 204–207). The same interpretation is proposed concerning the marks on the nine bracelets from Bad Aussee (Austria), where they are believed to correspond to the positioning order of the rings when worn (Windholz-Konrad 2008, 386–387).

The rings coming from the Landzunge Zellmoos lake-shore settlement (Sursee, Switzerland) is different. Here, bracelets are matched by a certain number of marks forming pairs. The rings from the same pair are decorated with precisely the same patterns arranged identically. Therefore, the marks are interpreted as signs put on the raw bracelet by the founder before the decoration was chiselled on the ring’s surface (Weidmann 1983, 182–185). Marks found on bracelets can be explained in different ways and be linked with the production process, the exchange/trade, and the use of the rings.

More complex marking systems are also documented on Late Bronze Age tools between the Alps and the Carpathian Basin, especially at salt or ore mining sites (Mayer 1976; Primas 1997, 124). They are interpreted as property marks related to mining activities or quality control by workshops (Mayer 1976, 378–379). Finally, another kind of marking system exists on Late Bronze Age sickles, even though the marks are here very different from what we discussed above since they consist of ribs that were not made directly on the objects but the moulds before they were cast (Brunn 1958, 43–50; Thrane 1962, 99; Sommerfeld 1994; Jahn 2013, 197–202).

In the light of the different examples presented so far, the marks on the Champagneux sword's tang can be interpreted in various ways. First, as these signs are not visible on the sword's surface, we can rule out the hypothesis of marks targeting the weapon user. It is, therefore, more likely to be related to the production process. The simplest explanation could be to consider these signs as workshop or craftsman's marks, simply indicating this blade is the fifth produced in a series. As we already saw, the sword's tang was probably slightly modified after it was cast to fit in the inner space of the handle. The marks seem unrelated to the tang adaptation process (often involving hammering to widen this part slightly). In this case, the signs chiselled on the tang's surface did not affect the tang outline as the induced deformation is local and very limited. One possibility is that these signs could be part of a marking system used to match a blade with a hilt.

Very little, or next to nothing, is known about the workshops where the octagonal-hilted swords were produced. About 250 swords belonging to this type are known – covering approximately 150 years (Bunnefeld 2014), indicating an average production of fewer than two swords per year. Although it is difficult to give a precise estimation of the number of octagonal-hilted swords that were produced in total, the production of this kind of weapon was probably somewhat limited. We should not picture large workshops with many craftsmen working on a large number of swords simultaneously, but instead small workshops or singular craftsmen mastering the whole or at least most of the *chaîne opératoire*. The similar composition of the Champagneux sword's hilt and blade (tab. 1) is consistent with the hypothesis whereby a single craftsman or workshop is in charge of production. Within this framework, the marks may have proven helpful for the craftsman to identify which blade has to be adapted to which hilt when working on a few swords at once, meaning that a similar marking system should also exist on the handle, which was not observed on the sword from Champagneux. For example, these marks could have been included in the ornamentation of the hilt, which is not preserved here. Comparing these marks with the ones known on Bronze Age bracelets and tools may provide other explanations, such as a marking related to the length of the blade or a way to test the casting quality. As the Champagneux sword is so far the only sword where such marks were observed on the tang, it is difficult to go further in their interpretation.

CONCLUSION

Although the sword from Champagneux does not easily fit in the typological classification of this kind of object, the technical study shows that it perfectly matches the technical standards of the solid-hilted swords coming from the north-Alpine region between Bronze C and Hallstatt B1 (mid-15th–10th century BC). The blade was likely cast from the top of its elongated tang, as indicated by the distribution of the inner blows and shrinkage porosity concentrated in its upper third. It is associated with a hilt that probably was cast from the side of its pommel using the 'cire perdue' (lost wax) process. The wax model was likely built around a clay core and may have included a vertical stand going through the pommel – at the origin of the canal between the handle's inner space and the pommel's surface. Both parts were then fixed together by blocking one another and then adding two rivets on the guard. The 'counting marks' observed on the sword's tang may relate to the fixation process where the tang needs to fit the shape of the hilt so that both elements can be blocked together. The marks may have helped the craftsman identify the blade to be adapted to one specific hilt. There could also be other explanations for the marks; related to the length of the blade, for example, or the quality of the metal, but it is, of course, difficult to discuss these hypotheses based on only one sword. It would be interesting to conduct an extensive and systematic CT-scan campaign on octagonal-hilted swords handles and re-examinations of previous scans to look for similar marks on other swords, hopefully producing substantial advances in identifying the production of specific workshops and the way their production was organised.

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