Post-medieval printing type from Mainz and Oberursel, Germany, and the composition of early German type metal

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ABSTRACT: Early post-medieval type pieces used for printing have rarely been the topic of archaeometric research due to the scarcity of archaeological evidence. Extensive finds from Wittenberg, Germany, in recent years, however, stimulated far-reaching interdisciplinary research into early book printing history which brought together results from typographical, typometrical, historical and archaeometallurgical examination. As a consequence, three older finds from Mainz and Oberursel are reappraised archaeometallurgically. Chemical analysis shows that type composition is rather homogenous within single finds, but differs between find locations. Two major groups of ternary type metal containing lead, antimony and tin are identified, differing in the content of alloy additives and their ratios. The results suggest, however, that alloy compositions have been chosen carefully in order to provide low-fusing metals with acceptable hardness and good wear resistance. Comparisons with the Wittenberg type pieces indicates probable interaction of craftsmen from different regions.

Introduction

Since 2012, large-scale typographical, typometrical and archaeometallurgical investigations of type pieces from Wittenberg (Saxony-Anhalt, Germany) shed new light on early post-medieval printing culture (Berger *et al* 2013; 2015; Berger and Stieme 2014a; 2014b; Berger and Rode in press). About 3000 type pieces dating to the 16th century AD are known from all over the town which became one of the most important European printing centres during the Reformation. Martin Luther posted his theses at the gate of the local Castle Church in 1517 thereby introducing the most enduring changes in Christian world view. However, this would not have been as successful as it was without the printing press and the book printing (Moeller 1979, 30; Eisenstein 1991). The roughly contemporary type pieces from Wittenberg thus manifest a critical chapter of European history. But the artefacts are also crucial for understanding the craftsmanship, especially those of the book printers and type founders.

Apart from the Wittenberg finds, early printing letters had been uncovered in Lyon and Ortenbourg, France (Audin 1954; Francis 1973, 47), in Kralice nad Oslavou, Czech Republic (Fialová 1959), Basel, Switzerland (Tschudin 2001), Holár, Iceland (Hansen 2005, 10), as well as in Mainz and Oberursel, Germany (Pelgen 1996). A few single finds from Great Britain, mainly published online in the Portable Antiquities Scheme database (https://finds.org.uk), can be added to this short list. In addition, hundreds of type pieces from the 16th and 17th centuries are preserved in the Museum Plantin-Moretus (Antwerp, Belgium) (Storme *et al* 2013).

The German finds from Mainz and Oberursel are the closest analogues to the Wittenberg type and are the topic of this paper which expands what is known of early printing type. The focus here is on the metallurgical aspects as F S Pelgen (1995; 1996) has already described the type from archaeological, typometrical and typographical viewpoints so only brief summaries of these aspects are presented below. The results and findings of the archaeometallurgical analyses are com-

Figure 1: Historical Mainz showing the find spots of the type from 1) Karmeliterstraße, 2) Hintere Flachsmarkstraße and 3) the copper matrix from the Holzhofstraße. The printing shops are 4) Zum Maulbaum and 5) Zur Wetterschellen (after Falck 1978, Karte 34C).

pared with those of the letters from Wittenberg, which are 25–50 years older, to give a more comprehensive picture of early German type metal and to identify possible exchanges within the printing culture.

Archaeological and historical background

The type pieces from Mainz

During an archaeological excavation in 1986 in the city of Mainz (Rhineland-Palatinate, Germany) 191 type pieces from the early post-medieval period were found (Figs 1–2). They came from the backfill of a latrine at the Karmeliterstraße 14 site which could be dated to the first third of the 17th century AD (Pelgen 1996, 182). This dating is primarily based on several glass vessels within the same feature that are typical of that time. The typographical characteristics of the type could not be used for a more exact dating because fonts (also called typefaces) are usually conservative designs with only slight modifications over time, especially since the early Baroque era (Kapr 1996). Furthermore, the faces of the type pieces from Mainz are mostly not well preserved, thus complicating the determination of font characteristics.

The type was found in the old town of Mainz where the Karmeliterstraße once crossed the Einhorngäßchen. The latter street no longer exists today. This corner site with the old numbering Karmeliterstraße 14/Einhorngäßchen 1 is still situated opposite to the Karmelite monastery and the Karmelite church not far away from the Rhine (Fig 1:1). From the city chronicles, especially the Häuserbücher (house books) from the years 1450 and 1620, and old city maps it is known that in the 16th century a house named '*Zum Flörsheimer*' stood on the site but it was replaced with a building named '*Zum Einhorn*' in the early 17th century (Falck 1978, 253, no 120; Pelgen 1996, 193–4). A tavern and a brewery were

Figure 2: The type from an early 17th century latrine at Karmeliterstraße 14 in Mainz. The large type piece (bottom left) is 21.7mm by 18.1mm.

established there later on. It is therefore surprising to find plenty of type pieces within the latrine here because they would only be expected if a printing shop had existed here. Such find contexts are typical for the type from Wittenberg where famous printers could be identified as owners (Berger *et al* 2013; 2015; Berger and Stieme 2014a; 2014b; Berger and Rode in press). Because no printing shop existed at this site in Mainz, it is difficult to explain how the type pieces found their way into the latrine, or who their owner was.

However, in the period of interest (first third of the 17th century) two printing shops existed at other places in Mainz: The first was called '*Zum Maulbaum*' headed by Johannes Albin and his widow in the years between 1598 and 1622 and by Anton Strohecker until 1631 (Baader 1958; Reske 2015). The shop was located at the crossroad Hintere Christophsgasse / Birnbaumsgasse (Pelgen 1996, 201) but was destroyed in course of the siege by the Swedes during the Thirty Years' War (Fig 1:4). The second printing shop was known as '*Zur Wetterschellen*' under the leadership of Balthasar Lipp and Hermann Meres from 1598 to 1635 (Pelgen 1996, 193). It was situated at the Flachsmarkt just 250m away from the find spot of the type pieces (Fig 1:5), though no direct relationship can be established between this printing shop and the type finds. Despite this, it seems reasonable that the type from the Karmeliterstraße originated from one of the named printing shops or a third one as suspected by Pelgen (1996, 193) and others. The existence of the latter, however, is not yet proven.

In addition to the Karmeliter type, a single type piece with a very large point size and a copper matrix had been found in the 1980s at other places in Mainz. The matrix that served for producing the faces of type pieces (Nisters 1989/90; Pelgen 1996, 202–3) came from a latrine in the Holzhofstraße (formerly just outside the town wall) (Fig 1:3). The type was found at the Hintere Flachsmarktstraße (Pelgen 1996, 200), again in a latrine (Fig 1:2). Both finds date from the last quarter of the 16th century and are direct evidence of local type founding since the type still possesses parts of its sprue (Fig 3). This relic from the casting process was usually removed by the founder leaving a groove at the same position (Fig 4). As a result, in its present state the type from the Flachsmarkstraße was not suitable for printing and it has to be seen as casting waste from a type founder or book printer. Because historical sources do not mention a type foundry at that time (*cf* Bauer and Reichardt 2011), Pelgen (1996, 200–3) believes that the two objects belonged to the only printing shop which existed in the second half of the 16th century (*Zum Maulbaum*) and which was probably associated with a foundry. The second printing shop (*Zur Wetterschellen*) that was situated close to the find spot of the single type piece (Fig 1) is less likely because it was only working from 1598 when the object had already been thrown away (Pelgen 1996, 193; Reske 2015). Looking at the face of the type, representing the capital letter 'L', this could well be related to several prints of *Zum Maulbaum* in which it was often used in headings or as an initial (Fig 3). However, other printers (in other towns) used this typeface as well, so it is not possible to determine its original owner securely. Moreover, the copper matrix was not necessarily utilised by a resident founder, but could also represent a tool of an itinerant craftsman.

Figure 3: Type piece with a sprue (just visible at the back) found in a latrine of the late 16th century at Hintere Flachsmarkstraße in Mainz (point size 13.6mm, type height 25.5mm, set width 11.3mm). Below, the reflected face of the type is compared with an upper-case L in a printing by Franz Behem from 1566/1573.

The type pieces from Oberursel

In 1978, 107 type pieces were discovered in the centre of Oberursel, a small town in the Taunus region (Hesse, Germany) just 35km NE of Mainz and not far away from Frankfurt am Main (Figs 5–6; Kopp 1990, 17; Pelgen 1996, 203). The type was found during an archaeological excavation in the church of St Ursula beneath the plaster at the western entrance. This find context is odd, and it is thought that the objects came here during renovation of the church after the great town fire in 1622 (Pelgen 1996, 204). Most likely the entire find complex originated from the only print shop that had existed in Oberursel just 50m SE of the church (Fig 5:2). The workshop was founded by Nicolaus Henricus in 1557 and after his death continued under Cornelius Sutor. It was later led by Wendel Junghen, Wendel Meckel and Bartolomäus

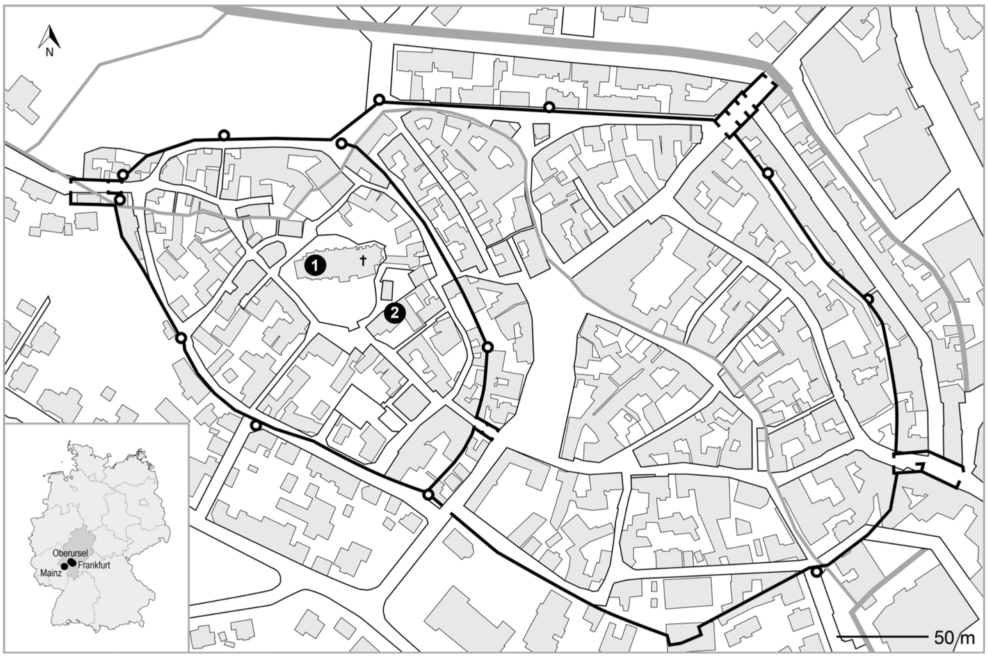

Figure 5: The old town of Oberursel showing 1) St Ursula church and 2) the location of the printing shop founded by Nicolaus Henricus in the 16th century AD (after Verein für Geschichte und Heimatkunde Oberursel eV 2009).

Busch until 1623, but there is no evidence of it after then (Kopp 1964; 1990). Because of this narrow timespan and because Kopp (pers comm) successful linked the type with several late prints from Oberursel by means of typography, the type can be dated into the first quarter of the 17th century like the type from Mainz. The letters from Oberursel now belong to the collection of the Vortaunusmuseum, Oberursel, but the type from Mainz is in private collections.

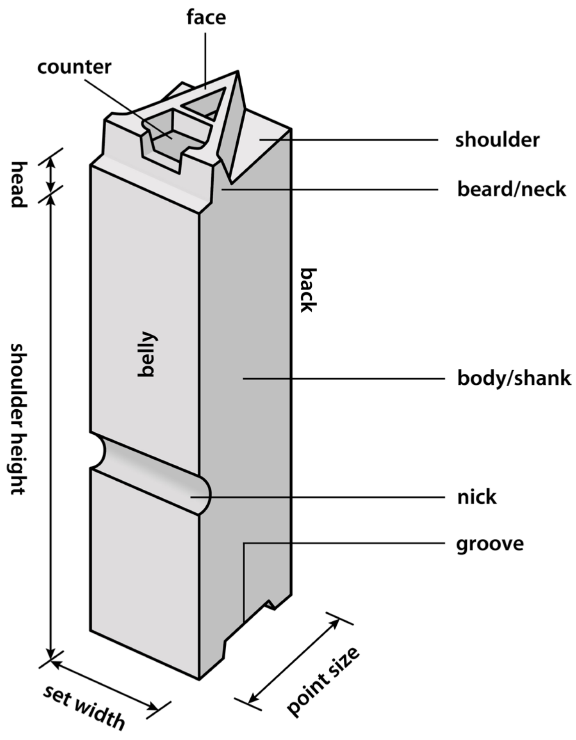

Figure 4: Terminology of printing type. Head + shoulder height = type height.

Typographical and typometrical features of the type

Typometrical characteristics

Typographical and typometrical terms and parameters (Eckersley *et al* 1994) are essential for all craftsmen involved in the printing process; the punch cutter, type founder, type setter and the printer (Wilkes 1990). All type features are necessary for the description of type pieces and printed fonts. The most important typometrical parameter is the point size which is the dimension from the belly to the back of the type body which is a measure of the font size (Fig 4); the larger the point size the larger is the font. Today, point sizes are standardised and are specified in the typographical point system, devised by François Ambroise Didot in 1770/1780, or the DTP point system used since the 1980s (Romano 2009), but in early printing no universal standards existed. Almost every printing shop had its own typometrical system (in order to prevent theft; Geßner 1740, 132), though the studies on the Wittenberg type showed that already in the 16th century first efforts were made to unify point sizes, at least at a local level (Berger *et al* 2013, Fig 4; Berger and Rode in press). The same applies to the type height which is the dimension of the type piece from its base to its face (Fig 4). Within a single printing shop, a high consistency of these two dimensions among type of the same point size is essential; otherwise no exact printing results could be produced. This requirement could only be fulfilled with a high precision casting mould, for example with the so-called *Handgießinstrument* (casting instrument) which was invented by Johannes Gutenberg in Mainz at about

Table 1: Typometrical characteristics (point sizes and type heights) of the printing letters from Mainz, Oberursel and Wittenberg, and their font groups (as defined by the Wittenberg type, cf Berger and Stieme 2014b; Berger and Rode in press). Average and standard deviation values in mm.

font group	Mainz		Oberursel		Wittenberg	
	point size	type height	point size	type height	point size	type height
A	-	-	2.95 ± 0.06	25.00 ± 0.06	2.96 ± 0.06	25.14 ± 0.11
B	3.49 ± 0.06	25.53 ± 0.10	3.49 ± 0.03	25.01 ± 0.08	3.53 ± 0.07	25.09 ± 0.17
C	4.26 ± 0.05	25.49 ± 0.10	4.25 ± 0.04	25.00 ± 0.07	4.38 ± 0.05	25.11 ± 0.22
D	4.76 ± 0.04	25.29 ± 0.11	4.86 ± 0.03	25.02 ± 0.05	4.91 ± 0.06	25.13 ± 0.25
E	6.01	25.51	5.92	25.06	5.88 ± 0.09	25.11 ± 0.10
F	6.60 ± 0.02	25.49 ± 0.02	-	-	6.63 ± 0.09	25.04 ± 0.12
J	13.26 ± 0.16	-	-	-	13.24 ± 0.9	-

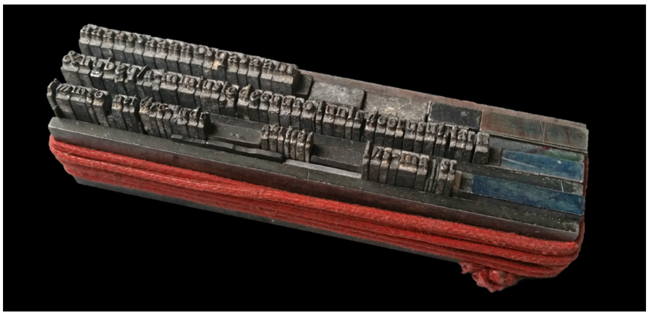

Figure 6: Type from Oberursel arranged for display (figure reflected). Full length c 96mm.

1440 (Bauer 1922; Reske 2010). This tool allowed the serial production of identical type pieces within a short time span.

Table 1 compares these two typometrical features of the type from Mainz and Oberursel with those from Wittenberg. Among the Mainz type (Karmeliterstraße and Flachsmarktstraße) six different font sizes (point sizes) occur; Oberursel has five sizes. This shows the font sizes at all three towns are identical (Table 1; Fig 7). The somewhat larger dimensions of the type from Wittenberg can be explained by the higher level of corrosion (*cf* Berger and Stieme 2014; Berger and Rode in press). Because of this coincidence, the letters (A–J) used to describe the font sizes of the Wittenberg type are also used for the Oberursel and Mainz type. Thus, type with 3.48mm point size from Mainz belongs to the same font group B as type from Wittenberg with similar point size. Unlike modern terminology which has specific names for each point size (*eg* Genzmer 1967, 29 for continental Europe), it is not known if the recognised groups had specific names in these early times.

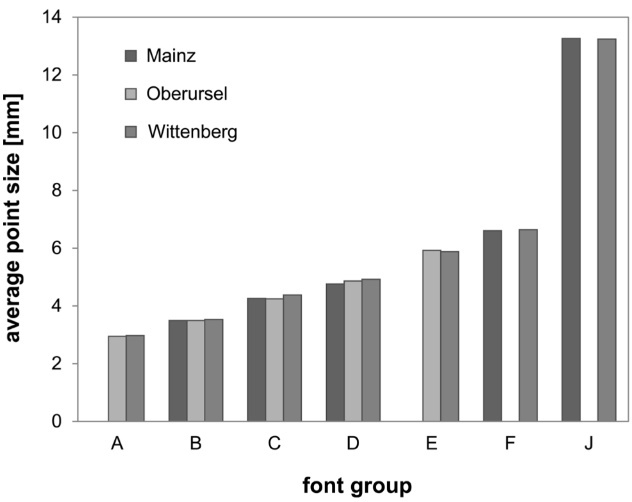

Figure 7: Comparison of averaged point sizes (font sizes) of type from Mainz, Oberursel and Wittenberg. The letters along the x-axis denote the different font groups defined during investigation of the Wittenberg type.

Differences are observed for the type height, *ie* the total length of the cast letter (Fig 4). The type from Mainz is approximately 0.5mm longer than those from the other two cities (Table 1). This slight difference is intentional, and crucial in terms of printing, and cannot be attributed to corrosion. Probably this is only specific to the printing shop where the objects had once been used, but it could also be a general characteristic of printing type from the end of the 16th and the beginning of the 17th century in Mainz. This assumption is supported by the height of the single type piece from the Flachsmarktstraße which is 25.5mm.

The typefaces

The find complexes from Mainz and Oberursel only display a small variety of fonts (typefaces). The type from the Karmeliterstraße in Mainz carries characters of only one typeface, known as Renaissance-Antiqua or Roman (Updike 1992; Kapr 1996; Dowding 1998). It was the most important font for early book printing in Europe which was almost always used for typesetting Latin and other foreign-language texts in the Holy Roman Empire of the German Nation. In German texts it often served to highlight foreign or special words instead.

Table 2: Composition of the type from the Karmeliterstraße in Mainz. Wt% values are means of nine measurements.

sample no	type no	font group/ font	Fe	Cu	Sn	Sb	Pb	Bi
MA-146278	182	B/blank	<0.05	0.26 ± 0.03	6.3 ± 0.2	8.1 ± 0.3	85 ± 0.5	0.28 ± 0.06
MA-146279	181	B/blank	<0.05	0.38 ± 0.06	6.1 ± 0.1	7.9 ± 0.2	85 ± 0.2	0.41 ± 0.04
MA-146280	164	B/*Antiqua*	<0.05	0.54 ± 0.04	7.2 ± 0.2	10.8 ± 0.3	81 ± 0.5	0.39 ± 0.04
MA-146281	154	B/*Antiqua*	<0.05	0.54 ± 0.03	5.1 ± 0.1	11.5 ± 0.1	82 ± 0.1	0.41 ± 0.05
MA-146282	151	B/*Antiqua*	<0.05	0.68 ± 0.03	5.9 ± 0.2	11.7 ± 0.2	81 ± 0.4	0.44 ± 0.04
MA-146283	140	C/blank	<0.05	0.41 ± 0.04	6.0 ± 0.1	9.3 ± 0.2	84 ± 0.2	0.47 ± 0.04
MA-146284	139	C/blank	<0.05	0.36 ± 0.03	6.1 ± 0.2	11.1 ± 0.2	82 ± 0.3	0.53 ± 0.04
MA-146285	82	C/Antiqua	<0.05	0.68 ± 0.05	2.2 ± 0.1	14.9 ± 0.2	82 ± 0.3	0.37 ± 0.02
MA-146286	73	C/Antiqua	0.22 ± 0.06	1.07 ± 0.04	2.2 ± 0.1	15.1 ± 0.2	81 ± 0.3	0.40 ± 0.03
MA-146287	51	C/Antiqua	<0.05	0.42 ± 0.03	6.9 ± 0.2	12.1 ± 0.1	80 ± 0.2	0.51 ± 0.04
MA-146288	50	C/Greek	<0.05	0.23 ± 0.01	6.3 ± 0.1	11.2 ± 0.2	82 ± 0.3	0.61 ± 0.06
MA-146289	36	C/*Antiqua*	<0.05	0.29 ± 0.03	2.8 ± 0.1	13.2 ± 0.1	83 ± 0.2	0.51 ± 0.03
MA-146290	34	C/Antiqua	<0.05	0.91 ± 0.05	8.6 ± 0.2	11.0 ± 0.2	79 ± 0.3	0.44 ± 0.05
MA-146291	26	C/Antiqua	0.05 ± 0.04	0.53 ± 0.06	6.4 ± 0.1	12.6 ± 0.1	80 ± 0.2	0.54 ± 0.06
MA-146292	38	C/Antiqua	<0.05	0.33 ± 0.02	6.0 ± 0.1	12.4 ± 0.3	81 ± 0.5	0.43 ± 0.05
MA-146293	132	D/blank	<0.05	0.53 ± 0.05	5.2 ± 0.1	10.3 ± 0.3	83 ± 0.3	0.51 ± 0.04
MA-146294	11	F/blank	<0.05	0.33 ± 0.02	5.2 ± 0.2	11.1 ± 0.3	83 ± 0.4	0.55 ± 0.04
MA-146295	8	F/blank	<0.05	0.27 ± 0.03	5.2 ± 0.1	11.0 ± 0.2	83 ± 0.3	0.49 ± 0.11
MA-146296	13	J/blank	<0.05	0.24 ± 0.01	4.2 ± 0.1	9.3 ± 0.3	86 ± 0.4	0.28 ± 0.05
MA-146297	12	J/blank	0.05 ± 0.02	0.24 ± 0.03	4.7 ± 0.2	9.2 ± 0.3	85 ± 0.4	0.57 ± 0.03
		mean	-	0.47 ± 0.23	5.6 ± 1.7	11.0 ± 2.1	83 ± 2.0	0.47 ± 0.10
		min	0.05	0.23	2.2	7.9	79	0.28
		max	0.22	1.07	8.6	15.1	86	0.61

Note: Antiqua denotes the Latin alphabet; both Roman and *italic* characters were identified.

The italic version of Antiqua, which occurs among the Mainz type along with the regular form, was used for highlighting purposes as well. Lowercase letters such as a, e, i, m, r, t and u clearly dominate both variants (54 in total) while only five capital letters (A, D, E, I and M) had been identified (Pelgen 1996, 186–91). Ligatures (double letters) and punctuation characters (commas, dots etc) are rare as well. Striking is the high number of the character 8 which occurs 29 times. In addition, 53 blanks have been recognised which served for inserting spaces between words and letters. Two Greek letters (ψ and ϑ), representing an autonomous typeface, complete the type repertoire from the Karmeliterstraße (Pelgen 1996, 187).

Regular and italic Renaissance-Antiqua also predominate within the Oberursel letters, but in contrast to those from Mainz only lowercase letters are present together with some ligatures, punctuation characters and blanks (Fig 6; Pelgen 1996, 206–8). However, two examples of the lowercase letter e in the Fraktur (Gothic) typeface are present (Fig 6). Fraktur was the most frequently used typeface throughout protestant Germany, especially for German texts which dominated book printing during the 16th up to 19th century (Updike 1922; Kapr 1993). The capital letter L on the type piece that was found in the Flachsmarktstaße in Mainz (Fig 3) also belongs to the Fraktur typeface.

Summing up, the font and character spectrum at both locations are rather limited with many characters that are under-represented or missing completely. Yet it should be borne in mind that the excavated type represents only a small part of the original workshop inventories. The whole assemblages of the printing shops must have been considerably larger; otherwise the shops would not have been able to operate.

Table 3: Composition of the type piece from the Hintere Flachsmarktstraße in Mainz. Wt% values are means of nine measurements.

sample no	find no	font group/ font	Fe	Cu	Sn	Sb	Pb	Bi
MA-146298	84/1/MH/56	J/Fraktur	<0.05	0.72 ± 0.13	7.9 ± 0.2	6.1 ± 0.2	85 ± 0.2	0.70 ± 0.05

Note: Fraktur denotes a blackletter (Gothic) typeface.

Scientific examination: Materials and methods

As with the point sizes and type heights, early type metal was not standardised, in contrast to modern ones (Fry's Metal Foundries 1956; NDR 1963). Moreover, so far the composition of Gutenberg's first type is not known. Some scholars believe that they were made of tin alloys (Giesecke 1949) which seems to be misleadingly proposed by the *Pirotechnia* of Vannoccio Biringuccio from the 16th century AD (Smith and Gnudi 1990, 374–6). Even if this assumption is not unreasonable for the earliest letters one may suspect that lead became the main component of printing type relatively quickly because of its cheapness compared to tin (Blanchard 2005). Tin and also antimony might therefore have only been alloying additives since the second half of the 15th century which is attested by some metal analyses of early printing letters (Audin 1954, 92–3; Fialová 1959, 90; Voet 1972, 95; Storme *et al* 2013; 2015; Storme 2016).

Several type pieces from Mainz and Oberursel had already been analysed in a pioneering study on behalf of Pelgen (1996) and by Kopp (1990). However the results, especially of the Mainz type are unsatisfactory. The presence of antimony (Sb) and tin (Sn) was verified, but the concentrations of the individual metals are not known because their contents were given as total Sb+Sn. Pelgen (1996, 198) lists gallium (Ga) with up to 1.5 wt% as another alloy component which is inexplicable from a metallurgical and geological viewpoint: Ga rarely occurs in nature in high concentrations and is in addition mainly associated with aluminium, zinc and germanium minerals (especially bauxite, sphalerite and germanite) rather than tin, antimony and lead ores (Burton *et al* 1959). Since it is a lithophile element it becomes slagged during smelting. It is thus thought that Ga is just an artefact of the analysis with the scanning electron microscope (SEM) used due to overlaps of peaks in the X-ray fluorescence spectra. One of the X-ray emission lines of lead (Pb L_ι at 9.18keV) and a further two (Pb $L_{\alpha1}$ and Pb $L_{\alpha2}$ at 10.55 and 10.45keV) overlap with the Ga K_α and Ga K_β lines (at 9.24 and 10.24keV) thus giving false results for Ga if the Ga L lines at low energies are not checked. The use of SEM also explains why Sn and Sb are summed because their X-ray lines partially overlap and at that time a precise quantification was not possible without reference materials.

Table 4: Composition of the type from Oberursel. Wt% values are means of nine measurements.

sample no	type no	font group/ font	Fe	Cu	Sn	Sb	Pb	Bi
MA-147910	10	B/Antiqua	0.07 ± 0.05	0.33 ± 0.03	3.7 ± 0.1	14.6 ± 0.2	81 ± 0.3	0.55 ± 0.03
MA-147911	18	B/*Antiqua*	0.08 ± 0.04	0.22 ± 0.04	5.1 ± 0.2	10.6 ± 0.5	83 ± 0.3	0.78 ± 0.05
MA-147912	27	C/Antiqua	0.15 ± 0.06	0.39 ± 0.08	3.6 ± 0.1	12.8 ± 0.3	82 ± 0.6	0.58 ± 0.05
MA-147913	29	C/Antiqua	0.08 ± 0.02	0.57 ± 0.02	3.8 ± 0.2	12.5 ± 0.5	82 ± 0.5	0.54 ± 0.05
MA-147914	36	C/Antiqua	0.08 ± 0.03	0.55 ± 0.04	3.3 ± 0.2	12.8 ± 0.6	83 ± 0.5	0.56 ± 0.06
MA-147915	37	C/Antiqua	0.14 ± 0.10	0.44 ± 0.03	3.7 ± 0.1	13.3 ± 0.3	82 ± 0.7	0.57 ± 0.07
MA-147916	44	C/Antiqua	0.10 ± 0.04	0.72 ± 0.03	3.8 ± 0.2	13.0 ± 0.4	82 ± 0.4	0.55 ± 0.03
MA-147917	54	C/Antiqua	0.09 ± 0.04	0.81 ± 0.03	3.7 ± 0.1	13.2 ± 0.4	82 ± 0.5	0.58 ± 0.08
MA-147918	76	C/Antiqua	0.08 ± 0.03	0.76 ± 0.03	3.3 ± 0.1	13.0 ± 0.2	82 ± 0.3	0.55 ± 0.05
MA-147919	86	D/Antiqua	0.06 ± 0.03	0.35 ± 0.03	3.7 ± 0.2	12.7 ± 0.3	83 ± 0.3	0.54 ± 0.05
MA-147920	92	D/Antiqua	0.08 ± 0.03	0.42 ± 0.04	3.4 ± 0.2	13.1 ± 0.4	82 ± 0.3	0.56 ± 0.08
MA-147921	93	D/Antiqua	0.06 ± 0.03	0.70 ± 0.05	3.9 ± 0.2	13.3 ± 0.3	81 ± 0.4	0.54 ± 0.07
MA-147922	95	D/Antiqua	0.08 ± 0.05	0.49 ± 0.03	3.4 ± 0.2	13.2 ± 0.4	82 ± 0.4	0.53 ± 0.08
MA-147923	100	D/Antiqua	0.08 ± 0.01	0.36 ± 0.03	3.5 ± 0.2	13.0 ± 0.4	82 ± 0.4	0.56 ± 0.04
MA-147924	101	D/blank	0.11 ± 0.08	0.18 ± 0.05	8.8 ± 0.4	5.0 ± 0.3	85 ± 0.4	0.57 ± 0.07
MA-147925	102	D/blank	0.09 ± 0.02	0.18 ± 0.02	1.36 ± 0.13	9.7 ± 0.4	88 ± 0.5	0.54 ± 0.04
MA-148037	9	B/Antiqua	0.09 ± 0.03	1.07 ± 0.13	3.6 ± 0.2	14.9 ± 0.5	80 ± 0.4	0.55 ± 0.06
MA-148038	31	C/Fraktur	0.07 ± 0.03	0.56 ± 0.03	3.0 ± 0.1	12.2 ± 0.2	84 ± 0.7	0.56 ± 0.04
MA-148039	45	C/Fraktur	0.43 ± 0.02	0.46 ± 0.04	3.5 ± 0.2	14.2 ± 0.3	81 ± 0.3	0.56 ± 0.06
MA-148040	73	C/Antiqua	0.07 ± 0.05	0.49 ± 0.03	2.8 ± 0.1	11.9 ± 0.3	84 ± 0.3	0.62 ± 0.04
		means	0.11 ± 0.08	0.50 ± 0.22	3.7 ± 1.7	12.5 ± 2.1	83 ± 1.8	0.57 ± 0.05
		min	0.06	0.22	1.36	5.0	81	0.53
		max	0.43	1.07	8.8	14.9	88	0.78

Notes: Antiqua is the Latin alphabet; both Roman and *italic* fonts were identified. Fraktur denotes a blackletter (Gothic) typeface.

In order to overcome both these problems new analyses on the Mainz type were made by the author using an energy dispersive X-ray fluorescence spectrometer (EDXRF), Fischerscope X-ray XAN 150, Co Helmut Fischer, Germany, at the Curt-Engelhorn-Zentrum Archäometrie in Mannheim, Germany. This device is equipped with a tungsten X-ray source that was run at 50kV for all measurements. The primary X-ray beam was filtered with an aluminium foil before sample excitation and collimated to 2mm representing the diameter of the measuring spot. The fluorescence spectrum was recorded with a silicon drifted detector (SDD) cooled by a Peltier element (energy resolution: ≤150eV at Mn K_α). The quantification was carried out with self-produced metal standards because certified reference materials were not available. The same device and experimental setup had already been employed for the analyses of the Wittenberg type, hence the datasets are directly comparable.

Twenty type pieces from the Karmeliterstraße and the single one from the Hintere Flachsmarksstraße in Mainz were selected for the study, including objects of three point sizes, different typefaces as well as blanks (quadrats). The investigation also involved 20 type pieces from Oberursel (Fraktur and Antiqua) because Kopp (1990, 17) reported on the analysis of only a single piece. All the type pieces examined are listed in Tables 2–4 with their original numbering allocated by Pelgen (1996). Each type piece was sampled with a drill providing turnings for analysis. This was done to ensure that the analytical results were not affected by the inclusion of corrosion products since all type pieces are covered with a corrosion layer and the bare metal is exposed only at a few places. This is another issue with the previous investigation of the Mainz type is that most of the analyses were performed on 'lightly-corroded and concretion-free areas' (Pelgen 1996, 198); only one out of 15 analyses was carried out on sound metal. This added to the imprecision of the results since metal corrosion can alter element ratios drastically (*eg* Robbiola *et al* 1998). The influence of the corrosion layer on the interpretation of the metal composition will be discussed below.

Results and discussion

The type metal

The results (Tables 2–4 and Figs 8 and 9) show the type from Mainz and Oberursel are lead alloys with significant amounts of Sn (5.6 ± 1.7 and 3.7 ± 1.7wt%) and Sb (11.0 ± 2.1 and 12.5 ± 2.1wt%) respectively, but no detectable Ga. Bismuth (Bi), copper (Cu) and in many cases iron (Fe) too are only observed in low concentrations. The latter elements should therefore be considered as impurities from the ores or the founders' tools rather than deliberate additions to the alloy. In particular, Bi (means 0.47 ± 0.10 and 0.57 ± 0.05wt%) is often observed in archaeological lead or pewter objects (Brownsword and Pitt 1990; Kuleff *et al* 1995; Hall and Richardson 2004) which is probably due to its association with lead and tin minerals, *eg* galena and cassiterite (Ramdohr 1975, 706, 766; Ball *et al* 1982). In addition, Bi cannot be removed completely from Pb and Sn, even with the early post-medieval pyrometallurgical processes (Tafel and Wagenmann 1953; Wright 1982; Pernicka and Bachmann 1983; L'Héritier *et al* 2015). Cu

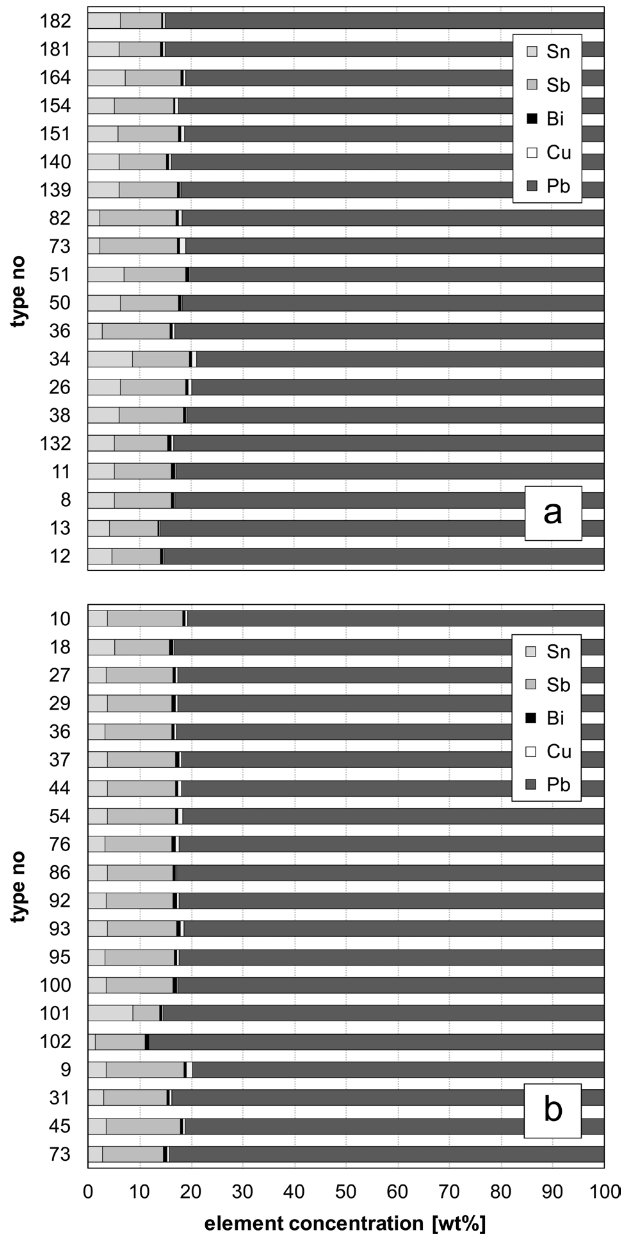

Figure 8: Normalised chemical composition of the sampled printing type from a) Mainz and b) Oberursel. Numbers on the y-axis correspond to the type numbers in Tables 2 and 4.

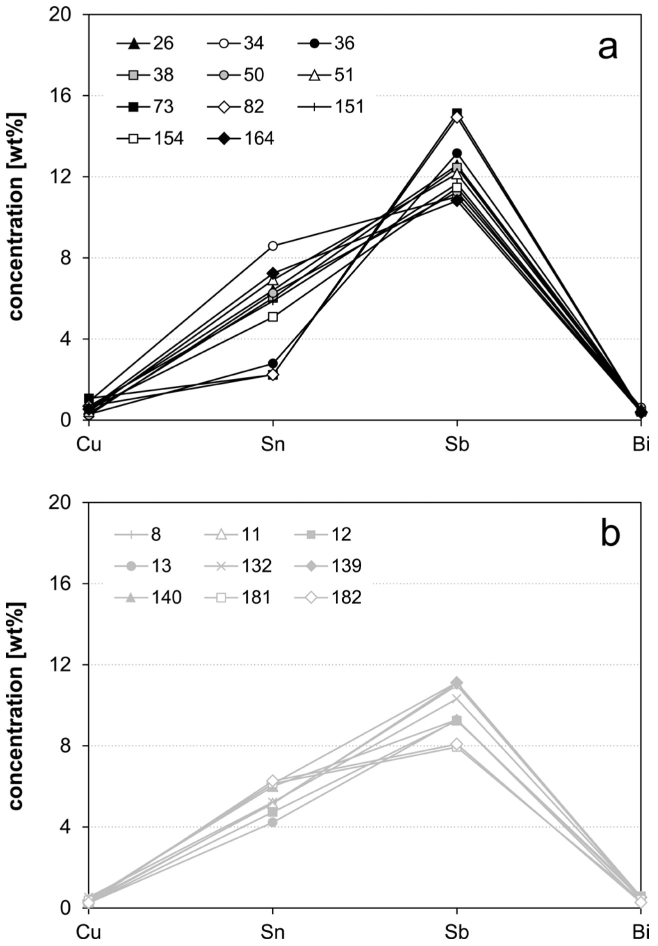

Figure 9: Elemental patterns of a) type letters and b) blanks from Karmeliterstraße in Mainz. Data dots are connected by lines only to aid legibility. Sample numbering corresponds with Figure 8a and Table 2.

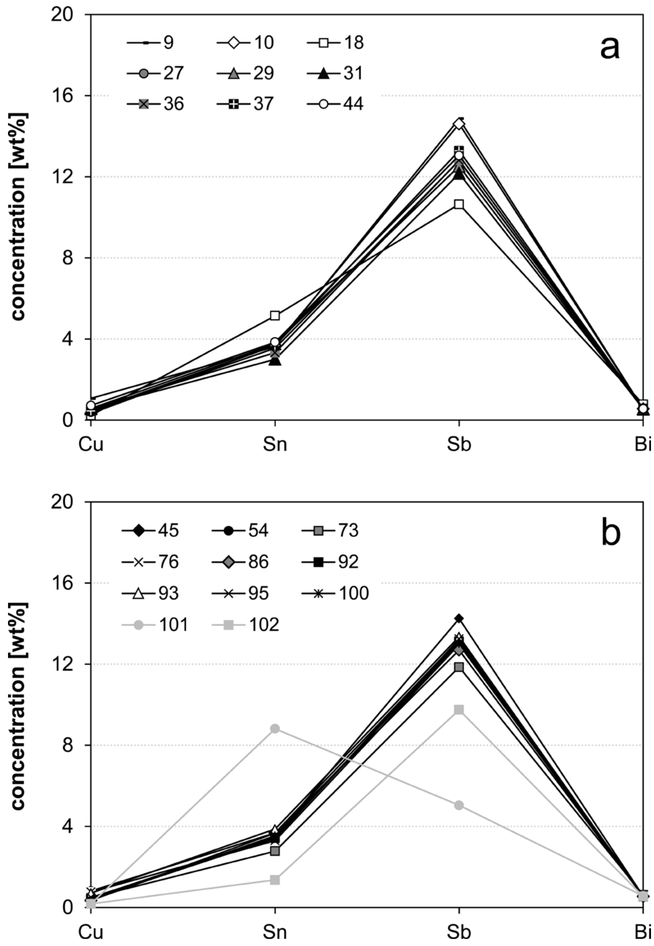

Figure 10: Elemental patterns of the Oberursel type. The grey symbols represent two blank type pieces. Sample numbering corresponds with Figure 8b and Table 4.

and Fe could originate from the ores as well (tin, lead, antimony ores), but process-related origins must be also considered: During hot working of type metal Fe and Cu based tools were often used, for instance melting pots, ladles and the *Handgießinstrument* with copper matrices (Geßner 1740, 130–3; Wilkes 1990; Tschudin 2001, 156). Depending on time, melt temperature and degree of remelting (Fry's Metal Foundries 1956, 57), Fe and Cu traces could have been absorbed by the type alloy. The only exceptions are three type pieces (MA-146286, MA-146290 and MA-148037) which have Cu contents of about 1wt%. This amount might indicate intentional alloying in order to provide four-phase alloys.

All the remaining type pieces are ternary Pb-Sb-Sn alloys. The alloying additions never exceed 20wt% in total (Fig 8) which is lower than Pelgen's (1996) results which indicated mean contents of 25wt% Sn+Sb. All the printing type analysed has less Sn than Sb except one piece from Oberursel (MA-147924) and the single one from the Flachsmarktstraße in Mainz (MA-146298). The other objects from Mainz have Sb contents between 10–12wt% and often twice that of the Sn content which is 5–6wt% (Fig 9). In contrast, the Oberursel type has slightly higher Sb contents (12–13wt%) while the Sn content (3–4wt%) is only half of that of the Mainz type (Fig 10); this corresponds to a Sb:Sn ratio of 3:1 or 4:1, demonstrating that different alloys were used in Oberursel and Mainz. Almost throughout the type from Oberursel the element contents are very similar, regardless of which point size or font is considered (Figs 8b and 10). Type with Fraktur characters is made from the same alloy as the regular and italic Antiqua printing letters. This observation underlines their origin in a single printing shop and in some cases one might even recognise type pieces originating from the same metal batch (*eg* MA-147922 and MA-147923).

The same applies to several pieces from the Karmeliterstraße (*eg* MA-146294 and MA-146295), although the variation within this group of type is somewhat larger, perhaps due to repeated metal recycling. Nevertheless, the overall similar composition (Figure 9a) also suggests origins in a single workshop. It is, however, noteworthy that other metal compositions also occur within this group: Three type pieces have exceptionally low Sn concentrations (2–3wt%) but Sb contents six or seven times higher (13–15wt%). Type nos 73 and 82 may be from the same metal batch according to their matching element concentration (*cf* Table 3). Another three pieces, two of which are blanks of a common metal batch (nos 181 and 182), have distinctly similar Sn and Sb concentrations (Figure 9b).

The other sampled blank type pieces (Fig 9b) contain less Sb and Sn than most of the other type, yet the element ratios are comparable (Sb:Sn = 2:1). Therefore, they certainly belong to the same metal group as the main group of finds and it is possible that the lower concentrations were chosen on purpose to reduce costs. In practice, however, the small differences would have been of little consequence. The higher Sn (8.8wt%) than Sb content (5.0wt%) of type no 101 from Oberursel and the lower alloying concentrations of type no 102 than the remaining type from that site are in contrast more significant (Fig 10b). Both are blanks as well.

Metal v corrosion

It is well known that natural corrosion alters metal composition. Elements developing poorly soluble minerals are preferentially retained in the patina region while elements with soluble compounds are often lost (Robbiola *et al* 1998). As a consequence, the composition of the patina may be distinctly different from that of the original metal, so surface measurements should be avoided whenever possible. Fortunately, sampling of the Mainz, Oberursel and the Wittenberg type was allowed. However, since sampling will probably not be possible on other early post-medieval type (from Lyon, Kralice nad Oslavou, Antwerp and Hólar on Iceland) for conservation reasons, the potential of surface analysis will be briefly addressed below.

A pilot study provided data on the composition of the core metal and of the surface of the type pieces. The analyses were carried out on the Mainz type with the same XRF device under the same conditions; the only difference was that nine single analyses of the corroded surfaces were performed *in situ*. The compositions of the sound metal (described above) are compared with the results from the surface analyses (Fig 11). Judging from the mean values, almost every type piece has significantly higher Cu, Sn, Sb and Bi contents at the surface, often 1.5 times or twice those of the uncorroded metal. A systematic relationship between surface and metal composition cannot be observed, but there is enrichment in all constituents relative to Pb, the matrix

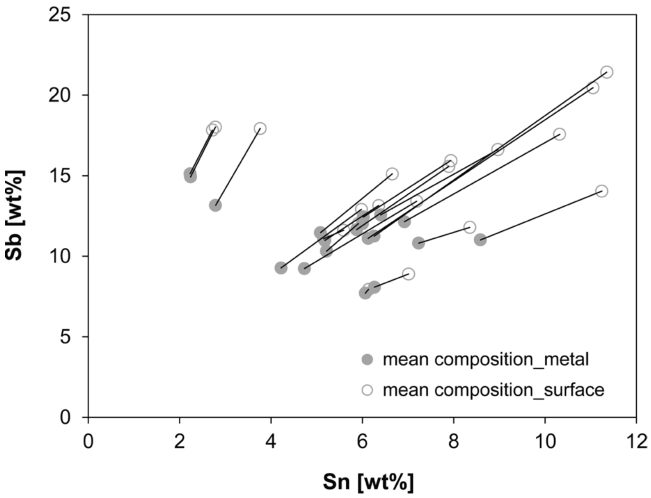

Figure 11: Sn v Sb content of uncorroded type metal (solid circles) and associated corrosion crusts (open circles). Analyses of the same type piece are connected by a line. Each point is an average of nine measurements.

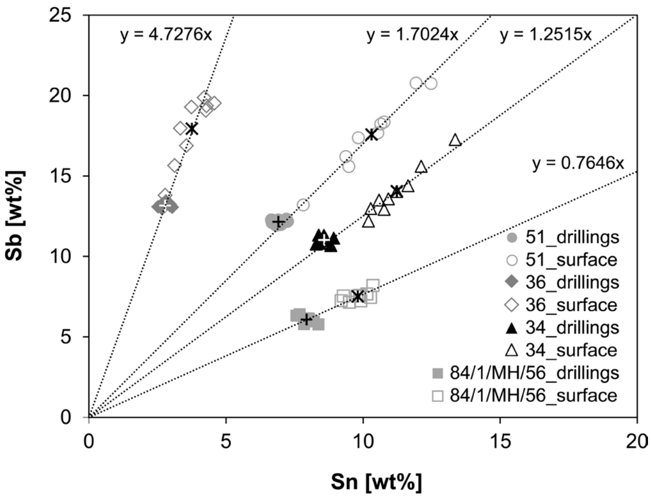

Figure 12: Variation and correlation of single measurements (open and solid symbols) and means (crosses) of four type pieces from Mainz with different Sb/Sn ratios. Note that the trend lines of means all pass through the origin. Sample numbering corresponds with Tables 2 and 3.

metal. Interestingly, the Sn/Sb ratios of the core often coincide with those of the corresponding corrosion crusts. The differences of the ratios of original to corroded metal is only 0.2 to 2.8% for a single type piece (Fig 13), so it seems to be possible to reconstruct the relative relationship of Sn and Sb of the original metal by determining the ratio in the patina. It is, however, impossible to infer the absolute element concentrations. This is demonstrated in Figure 12 which shows the distribution of nine single measurements at the surface of four pieces of type compared to nine measurements of the corresponding drillings. Although there is good correlation between Sn and Sb (all points and the means plot on the same line), the data displays high variance. The data for the metal, in contrast, plots within a narrow

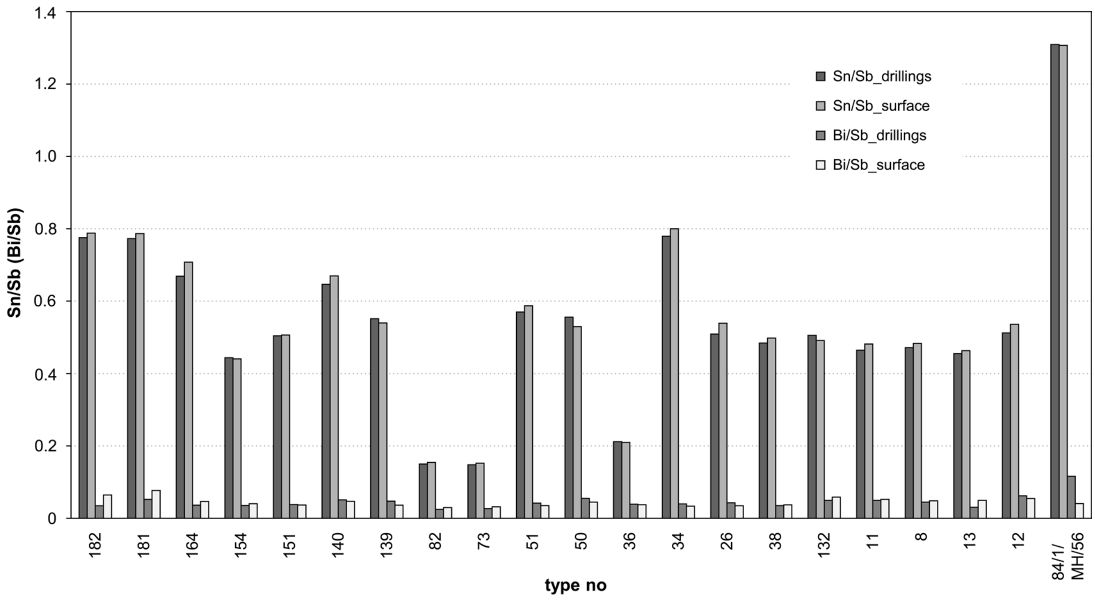

Figure 13: Comparison of Sn/Sb and Bi/Sb ratios of uncorroded type metal and corresponding corrosion crusts.

range at lower concentrations.

The Bi/Sb and Bi/Sn ratios of the metal and the patina show much poorer correlation which is also true for the ratios of Cu with the other components. As a rule, high differences, up to 30%, between patina and metal do occur (Fig 13). This discrepancy between major and minor elements is possibly linked to higher analytical errors at low concentrations, but also the random behaviour of Cu and Bi during corrosion must be considered. The latter point might be underlined by the results of the single type piece from the Hintere Flachsmarkstraße in Mainz. Both the Bi/Sb (Bi/Sn) and the Cu/Sb (Cu/Sn) ratios of its patina are significantly lower than the ratios of the sound metal (Fig 13, 84/1/MH/56), in this case due to depletion of Bi and Cu. Sn and Sb in the patina are enriched relative to the metal, but their ratio is similar to that of the other Mainz type. This is also seen in Figure 12 (84/1/MH/56) where small variance in Sn and Sb contents between nine measurements in the patina on the type can be observed besides its higher mean value compared with that of the original metal. This indicates a homogenous patina composition and implies a similar corrosion behaviour of Sn and Sb as observed on the type from the Karmeliterstraße.

The analogous behaviour of Sn and Sb during corrosion is, however, difficult to understand. Considering the different standard electrode potentials of Sb (+0.15V for Sb^{3+}/Sb^{0}) and Sn (–0.14V for Sn^{2+}/Sn^{0}) one should expect anodic behaviour of Sn relative to Sb and thus a higher corrosion tendency of Sn. However, one must also consider the different solubility of Pb, Sn and Sb compounds that form during corrosion and the microstructure of the type metal. According to the Pb-Sb-Sn phase diagram (Osamura 1985), the type from Mainz should be composed of Pb crystals, (Pb+SbSn+Sb) or (Pb+SbSn) eutectic and/or Sb crystals (Figs 14 and 15a). Depending on the proportion of the alloying elements, most of the Mainz type should have primary Pb crystals, three type pieces should show primary Sb, and a further four primary crystals of SbSn intermetallic compound.

It is not yet well known how type metals and their metallic phases corrode under burial conditions. Only one recent study on the archaeologically-recovered type from Kralice addressed this field of research (Storme *et al* 2015), while a second one examined the corrosion phenomena on historical printing letters in the Museum Plantin-Moretus (Antwerp, Belgium) by comparing them with artificially corroded lead alloys (Storme *et al* 2013; Ghiara *et al* 2014). The latter study found Sb-rich type metals to be more prone to corrosion than alloys with low Sb or high Sn content whereas the study of Storme *et al* (2015) observed no clear correlation between metal composition and corrosion intensity. Storme *et al* (2015) did, however, recognise that Sb-rich alloys are more often seriously corroded. Moreover, both studies revealed the presence of metallic, non-corroded Sb or SbSn crystals within mineralised layers of Pb corrosion products, mainly Pb oxides and carbonates (Storme *et al* 2013, 314; 2015, 64).

Even though X-ray diffraction analyses of the Mainz type are still pending, metallic inclusions of SbSn had been observed in the corrosion crusts on the type from Wittenberg. Thus, the intermetallic compound and possibly Sb-rich crystals appear to behave as a cathode during corrosion and are more corrosion resistant than Pb-rich alloy components which are preferentially dis-

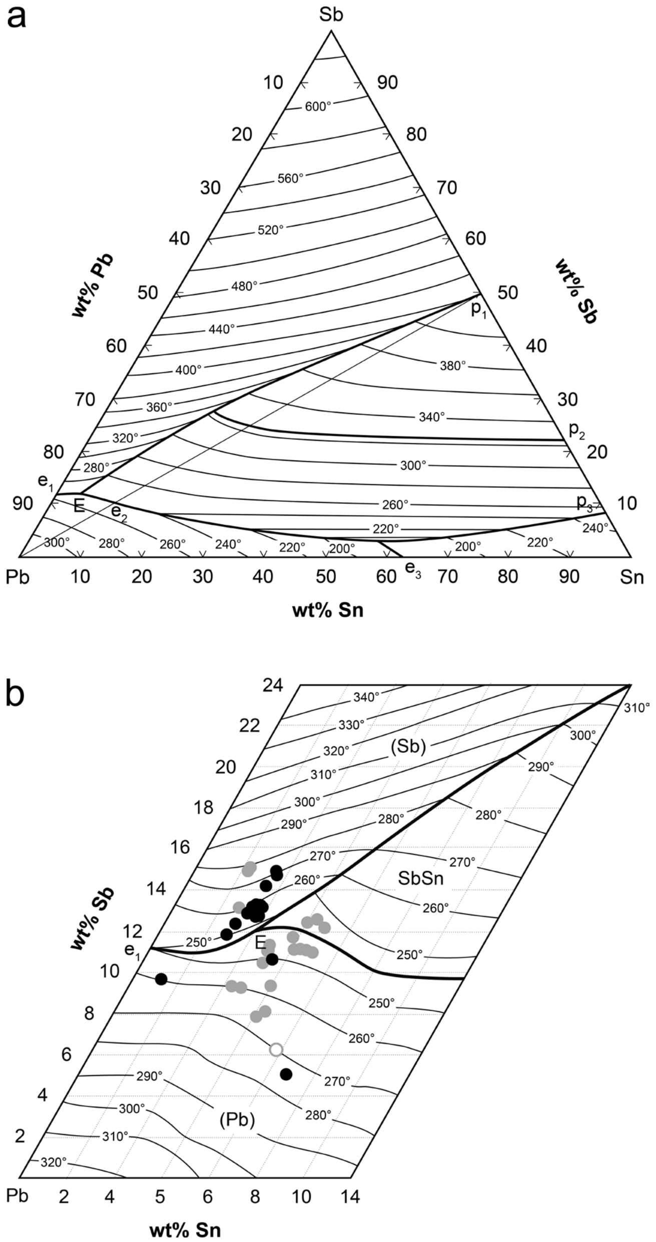

Figure 14: a) Ternary Pb-Sb-Sn phase diagram and b) detail showing the liquidus surface, isotherms, ternary (E) and binary eutectic (e_1, e_2, e_3) as well as peritectic points (p_1, p_2, p_3). Melting points and primary alloy phases of analysed type from Mainz (Karmeliterstraße: solid grey circles; Flachsmarkstraße: open grey circle) and Oberursel (black circles) can be estimated from the plotted data . The diagram ignores the low Cu and Bi contents of the metals (after Osamura 1985, figs 3 and 4, with additions).

solved. Often voluminous Pb corrosion products such as cerussite, hydrocerussite and pyromorphite developed as an outer layer of whitish colour above an inner layer of Sb and Sn corrosion products or non-corroded crystals. According to F S Pelgen (pers comm), the type from Mainz once also had a whitish outer patina region like the specimens from Wittenberg. It was removed during conservation and only some type pieces still retain traces of it. The X-ray measurements were carried out at the top of the grey-coloured inner layer which possibly contains

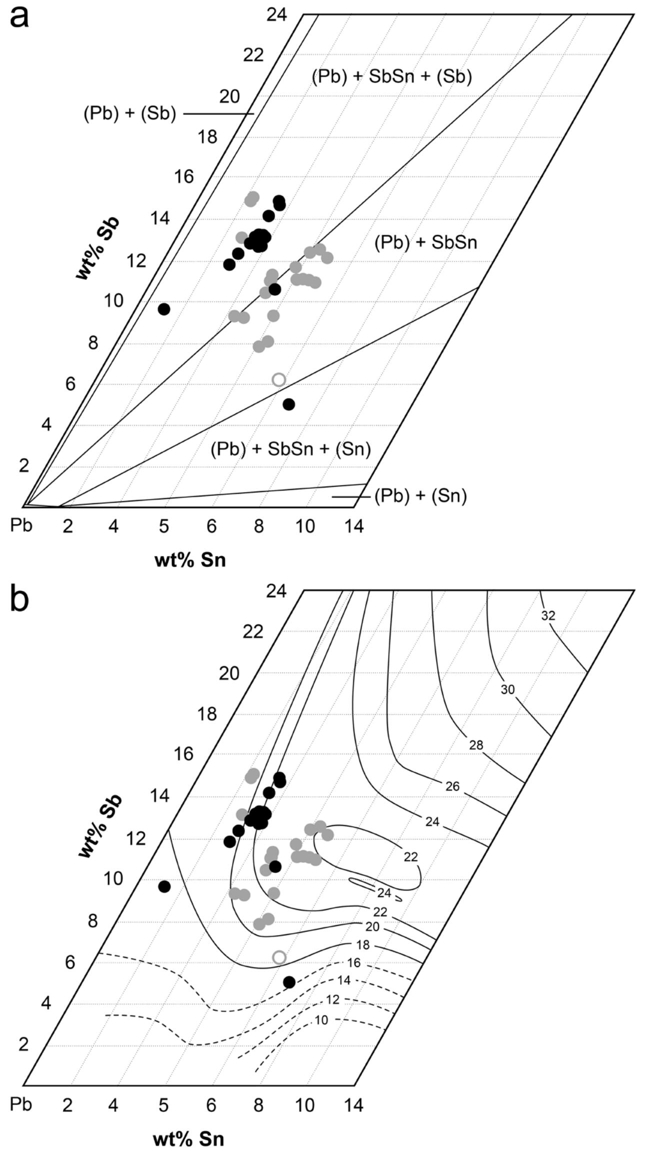

Figure 15: Isothermal sections of ternary Pb-Sb-Sn system at 20°C for the type from Mainz (Karmeliterstraße: solid grey circles; Flachsmarkstraße: open grey circle) and Oberursel (black circles) for evaluating a) the final microstructure (after Hilger 1995, fig 1) and b) Brinell microhardness (after Hedges 1960, fig 139).

uncorroded alloy phases. Since the corrosion crusts have not been studied in detail, one can only speculate on their micro-morphology. At present it is reasonable to assume that un-corroded compounds explain the preservation of the Sb/Sn ratio in the patina, but further investigations are necessary.

Conclusions

The printing letters from Mainz and Oberursel are unique historical and archaeological documents from the late 16th and early 17th century AD. They give an invaluable glimpse of contemporary book printing, which had been invented nearly 150 years before by Johannes Gutenberg at the same place (Mainz). Beyond that, they allow

Figure 16: The underside of the type from Oberursel (cf Fig 6) showing their feet and grooves. Parallel scratches running from one type piece to the next indicate simultaneous working with a plane within a single workshop. The type pieces hence belong to the same set. Image width c50mm.

insights into the composition of type metals that were already ternary Pb-Sb-Sn alloys, as in later times, with Pb as the main component. Compared to modern type metal for manual typesetting, which contains 28–29wt% Sb and 5–6wt% Sn (Fry's Metal Foundries 1956), the concentration of Sb, and in the case of the Oberursel type also Sn, is considerable lower. Taken together, the two alloying elements rarely exceed 20wt% and the low concentrations of Cu and Bi do not significantly change this; it is not even sure whether these metals were added deliberately in order to manipulate the properties of the type metal. Modern printing metal commonly contains 0.3wt% Cu for hardening purposes and sometimes Bi too. The low Bi concentrations (*c*0.5wt%) in the ancient type, however, would not have noticeably altered the metal's properties, such as hardness, tensile strength and melting temperature (Thompson 1931; Berger and Stieme 2014b).

Two different alloy groups could be identified among the examined type. Among the artefacts from the

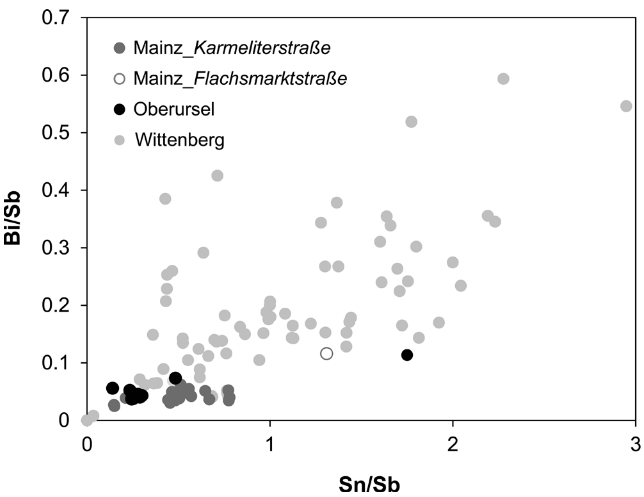

Figure 17: Comparative alloying element ratios of the printing letters from Mainz, Oberursel and Wittenberg.

Karmeliterstraße in Mainz metals with Sb contents roughly twice of that of Sn prevail, while the Oberursel type often have Sn contents that are only a quarter of their Sb concentrations. The data from Oberursel matches well the earlier analyses quoted by Kopp (1990). In general, the compositional variation is small, indicating that the Oberursel type was cast by the same craftsman within a short time span. This is confirmed by matching element patterns of some type pairs as well as production details on the grooves of the types (Fig 16). In contrast, the scattered composition of the Mainz type suggests production within a broader time span, but the data could also indicate recycling of unusable objects and re-melting of type metal. Nevertheless, the origin from the same printing shop or type foundry is possible. The occurrence of type with similar compositions like those at Oberursel is difficult to interpret. A possible explanation is that the type from both locations originate from the same workshop because in either Mainz or in Oberursel a type foundry at the turn of the 16th century is not yet known (Bauer and Reichardt 2011). However, type foundries in nearby Frankfurt am Main could have served as suppliers, for instance the great and famous foundry of Christian Egenolff and his successors (Baader 1958; Benzing 1959; Bauer and Reichardt 2011). Relationships between Frankfurt and several of the above-mentioned printers from Mainz and Oberursel might reinforce that idea (Kopp 2016; Reske 2015). Such a theory, however, would not be verifiable unless printing type from Frankfurt is excavated in the future.

Irrespective of their actual origins, the composition of the type metal was certainly not chosen by chance. As can be seen from Figure 14, the melting temperatures of the observed ternary alloys concentrate near the ternary eutectic point of the Pb-Sb-Sn system (12wt% Sb, 4wt% Sn, balance Pb) which is characterised by the lowest possible melting temperature of that system at 239°C (Osamura 1985). At the same time, such alloys exhibit rather high hardness values due to the presence of SbSn intermetallic crystals (Fig 15b) as well as good wear resistance properties. Last but not least, the casting of the metals was easier and caused fewer problems than alloys with higher melting temperatures (Fry's Metal Foundries 1956, 26–31; Hedges 1960, 317). All parameters taken together, the type from Mainz and Oberursel are most suitable tools for book printing at that time. The same might be true for the single printing letter excavated from the Hintere Flachsmarktstraße in Mainz, although the hardness value is somewhat lower and the melting temperature also lies above those of the other type (Figs 14 and 15). The different composition of this type possibly suggests another origin.

Regarding the types from the Karmeliterstraße, there is interesting analogy with the older printing letters found in Wittenberg. At this place, a metal group with Sb:Sn ratios of *c*2:1 was also observed (Berger and Stieme 2014b; Berger and Rode in press), even though the type contains considerable amounts of Bi, up to 2wt% (Fig 17). Ignoring the Bi content which might be specific to Wittenberg type founders, it appears that similar type metals were used in different regions of the Holy Roman Empire of the German Nation. We are far away from properly understanding the reasons for that observation and it is possible that this is only an accidental coincidence, but it is at least not unreasonable to claim that there were interactions between different type foundries/printing shops or their staff at that time, regardless of whether they were desired or not. Further supporting observations are the matching typometrical parameters, especially the same point sizes (Fig 7), which would not be expected if there were no interactions between different printing shops. We probably have to see these observations as the first attempts at unifying the typometrical systems, although F Geßner in the 18th century (Geßner 1740, 132) still reports on font sizes differing from one printing shop to another. Far more printing letters of early date are thus necessary to illuminate one of the most important chapters of history comprehensively.

Acknowledgements

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The printed text in Figure 3 is from *Der Erste Theyl.|| Aller des heiligen || Rœmischen Reichs Ordnungen* from the Universitäts- und Landesbibliothek Sachsen-Anhalt, Germany. Other figures are by the author.

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