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THE MERKEL CENTREPIECE BY WENZEL JAMNITZER: PROVING THE EXISTENCE OF A PREVIOUSLY UNKNOWN INSCRIPTION USING THE AGLAE PIXE MAPPING SYSTEM

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ABSTRACT The so-called 'Merkelsche Tafelaufsatz', a centrepiece made by the Nuremberg goldsmith Wenzel Jamnitzer in 1549, is one of the most famous masterpieces in goldsmithing from the sixteenth century. For the opening of the new Rijksmuseum, the centrepiece needed conservation treatment, which provided the opportunity for an in-depth examination. One of the most interesting findings concerned the so far undiscovered remnants of a largely removed etched text on the silver plaque fixed to the bottom of the piece. The traces of the text, which must derive from the time Jamnitzer made the centrepiece, were non-destructively analysed with the AGLAE mapping system at the Musée du Louvre, and some letters could be discriminated. These results shed new light on the history of the piece and a possible special occasion for which this object may have been made.

Introduction

The so-called 'Merkelsche Tafelaufsatz' (Merkel centrepiece) made by the Nuremberg silversmith Wenzel Jamnitzer (1507/08–1585) in 1549, and part of the collection of the Rijksmuseum, Amsterdam, is one of the most famous masterpieces in goldsmithing from the sixteenth century. The centrepiece (Figure 1) is approximately 1 m tall,[1] is made entirely out of partially gilded silver, and is well known for its life casts, plants and animals all cast from specimens collected in the wild.

During the past two years, the metal conservation department of the Rijksmuseum has been working on a large project involving the conservation of this centrepiece. Aside from seeking the appropriate cleaning techniques, researchers examined the way these lifecasts were constructed in order to understand the production technique used by Jamnitzer.

The main topic of this paper concerns a plaque, approximately 9 cm in width, which is fixed to the bottom of the centrepiece (Figure 2). As a text scroll can be discerned, seemingly without text, it was decided to investigate if any text was present. In the art historical literature on the centrepiece, the plaque is often mentioned, but has always been considered as having been left empty.[2] Until now, art historians have hypothesised that the centrepiece was intended as a gift to either Charles V or Philip II (successive rulers of the Roman Holy Empire) or was perhaps made for another special occasion. The literature also suggests that, as both Charles V and later Philip II did not visit Nuremberg, the plaque therefore remained empty.[3]

However, careful examination of the object shows that originally the plaque may have been inscribed. Using raking light, horizontal ridges were visible on the surface at regular intervals, which might indicate the presence of characters. Retrieving this text could shed new light on the history of this piece.

Figure 1. Merkel centrepiece, 1549, Wenzel Jamnitzer, Rijksmuseum Amsterdam, BK-17040-A.

Figure 2. Plaque screwed to the backside of the foot of the centrepiece, approximately 9 cm in diameter. The lines of the removed text are slightly visible.

History of the centrepiece

The centrepiece was made in 1549 in Nuremberg by Wenzel Jamnitzer, who called himself *aurifaber* (goldsmith), and who was known to all the courts in Europe. The commission was given by the city of Nuremberg, which paid 1321 guilders for the piece.[4] From 1549 until 1806, the object remained, presumably in its custom-made and gold leaf adorned leather case, in the so-called 'Gehaimen Privilegi Gewölblein' at the Rathhaus in Nuremberg.[5] In 1806, Napoleon's army took control of Nuremberg, leading to a money shortage in the city. Subsequently the city sold many of its artworks including the centrepiece, which was bought for 1250 guilders by the Nuremberg salesman Paul Wolfgang Merkel (hence its name). In 1880 the object was sold to Mayer Carl von Rothschild, a banker from the famous Frankfurt banking family for 600,000 marks.[6] His Parisian granddaughter, Baroness James Mayer de Rothschild, sold the centrepiece to the German banker and collector Fritz Mannheimer, who in the 1920s lived in Amsterdam and opened his house and collection to the public. Mannheimer died in 1939, after an extraordinary life that ended in bankruptcy, and his large collection was acquired by his creditors, the Dutch state. However, in 1941, Adolf Hitler bought the collection for his new museum in Linz. In 1944, following pressure from the creditors, the Dutch part of the collection was bought for 5.5 million guilders by the German Reich.[7] The collection was moved by train to the Altausee in Bayern, and another part was brought to Munich where, at the end of the war, the allied forces took detailed pictures of the centrepiece in the salt mines. After 1950 the piece was returned to the Netherlands, and is now part of the permanent collection of the Rijksmuseum. In 1951–52 it travelled to its first exhibition, in Nuremberg, the *Aufgang der Neuzeit*.[8] The last time the centrepiece was sent out on loan was in 1985 when it was on display at the Jamnitzer exhibition, also in Nuremberg.[9]

Preliminary research at the Rijksmuseum

Jamnitzer was known for both his etching and engraving techniques, hence both methods were investigated.[10] However, looking at other parts of the object, the most probable option was that the letters were etched rather than engraved. In addition to the large plaque, eight smaller plaques are attached to the centrepiece that bear the sentences of a Renaissance ballad to Mother Earth, 'who is carrying her load as easy as a mountain is carrying a burrow'. All these small plaques have letters in high relief (Figure 3) and microscopic examination of their surfaces indicates that all are etched. The borders of the letters are irregular and have a jagged appearance (Figure 4) – had these letters been engraved they would have sharp, regular edges.

The characters that are used on the small plaques are in Latin script and not in the Gothic script that was also in use at this period in Germany.[11] The small plaques are

Figure 3. One of the smaller text plaques on the object.

Figure 4. Detail of Figure 3 showing the jagged edges around the letters.

Figure 5. X-radiograph of the plaque. The white blotch in the centre is the screw thread soldered to the back of the plaque.

Table 1. Composition of the silver alloy as determined by XRF.

	Ag	Cu	Pb
Percentage (n=5)	87.5	12.1	0.4
Standard deviation	0.4	0.5	0.1

filled with a red or black organic lacquer, which makes the letters stand out against the background. The same kind of lacquer can be found on the large plaque.

Etching

The procedure for etching a scene or a text in silver has been in use for centuries. A wax- or tar-like substance, the etch ground, is evenly applied on the surface of the silver. The scene is then scraped away in the etch ground or, if high relief is required, the scene is ‘drawn’ with this substance directly on the silver. The scene is covered with an acid to dissolve the silver alloy. When the desired depth is reached, the etchant is removed and the silver is rinsed in clean water. The acid preferably removes the less noble metal, leaving an enriched silver surface. An unpublished research paper on etching techniques used on silver through the ages, based on old recipes, helped to make an inventory on possible etching techniques used on the Jamnitzer piece.[12] One of the oldest recipes dates from the eleventh century and uses mercury chloride and lemon juice to etch a scene. The characters or the design for decorating the silver are either scratched in a wax layer or built up in wax. In manuscripts from the sixteenth century and earlier, ‘strong water’ is mentioned, which normally refers to nitric acid. In later sources mostly nitric acid and sometimes mercury compounds are mentioned.

Scientific techniques

Different techniques, available at the Rijksmuseum, were employed to research the plaque, X-radiography being the first method used (Figure 5). The radiograph shows clear

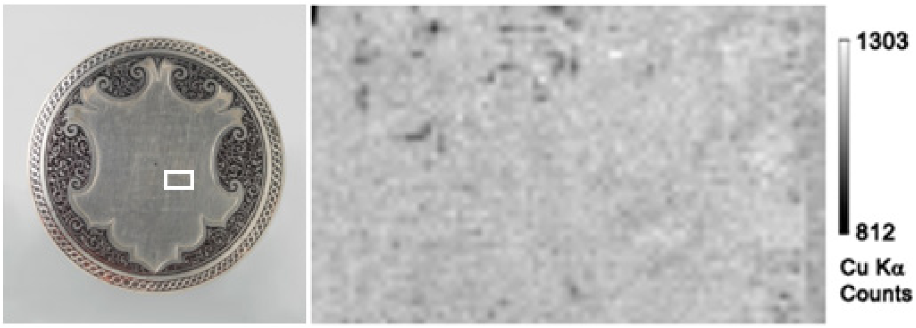


Figure 6. XRF analysis of a 12.25 × 20 mm area, located 2 cm to the right and 1.2 cm downward from the centre point of the plaque.

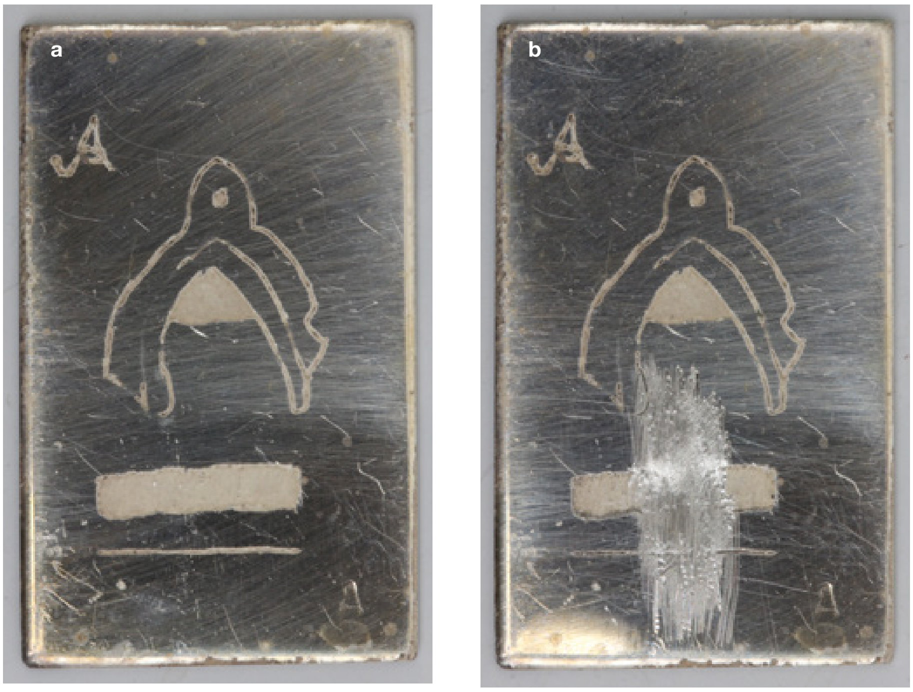


Figure 7. Etched test plate A (a) before and (b) after sandpapering.

differences in the thickness of the silver in certain areas; thicker metal appears whiter because of higher X-ray absorption.[13] Horizontal bands are visible, with thick and thin areas alternating. These bands cannot be associated clearly with any writing, although they indicate the existence of a pattern.

X-ray fluorescence (XRF)[14] analysis of a part of the plaque shows a difference in the copper/silver (Cu/Ag) ratio between areas that might contain characters and their surrounding areas. The resolution (250 μm²/pixel) of the XRF mapping did not seem precise enough to distinguish any characters. Furthermore, the time necessary (approximately 33 hours) to map this small portion of the plaque made it prohibitive to map the plaque in its entirety. The overall ratio of the alloy of which the plaque was made was determined by XRF[15] and is presented in Table 1. As the small XRF area scan (Figure 6) showed that some differences existed in the composition of the plaque, it was hoped that analysis of all elements of the plaque's entire surface could show more detail in the patterns found using radiography. The Accélérateur Grand Louvre d'analyse elementaire (AGLAE)[16] beam in Paris, seemed to provide the solution.

Materials and methods for research at AGLAE

The AGLAE extracted beam line provides analytical data for understanding the structure of archaeological and artistic objects, including their composition, properties, and how they have changed over time. The 2MV tandem accelerator, located in the basement of the Louvre Palace, can produce proton and alpha beams. It can perform simultaneous high-resolution particle induced X-ray emission (PIXE) mapping and give overall PIGE and RBS spectra.[17] The configuration and characteristics of the system have already been described elsewhere.[18] PIXE gives a quantitative analysis of the composition of the silver, while RBS provides information on the in-depth profile of the surface. It allows high-resolution mapping and has a good sensitivity for trace elements.

Table 2. Alloy composition of the different areas seen in the mapping.

	Cu (%)	Ag (%)	Fe (ppm)	Au (ppm)	Hg (ppm)	Pb (ppm)	Bi (ppm)
Black area	9.6	89.7	130	260	390	3,900	1,900
Dark grey area	10.4	89.1	90	140	360	4,600	2,300
Light grey area	11.7	87.8	100	130	340	4,600	2,300
Total	11.5	87.7	80	140	380	4,800	2,400

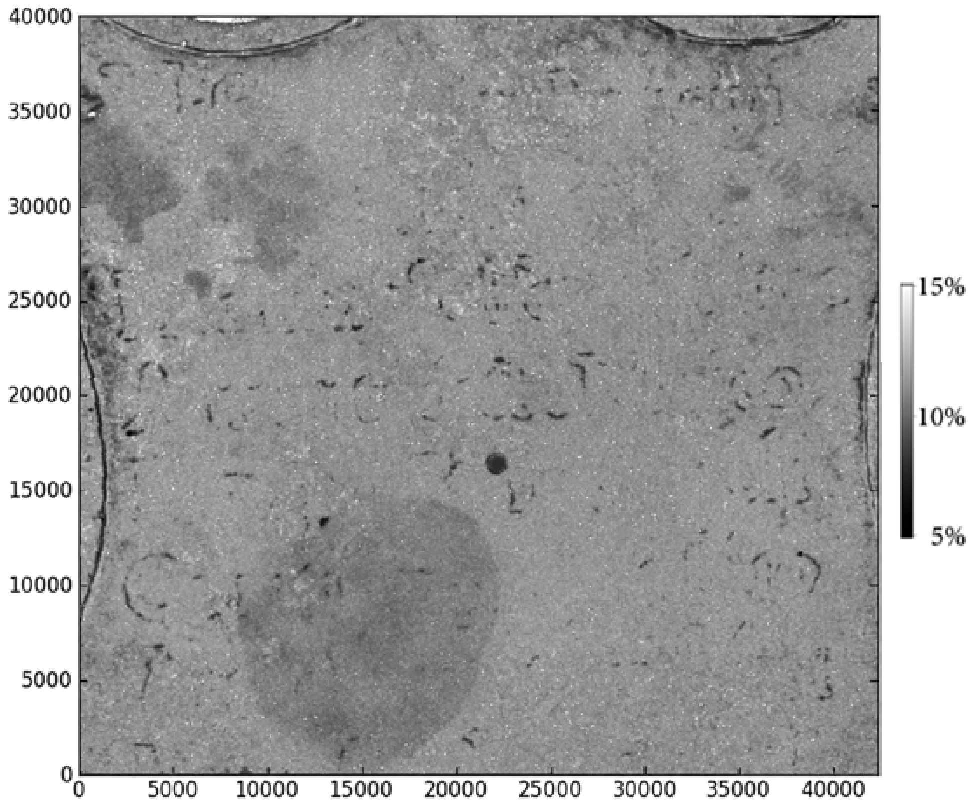


Figure 8. The combination of Cu mappings on different areas. The black areas show the lowest concentrations of Cu (measured in ppm). The area shown is 4 × 4.4 cm², pixel size is 80 × 80 µm².

Slow PIXE mappings were carried out in order to acquire an exploitable image.[19] The scanning process took approximately six hours to cover a total area of 4 × 4.4 cm². Mapping the peak area of key elements (Ag and Cu) brought interesting patterns to light. A quantitative processing of these mappings was done using the GUPIX[20] software, which allows concentrations from PIXE spectra to be calculated. Coupled with the custom-made TRAUPIXE_EDF program,[21] calculations on series of spectra can be executed allowing quantitative mappings to be made available.

After scanning the large plaque, two test plates (A and G) with a pattern etched with nitric acid were researched for comparison, using a known etching technique, with the large Jamnitzer plaque to determine whether there were any similarities. Test plate A was a plaque of sterling silver (92.5% Ag and 7.5% Cu) (Figure 7). On the left, the unetched area between the broad etched rectangle and the etched line could be seen as an imitation of a high-relief letter. A part of this area has been sandpapered away. The sample was analysed by PIXE.[22]

A cross-section was made of the etched part of test plate G, also made of sterling silver, and the edge analysed by PIXE[23] to examine how the etching process affected the alloy, and whether there was a gradient of Cu leaching visible, either in a straight downward direction or spreading to the sides.

Results

Composition of the silver plaque

Three different alloy compositions in the large plaque can be discriminated (Table 2): one corresponds to what can be regarded as the background of the pattern, while a second corresponds to the supposed letters. A third alloy composition can be found in three areas of the background.

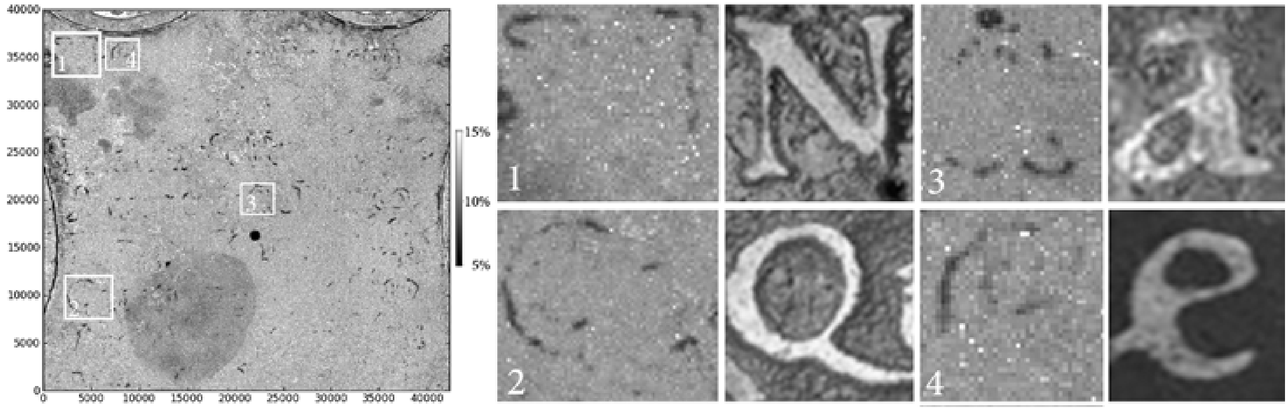


Figure 9. Particular patterns from the Cu mapping compared to some letters found on the smaller plaques of the Merkel centrepiece.

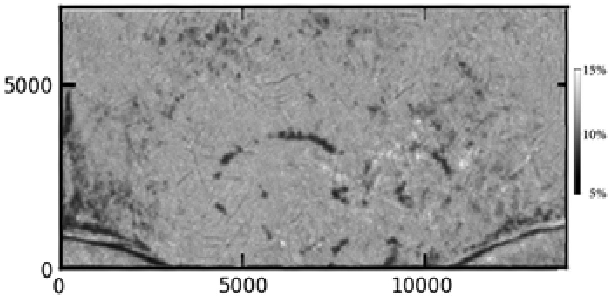


Figure 10. End adornment at the bottom of the plaque (horizontal line = c. 1 cm).

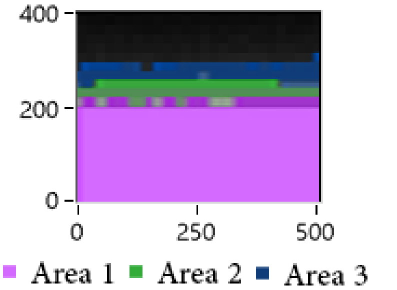


Figure 13. Enlarged area of the cross-section of etched test plate G separated into three subareas according to the Cu Ka peak area.

Average compositions have been calculated by selecting large amounts of pixels (over 1000) from different areas and treating the corresponding spectra with GUPIX. The overall spectrum (the sum of all pixels) gave a mean composition of the plaque. Some fluorine (F) was also found.

The quantitative results of the PIXE measurements for the total mapping do not differ much from the quantitative results achieved with XRF. The differences in metal concentration with XRF and other methods sometimes seem difficult to compare, due to different energies and other parameters.[24] The good matching here can be linked to the fact that for XRF analysis a filter of nickel (Ni) 12.50 µm was used. This filter is known to be the best for quantitative results on silver from the authors' own testing results.[25]

In 1540, the Nuremburg City Council decreed that silverware needed a purity of 14 lot, with a tolerance of 1 quint,[26] that is 875 parts silver and 125 parts copper (87.5% Ag and 12.5% Cu), a less pure standard, for example, than in the Netherlands, where 92.5% Ag and 7.5% Cu were compulsory. The silver matches the purity standards set by the Nuremburg City Council.

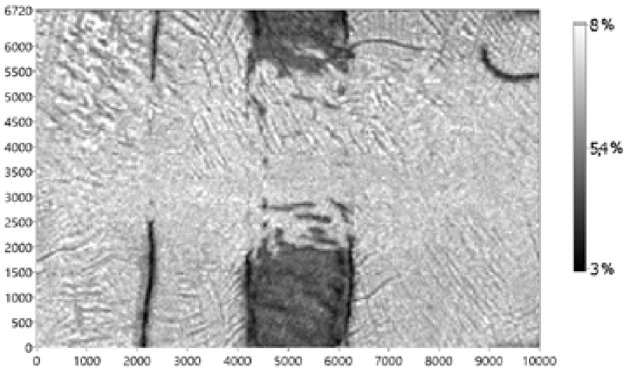


Figure 11. Cu mapping of etched test plate A.

Etched areas

The PIXE measurements of the large plaque showed that there were clear differences in the metal compositions, especially in the main alloy composition. The high-energy

Figure 12. Cu peak-area mapping of a cross-section of etched test plate G. The area in the red square can be seen in greater detail in Figure 13.

Table 3. Composition of the different areas in the cross-section.

	Cu (%)	Ag (%)
Area 1	8.0	91.6
Area 2	6.3	9.1
Area 3	5.2	94.3

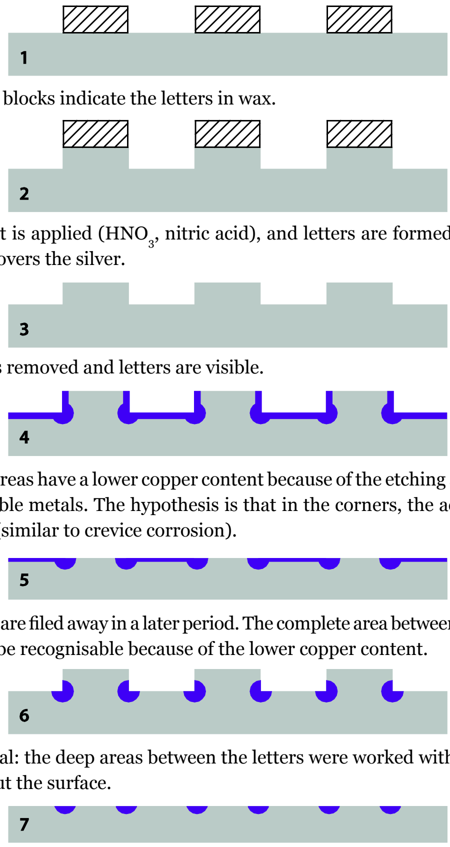
detectors enabled the exposure of several elements of the alloy such as Ag, Cu, lead (Pb), gold (Au), bismuth (Bi), and iron (Fe). It appeared that Cu, Ag, Pb and Au showed a correlated pattern behaviour. These elements were present in different concentrations in specific areas. Where the Ag was high, the Cu and Pb concentrations were relatively low, and the Au concentration was relatively high. The quantity of the main elements in the whole surface was mapped. Quantitative maps were generated with custom-made software called DataImaging.

The Cu map (Figure 8) enables the best visualisation of the remnants of the past inscription due to the differences in concentration within the plaque. This result was to be expected because Ag and Cu comprise the major elements of the alloy and Cu, being the less noble metal, would be the marker metal in terms of whether or not it had been etched away. The black lines, indicating the areas where the Cu concentration is relatively low, seem to form the outlines of letters. Horizontal zones with letters did show up clearly and some letters could be identified such as an ‘a’ and a ‘Q’ (Figure 9). These letters are of the same font as the type used on the smaller plaques, as can be seen in the ‘Q’ with its typical long tail. The X-radiograph showed horizontal bands in the plaque. With the help of the PIXE mapping, alternating thick and thin areas could be related to the letters. The black areas. i.e. the thinner areas, corresponded to the places where letters could be seen. There are approximately eight or nine lines of text to be discriminated, with an adornment at the end in the centre (Figure 10).

The result of the mapping of etched plate A is shown in Figure 11. The alloy is different, but the difference in copper content is similar to that seen in the Jamnitzer plaque. The outlines of the etched rectangle are less rich in copper, so have been more intensely etched. The etchant seems to be more reactive at the borders, in the areas where sharp ridges are present. The same can be said of the single line. There is a slight grey shadow around the black line showing a small Cu gradient. In the sandpapered area, however, the traces of etching cannot be seen.

The results of the scanning of plate G were not clear. Differences (Figure 12) could hardly be seen, but different areas had been separated regarding the area of the Cu peak in the PIXE spectrum. These areas were selected and a quantitative composition calculated (Figure 13 and Table 3).

Given that the beam size is approximately 50 µm, the actual size of the etched area could be less than the 100 µm layer in which the Cu content has been etched away.



1. Arched blocks indicate the letters in wax.
2. Etchant is applied (HNO_3, nitric acid), and letters are formed where the pitch covers the silver.
3. Pitch is removed and letters are visible.
4. Black areas have a lower copper content because of the etching away of the less noble metals. The hypothesis is that in the corners, the acid is more active (similar to crevice corrosion).
5. Letters are filed away in a later period. The complete area between the letters would be recognisable because of the lower copper content.
6. Optional: the deep areas between the letters were worked with a burin to even out the surface.
7. Therefore, only the outlines of the letters are still visible with the lower copper content.

Timeline 1: Etching and the theory of the outlines.

Assuming the etched area to be no more than 20 µm thick could explain why, in plate A, the patterns in the sandpapered area were not seen. The sandpapering may have sufficiently deep to remove all the etched parts.

Discussion

The results from the measurements show that there are areas in the plaque where there are differences in Ag, Cu, and Au percentages, and that they complement each other. When the Cu percentage is low, Ag and Au percentages are high, and vice versa. Etched test plate A showed the same results. As in the large plaque such areas appear as outlines of characters, the theory that this plaque was also etched is supported. There were also three areas that could be discriminated as irregular spots. One possibility is that some drops of acid or etchant may have been spilled on the plaque, leaving a slightly silver-enriched surface in these areas.

Although the text is not yet readable – there are simply not enough characters to decipher it – it is clear that letters are present. Furthermore, they are in Latin script, the same type of script that was used on the other smaller plaques in the centrepiece. These results make it very probable that the text dates to the same time period as Jamnitzers and probably was even applied by him or his workshop. It could even be argued that the text starts with an ‘N’, followed by an ‘e’, referring to the city of Nuremberg, where the object was made.[27] It should also be possible to visually compare the letters on the small plaques with the outlines that were found and, as a cryptograph, look for the most probable combinations. It was unexpected to see just the outlines of letters instead of complete, full letters.

If the letters were indeed fabricated in the same manner as those on the smaller plaques located on the centrepiece, i.e. in high relief, one would expect the areas between the letters to be Cu-poor, and the areas under the filed away letters to be Cu-rich. On the chemical maps a letter would then appear completely white and the area between them black (see Timeline 1: steps 1, 2, 3 and 4). Instead a different image is seen – only the outlines of letters are visible as dark lines.

On this basis, the following theory was developed (Timeline 1: steps 1, 2, 5 and 6) to explain this phenomenon: the letters were modelled in wax, the silver plaque was placed in acid, the plaque was removed from the acid, and the silver was rinsed. At the sides of the letters and the surrounding surface of the plaque, Cu-poor areas are now present. Because the etching gives the silver an irregular (pitted) surface, it is possible that these irregularities were scraped away with a burin (step 5). After some period of time, the letters were also filed away, leaving very small areas (step 6) of the corners of the standing walls of the letters, the only areas where a Cu-poor alloy still remains.

The results from the research on test plates A and G showed that, in their cases, the etching seemed to be on the sides not into the depth of the silver. Even if this mechanism is always seen with etching, the outlines of letters that are seen in the plaque still cannot be explained. It could also be argued that the sandpapering was too robust or that the etching was not carried out for a sufficient length of time, which would account for why there is no longer anything to be seen. More research is necessary to completely understand why only the outlines of the characters are visible in the plaque.

The depth of analysis with a 3-MeV proton beam is 34 μm for Ag and 15 μm for Cu. If the etched depth is less than 100 μm as in the test plaque, the effects of the etching should be still visible slightly deeper in the surface. Therefore, one option would be to utilise an elemental analysis technique that could investigate the surface more deeply, such as synchrotron radiation or 4MeV protons. Nevertheless, the main limitation is the absorption of Cu X-ray radiation in the silver matrix, and there is no proof that a better contrast can be achieved.

RBS and PIGE analyses were also available on the AGLAE facility but at the time of research only in punctual mode. Implementing these mapping techniques may allow a complementary study. For example, in the PIGE spectrum, fluorine (F) peaks were present, indicating there is some F on the object, but it was not possible to determine whether it is located all over the plaque or only in certain areas. The reason for the presence of the fluorine element is as yet unknown. Some parts of the centrepiece (the life casts) were rinsed in Freon (a chlorofluorocarbon compound) in 1980. Although Freon is volatile, perhaps some of the remnants adhered and/or seeped through to the bottom of the piece. The halons, like chlorine and fluorine, are known to be highly reactive with silver (for example, photographic processes are based on these reactions). Fluorine is also an etchant in the compound of HF but has only been used as such in modern times.

PIXE analysis found mercury (Hg) on the surface of the plaque but in very small quantities, and in all areas in more or less in the same amount. In the case of mercury-based etching, one would expect Hg to be present in higher concentrations in the areas where there are no letters. Etching with mercury was found to be less likely because Hg can also be a contaminant in silver – in fact silver often consisted of remelted scrap silver, along with parts of gilded silver. In the past, gilding was carried out using the fire-gilding method which involved making a solution of Hg and Au, brushing this on the surface of the silver, and heating it until most of the Hg had evaporated, leaving an alloyed surface of Hg, Au and Ag.[28] Citric and nitric acid would not leave detectable traces.

Conclusion

Ion beam analysis (IBA) at the AGLAE accelerator helped to decipher the removed text from the plaque. The technique was relatively quick, and the fast preliminary scanning mode gave a good first impression of the text, showing that there was indeed something to be discovered. The slow scanning mode gave results in high resolution, which showed more detail.

The precise scanning of the surface and mapping of the whole area of the centrepiece’s plaque, followed by quantitative data processing, demonstrated the differences in the proportions of elements present caused by etching. The research shows that this technique can indeed be used to distinguish removed etched patterns, such as characters. These characters seem to form eight or nine sentences. The letters are in Latin script and resemble the typescript used on the smaller plaques found on other parts of the centrepiece. The text must have been applied during the same time period in which the centrepiece was made by Jamnitzer or his workshop.

These findings are completely new and are highly significant for the study of the Merkel centrepiece, as until now it was thought that the large plaque did not bear a text. However, new questions have been raised such as what the text originally read and why it was removed. These questions will hopefully be an incentive for historians to look for possible answers in the future.

Acknowledgements

Financial support by the Access to Research Infrastructures activity in the 7th Framework Programme of the EU (CHARISMA Grant Agreement n. 228330) is gratefully acknowledged. We would like to thank the Rijksmuseum, Amsterdam, for supporting this research, as well as the team of metal conservators who were employed at the workshop during the reinstallation period of the museum for their help and insights.

Notes

1. Height: 99.8 cm, diameter: 46 cm.
2. 'Welcher Widmungsinschrift war wohl für die groβe leergebliebene Kartusche auf der Unterseite der Kredenz vorgesehen und sollte nicht den Anlaβ der Übergabe festhalten'. In K. Pechstein, 'Der Merkelsche Tafelaufsatz von Wenzel Jamnitzer', *Mitteilungen der Vereinigung für Geschichte der Stadt Nürnberg*, 1974: 90–121, 98. 'Auf der Unterseite der Bodenplatte befindet sich eine groβe Kartusche, die leer geblieben ist und vermutlich einst eine Widmunginschrift aufnehmen sollte'. In G. Bott, *Wenzel Jamnitzer und die Nürnberger Goldschmiedekunst 1500–1700*, Goldschmiedearbeiten - Entwürfe, Modelle, Medaillen, Ornamentstiche, Schmuck, Porträts: eine Ausstellung im Germanischen Nationalmuseum Nürnberg, vom 28. Juni-15 September 1985, Munich, Klinkhardt & Biermann: 220.
3. 'Karl V. erscheint einleuchtend als Adressat deses Jamnitzerschen Tafelaufsatzes, des Huldigungsgeschenkes des Rates. Wem anders als ihm hätte der Rat ein solches Meisterwerk der Kunst wie der Kaum vertecktenpolitschen Berechnung verehren können?'. In Pechtsein 1974: 99. 'Ursprünglich war diesers aufwendige werk ... als Geschenk für einem Besuch für Kaiser Karl V oder seiner Sohn und möglichen Nachfolger Philip II von Spanien bestimmt, die aber die Stadt nach 1549 nicht mehr besuchen sollten'. In Bott 1985: 220.
4. Timann, U. 'Goldschmiedearbeiten als diplomatische Geschenke'. In H. Maue et al, *Quasi Centrum Europae: Europa Kauft in Nürnberg 1400–1800*, Verlag des Germanisches Nationalmuseum, 2002: 217–39, 219. In the archives it is noted that Jamnitzer's wife received 12 thaler, and his journeymen one guilder for the safe transport of the centrepiece to the Ratthaus.
5. U. Timann, 'Zur Handwerkgeschichte der Nürnberger Goldschmiede'. In *Nürnberger Goldschmiedekunst 1541–1868, Band II , Goldglanz und Silberstrahl*, Verlag des Germanischen Nationalmuseums, Nürnberg, 2007: 33–69, 34–6.
6. P. Glanville, 'Mayer Carl von Rothschild: collector or patriot'. Available at: www.rothschildarchive.org.
7. In a letter from February 1941, Generalkommissar zur besonderen Verwendung Schmidt in the Hague reported that: 'der Führer den umgehenden Kauf der Sammlung Mannheimer wünscht,': G. Haase, in *Kunstraub und Kunstschutz Band I Eine Dokumentation*, Books on Demand GmbH, Norderstedt, 2008: 194–5.
8. B. Deneke,'Aufgang der Neuzeit: Deutsche Kunst und Kultur von Dürers Tod bis zum Dreißigjährigen Kriege 1530–1650'. In *Das Germanische National Museum Nürnberg 1852–1977* R. Kahsnitz Deutscher Kunstverlag, Munich/Berlin, 1978: 773.
9. K. Pechstein, R. Schürer and M. Angerer, *Wenzel Jamnitzer und die Nürnberger Goldschmiedekunst 1500–1700*, (Germanisches Nationalmuseum), Klinkhardt & Biermann Verlagsbuchhandlung GmbH Munich, 1985.
10. K.H. Manegold and W. Treue, *Documenta Technica Darstellungen und Quellen zur Technikgeschichte, Reihe II.* Hildesheim and New York, Georg Olms Verlag, 1972.
11. In the Middle Ages and Renaissance period there were two different types of letters in common use: *litterae antiquae* (ancient letters, used by humanists and developed at the beginning of the fifteenth century in Italy) and *litterae modernae* (Gothic/black letters, c. 1150 to the seventeenth century). The first script has a minuscule that most resembles the *litterae modernae* script.
12. M. Meddeler, *Het etsen van zilver: technologie, toepassing en herkenning*, unpublished Masters thesis, University of Amsterdam, Amsterdam, 2011: 1–75.
13. D4 film 130 kV 2 mA. Final picture taken by Röntgen Technologische Dienst Rotterdam (RTD).
14. XRF excites electrons in atoms, which fall back into their orbits with specific energy; these energies thus indicate specific materials.
15. ARTAX Spectra version 7.3, W tube, Ni 12,00 µm filter, collimator 0.2 mm, 30 s measurement time, 50 kV, 498 mA, air, normalised counts.
16. Accélérateur Grand Louvre d'analyse elementaire
17. PIGE: particle-induced gamma emission; RBS: Rutherford backscattering spectroscopy.
18. L. Pichon, B. Moignard, Q. Lemasson, C. Pacheco and P. Walter, 'Development of a multi-detector and a systematic imaging system on the AGLAE external beam', *Nuclear Instruments and Methods in Physics Research B318*, 2014: 27–31.
19. The PIXE analysis was performed using 50 µm aluminium filters on the PIXE detectors and an external RBS system. The operating conditions were 3-MeV protons, 4 nA with a beam size of 50 µm.
20. GUPIX is a software package for fitting PIXE spectra from thin, thick, intermediate and layered specimens. It extracts peak intensities and converts these to concentrations via the H-value standardisation method. X-ray excitation may be via protons, deuterons, He-3 or He-4 ions. X-ray spectrometry may be via Si (Li) or Ge detectors. Interactive or batch processing may be selected.
21. L. Pichon, L. Beck, Ph. Walter, B. Moignard and T. Guillou, 'A new mapping acquisition and processing system for simultaneous PIXE-RBS analysis with external beam', *Nuclear Instruments and Methods in Physics Research B 268*, 2010: 2028–33.
22. 3-MeV protons, 4 nA, 1 × 0.67 cm^2 with pixel size of 40 × 40 μm^2.
23. 3-MeV protons, 4 nA, 8 ×1 cm^2 with pixel size of 20 × 20 μm^2.
24. A. Heginbotham et al., 'An evaluation of inter-laboratory reproducibility for quantitative XRF of historic copper alloys'. In P. Mardikian et al. (eds), *Metal 2010*, *Proceedings of the International Conference on Metal Conservation, Charleston, South Carolina, USA, October 11–15, 2010,* Clemson University, 2010: 244–55.
25. Unpublished report on quantitative research on silver objects in the Rijksmuseum, Amsterdam.
26. U. Timann, 'Zur Handwerksgeschichte der Nürnberger Goldschmiede', in K. Tebbe et al., *Nürnberger Goldschmiedekunst 1541–1868*, exhibition catalogue, Nuremberg (Germanisches Nationalmuseum) 2007, vol. 2: 33–69, 36.
27. In German, Nuremberg was written Nürenberg, but on some occasions, for example in Latin (the language in which the text was probably written) the city's name could be spelled 'Neurenbergensis', meaning 'from Nuremberg'. It is not impossible that a sentence could start with this preposition.
28. See for example O. Untracht, *Jewelry Concepts and Technology*, London, Robert Hale, 1982: 666–8.

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