The manufacturing process of the gold bust of Marcus Aurelius: evidence from neutron imaging

Anne de Pury-Gysel, Eberhard H. Lehmann and Alessandra Giumlia-Mair

This paper presents the results of applying neutron imaging methods to the gold bust of Marcus Aurelius, an analytical procedure that was carried out in 2006 at the Paul Scherrer Institut in Villigen (Switzerland). The results have produced a better understanding of the gold repoussé manufacturing techniques for large pieces.

Given the number of gold statues that existed at Rome and in its provinces,[1] the preserved pieces represent only a tiny fraction; to recover the precious metal, most gold objects were eventually melted down, with the result that only a very small number of pieces are left. That scarcity explains our difficulties in studying the characteristics of this category. Just 6 gold busts of the Roman period have been documented. The bust of Marcus Aurelius[2] was found in a sewer running beneath a sanctuary of *Aventicum* (figs. 1, 6a and 16).[3] Then there is the bust of Septimius Severus discovered at Didymoteichon (NE Greece),[4] a small fragment from the shoulder *pteriges* of a breastplated bust of the 2nd c. A.D. found at the fort of Dambach (Germany),[5] the Late Roman head inserted into the 9th-10th c. statue of St. Fides in the Abbeye of Conques (France),[6] and the much smaller busts of (possibly)

1 G. Lahusen, *Römische Bildnisse. Auftraggeber, Funktionen, Standorte* (Mainz 2010) 510-13.

2 The original (inv. no. 39/134) is not on permanent display in the Römermuseum Avenches but a copy of the bust is. H. 33.5 cm; wt. 1589.07 gm, 22 carat. The first publication was by P. Schazmann, "Buste en or représentant l'empereur Marc-Aurèle trouvé à Avenches en 1939," *ZSchwArch* 2 (1940) 69-93. When found, the bust was only slightly damaged; it was cleaned and restored in the Swiss National Museum in Zurich (ibid. 70). No restoration report exists, but there are photographs in the archives of the Swiss National Museum.

3 The main illustrations are: Schazmann ibid. figs. 1-5, 13, 15 and 17-19; H. Jucker, "Marc Aurel bleibt Marc Aurel," *Bull. Assoc. Pro Aventico* 26 (1981) 5-36 with Abb. 1-10; G. Lahusen, "Zu Bildnissen aus vergoldeter Bronze und Edelmetall," in id. and E. Formigli, *Römische Bildnisse aus Bronze: Kunst und Technik* (Munich 2001) 505-21 with Abb. 1-3; L. A. Riccardi, "Military standards, *imagines*, and the gold and silver imperial portraits from Aventicum, Plotinoupolis, and the Marengo treasure," *AntK* 45 (2002) 86-99 with pl. 20.1; A. Hochuli-Gysel and V. Brodard, *Marc Aurel. Die unglaubliche Entdeckung der Goldbüste in Avenches* (Documents du Musée Romain d'Avenches 13; 2006) figs. 50-64; K. Lapatin, *Luxus: the sumptuous arts of Greece and Rome* (Los Angeles, CA 2015) 82 pl. 51, with p. 235 (*contra* Lapatin, the bust is not conserved in the Musée d'archéologie et d'histoire, Lausanne).

4 Bust of Septimius Severus from Didymoteichon, now in the Archaeological Museum Komotini, inv. no. 207, h 25 cm, wt 980 gm). It was found without an archaeological context. See Lahusen (supra n.3) fig. 4; Riccardi (supra n.3) pl. 20.3; Hochuli-Gysel and Brodard (supra n.3) 96, fig. 104; Lapatin (supra n.3) 83, pl. 52, with p. 235. Publication is in preparation by A. de Pury-Gysel.

5 Archäologische Staatssammlung, Munich, inv. no. 1985.2505. Found in a military context of the 2nd c. A.D. Fragment of the board from the *pteryges*, the leather shoulder protection of the cuirass; l. 4.5 cm. See B. Steidl, "Die goldene *imago* eines Kaisers vom raetischen Limes," in M. Kemkes and C. Sarge (edd.), *Gesichter der Macht. Kaiserbilder in Rom und am Limes* (Schriften des Limesmuseums Aalen 60; 2009) 108, fig. 150; V. Selke, *Römische Funde aus Dambach am Limes (1892-2007)* (Materialhefte zur Bayerischen Archäologie 100; 2014) 76, pl. 49, no. 1561.

6 Now in the Abbeye de Conques; h 16 cm. Provenance unknown; mediaeval re-use. See J. Taralon and D. Taralon-Carlini, "La majesté d'or de sainte Foy de Conques," *BMon* 155.1 (1997) 7-73; *Le trésor de Conques* (exh. cat., Paris); Hochuli-Gysel and Brodard (supra n.3) 98, fig. 105.

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Licinius I[7] and of Licinius II[8] probably of the early 4th c.

The bust of Marcus Aurelius (A. de Pury-Gysel)

Our main focus here is to present the neutron imaging applied to the bust of Marcus Aurelius, discuss the insights it provides, and show the implications it might have for the study of other gold objects. Other questions relating to the iconography, chronology and use of the busts will be outlined here only in order to set the object of our inquiry in its artistic and historical context. This gold bust deserves our attention not simply because it is an extraordinarily rare object, but also because of its intrinsic significance, the interpretations proposed by earlier scholars, and questions pertaining to its manufacture. The 22-carat gold object, weighing 1589.07 gm, consists of a sheet of hammered gold between 0.24 and 1.4 mm in thickness. The surface was worked by adding the eyebrows, iris and crescent-shaped pupils, each punched facing outwards, as well as fine lines around the eyes; the facial skin and other parts were worked using a fine punch, thereby transforming the high-gloss surface of the gold into a matte one.[9] The head is roughly three-quarters life size (it measures 33.5 cm in width, including the chest area). The bust portrays a bearded man of advanced age. The face is framed by a row of curls combed upwards, its most distinctive feature being the high-arched and somewhat asymmetrical brows over slightly bulging eyes. Age is indicated by wrinkles on the forehead, around the root of the nose and the eyes, and by the line from nose to mouth.

This "armoured bust" shows the subject wearing a cuirass (*lorica plumata*, decorated with a *gorgoneion*) which in real life would have consisted of metal (front and back parts) and leather (shoulder parts) over a textile undergarment. A military cloak (*paludamentum*) is draped across the left shoulder where it was once held in place by a round *fibula* (now lost, but the spot where it was attached turned into a dark stain, due probably to the fixing substance used by the goldsmith — the *fibula* was not fixed by a rivet). The lower edge of the front side of the bust shows three holes to contain rivets; two survive, realised as clips made of narrow folded gold bands;[10] it is not known if the rivets were used to attach some kind of textile, simulating a garment, or to fix the non-freestanding bust on a support.

Since the discovery in 1939, four questions have exercised the minds of researchers:
1. Whom does the bust depict?
2. What was the function of gold busts?
3. Who commissioned such busts and where were they manufactured?
4. How can we explain the strong stylistic heterogeneity of our bust?

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7 Licinius I(?), now in a private collection; h 13.2 cm; wt 147.78 gm. Provenance unknown. See B. Steidl in L. Wamser and R. Gebhard, *Gold. Magie–Mythos–Macht. Gold der Alten und Neuen Welt* (Stuttgart 2001) 294-95, no. 198.

8 Licinius II, now in the Ferrel Collection, Houston, TX; h 11.5 cm; wt 153.6 gm. Provenance unknown. See J. Spier, *Treasures of the Ferrel Collection* (Wiesbaden 2010) 124, no. 100.

9 Schazmann (supra n.2) 87. The skin surface of the gold bust of Septimius Severus from Didymoteichon and of the silver bust of Lucius Verus from the Marengo treasure were worked in the same way, whereas the smaller late-antique busts have smooth and shiny surfaces. For the Lucius Verus, see G. Sena Chiesa, "Imago Caesaris argentea. Il busto di Lucio Vero del Tesoro di Marengo," *Lanx* 1 (2008) 1-25 with figs. 3-4; G. Lahusen, "Zu römischen Bildnissen aus Gold und Silber," *ZPE* 128 (1999) 251-66 with pl. III; Hochuli-Gysel and Brodard (supra n.3) 100 with fig. 107.

10 Schazmann (supra n.2) pl. 32, fig. 23. Hochuli-Gysel and Brodard (supra n.3) 93, figs. 99-102.

1. Whom does the bust depict?

In the 1st c. A.D., gold could be used for the portraits of emperors as well as of officials and even private persons, but from the 2nd c. onward it seems that the use of gold, and probably even silver, was restricted to portraits of the emperor and perhaps close members of his family.[11] The fact that our bust is bearded suggests that it dates at the earliest to the 2nd c. A.D., since Hadrian was the first bearded emperor, leading to a general fashion for men that lasted until the end of antiquity. While for a time the bust was believed possibly to depict Antoninus Pius or Julian the Apostate,[12] the identification as Marcus Aurelius remains the most likely.[13] The facial area from the chin to the lower edge of the forehead, as well as the front curls and the way they are arranged along the hairline, basically follow his fourth officially-sanctioned portrait type as introduced on coins which are, from 176 onwards, the only official documents at our disposal.[14] This fourth type can be studied in detail thanks to the coins and a series of stone portraits.

A number of pecularities on our bust, however, still need to be explained. One is the fact that the head is shown in frontal position. Portraits from the 1st and 2nd c. often have their faces slightly turned to one side. In these cases the head is often asymmetrical, with a noticeably broader left side of the face which is not so obvious when the portrait is seen in three-quarters view. The artisans who produced our bust apparently copied this head position along with the asymmetrical design, but instead of being slightly turned towards its right side the head faces straight ahead, giving it a rigid appearance.[15] Further, probably due to the toreutic techniques employed, the copying of the model[16] led to this portrait being executed as a mirror image, as is best seen on the tomography from the inside of the bust.[17]

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11 Lahusen (supra n.3) 512-13: T. Pekáry, *Das römische Kaiserbildnis in Staat, Kult und Gesellschaft. Dargestellt anhand der Schriftquellen* (Das römische Herrscherbild III.5; 1985) 68. Pliny on portraits: *NH* 35.4-14, 52, 147-48 and 153.

12 The identification of the portrait as that of Antoninus Pius was postulated by L. Bosset, archaeologist in charge of Avenches excavations in 1939: cf. Hochuli-Gysel and Brodard (supra n.3) 20. Julian the Apostate: J.-C. Balty, "Le prétendu Marc-Aurèle d'Avenches," in *Eikones, Festschrift für Hans Jucker* (AntK Beiheft 12; 1980) 57-63.

13 Schazmann (supra n.3) 72-77; M. Wegner, *Die Herrscherbildnisse in antoninischer Zeit* (Das römische Herrscherbild II.4; 1939) pl. 27; Jucker (supra n.3) 12-13; Hochuli-Gysel and Brodard (supra n.3) 71-75.

14 The fourth type on Marcus Aurelius coinage: *BMC* IV, pls. 64-65; M. Bergmann, *Marc Aurel* (Frankfurt 1978) 8 and 11, fig. 6 (= *BMC* IV, pl. 64.7); Hochuli-Gysel and Brodard (supra n.3) 65, fig. 71 (= *RIC* III, 306, no. 1186). Three-dimensional portraits of the fourth type: Wegner ibid. 44-47, pls. 28-30; Bergmann ibid. 24-27 and 40-42; K. Fittschen and P. Zanker, *Katalog der römischen Porträts in den Capitolinischen Museen und den anderen kommunalen Sammlungen der Stadt Rom.* Bd. 1. *Kaiser- und Prinzenbildnisse* (2nd edn., Mainz 1994) 74-78.

15 Jucker (supra n.3) 18, fig. 1; E. Künzl, "Zwei silberne Tetrarchenporträts im RGZM und die römischen Kaiserbildnisse aus Gold und Silber," *JbRGZM* 30 (1983) 381-402, pl. 81.1; Riccardi (supra n.3) pl. 22.1; Hochuli-Gysel and Brodard (supra n.3) 56, fig. 50.

16 On the original model for imperial portraits and how the model was disseminated, see D. Boschung, *Die Bildnisse des Augustus* (Das römische Herrscherbild I.2; Berlin 1993) 4-8.

17 Hochuli-Gysel and Brodard (supra n.3) 40, fig. 31, and p. 62. The inversion is best visible by comparing the arch of the left eyebrow and the range of the curls on the left side of our bust (ibid. 57, figs. 53-54) with three marble portraits of Marcus Aurelius in the Louvre: inv. no. 1159 (of his third type[?] type; Wegner [supra n.13] pl. 21 left), inv. no. 1161 (of his fourth type; ibid. pl. 30), and inv. no. 1179 (of his fourth type; ibid. pl. 29 right).

One of the discrepancies with the fourth official type is the fact that various parts of the bust must be dated to different periods. The narrow form of the bust, for instance, imitates a model that was in use *c.*100.[18] The back of the head does not show Marcus Aurelius' curls but rather short wavy hair reminiscent of hairstyles from the late 1st and early 2nd c. The chief difference between it and other known portraits of Marcus Aurelius,[19] however, concerns the proportions between head and face: instead of an elongated, rectangular head with a relatively narrow, high forehead, our bust has a rather rounded skull with the broadest part at the temples; this gives the face a triangular appearance rather than the 'usual' vertical, more rectangular shape. Would it be too narrow an opinion to consider this an artistic failing caused by a lack of knowledge on the part of the goldsmith, leading us to the conclusion that the bust was made in a "provincial" workshop?[20]

2. What was the function of gold busts?

We know of two main uses for non-freestanding imperial portrait busts (*imagines*)[21] which symbolized the absent emperor. The first was in the context of the cult of the emperor which each city celebrated. During such celebrations and certain judicial acts the emperor's portrait had to be present.[22] Some of these portraits (*imagines*, εἰκόνες) are reported to be busts (προτομαί) and were made of different types of metal (gold, silver or bronze). Produced in metal, the busts were not too heavy to be carried along in the *pompa*:

> Then in regard to the images which you have wanted to make of ourselves and of our consorts in gold or silver, or best of all, if understanding from our own proposal, you are willing to content yourselves with images of bronze, it is clear that you will make statues such as the many more commonly call προτομαί (busts), and you will execute them on a moderate scale, the four of equal size, so that it will be easy on your holidays at every gathering to transport them wherever you may wish on every occasion, as for example to the popular assemblies.[23]

The second main use of this type of bust was as the *imago militaris*. The portrait of the emperor, as commander of the army, was mounted on a pole and carried by the *imaginifer*, a special assignment, as is illustrated on tombstones[24] and reported by various sources (e.g., the Younger Pliny, *Pan*. 10.3):

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18 Jucker (supra n.3) 16.

19 Wegner (supra n.13) pl. 29, left; Jucker (supra n.3) 33, fig. 23; Hochuli-Gysel and Brodard (supra n.3) 70, fig. 76.

20 Use of the term "provincial style" is debated. While manufacture in the City of Rome is usually associated with the highest artistic quality when compared to works created in some provinces, a number of important artistic centres existed, not least in Asia Minor and Egypt, working to high standards. In the case of a gold artefact like ours, of course we cannot assume that the piece was made close to the place where it was found. But the main problem for determining possible "provincial" stylistic features remains the dearth of parallels in terms of material, chronology and genre.

21 R. Daut, *Imago. Untersuchungen zum Bildbegriff der Römer* (Heidelberg 1975) 41.

22 Pekáry (supra n.11) 66-83. The fact that the gold bust of Marcus Aurelius was discovered in a sanctuary in Avenches indicates its probable use in cult as an *imago*.

23 J. H. Oliver, *The sacred gerusia* (Hesperia Suppl. 6, 1941) 108-20, no. 24, letter 2, transl. of restored text p. 116 (mention of gold, silver and bronze busts, in a letter from Marcus Aurelius and Commodus to the *gerusia* of Athens preserved on a marble *stele*). Cf. Lahusen (supra n.9) 262-65.

24 Riccardi (supra n.3) 93-97, pl. 22.2; J. Stäcker, *Princeps und Miles: Studien zum Bindungs- und Nahverhältnis von Kaiser und Soldat im 1. und 2. Jahrhundert n.Chr.* (Hildesheim 2003) 186-91; K. M. Töpfer, *Signa militaria. Die römischen Feldzeichen in der Republik und im Prinzipat* (Monog. RGZM Mainz 91, 2011) 26-28. It is not certain what size these *imagines* could achieve; probably they were normally smaller than lifesize.

Fig. 1. Gold bust depicting Marcus Aurelius as an army commander wearing a cuirass and the *paludamentum* (military cloak). Repoussé object with worked surfaces. Dated *c.*A.D. 176–80. 1587.07 gm of 22-carat gold. Overall h 33.5 cm (i.e., three-quarters life size). Musée Romain d'Avenches, Inv. no. 39/134. (Jürg Zbinden, Bern/Musée Romain d'Avenches).

Fig. 6a. Left side (face) of the bust (Jürg Zbinden, Bern/Musée Romain d'Avenches).

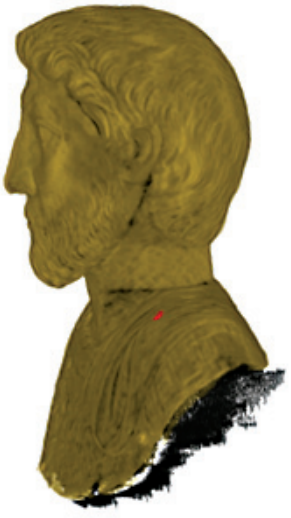

Fig. 6b. Comparison of a photographic view with the result of the tomography rendering process (E. H. Lehmann, Paul Scherrer Institut).

Fig. 7. Comparison of photographic view (fig. 1) with the result of the tomography rendering process. (E. H. Lehmann, Paul Scherrer Institut). (figs. 6b and 7 are low resolution due to the constraints of the measuring instruments employed).

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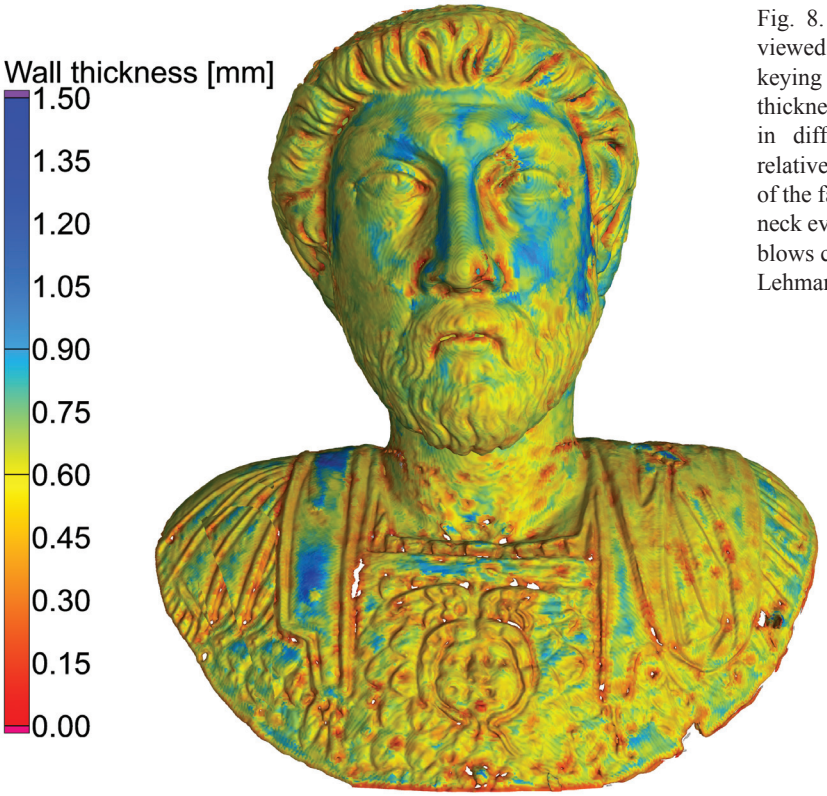

Fig. 8. Tomography of the bust viewed from the front. The keying on the left indicates the thickness of the gold sheet, shown in different colours. Note the relatively homogeneous thickness of the face. On the cuirass and the neck even the individual hammer-blows can be distinguished (E. H. Lehmann, Paul Scherrer Institut).

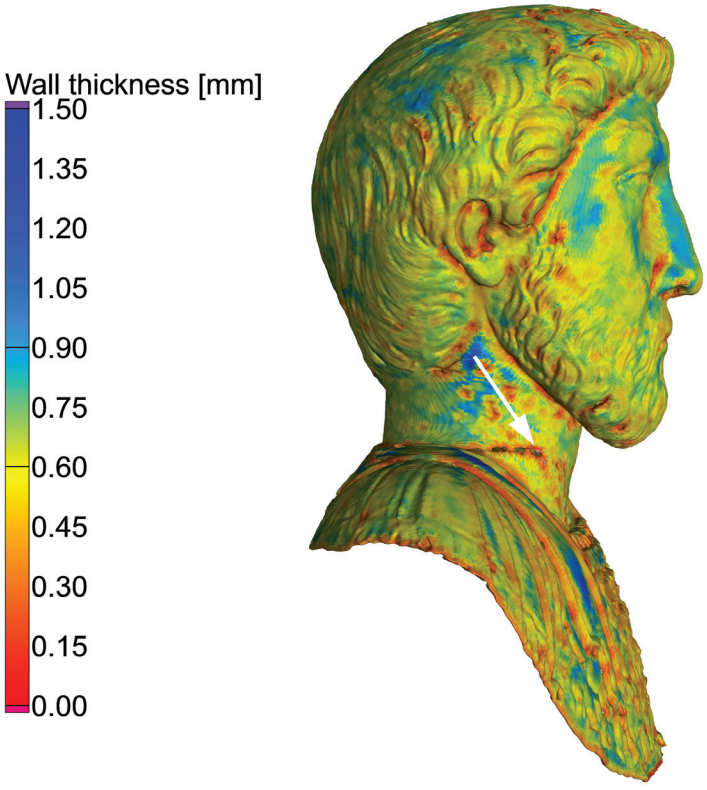

Fig. 10. Tomography of the bust. The red line around the face indicates that here the sheet is only 0.15 mm thick. There is no overlap and no join, which clearly demonstrates that the bust was produced in one piece. The small blue spots on the red line are small repairs of tiny cracks (E. H. Lehmann, Paul Scherrer Institute).

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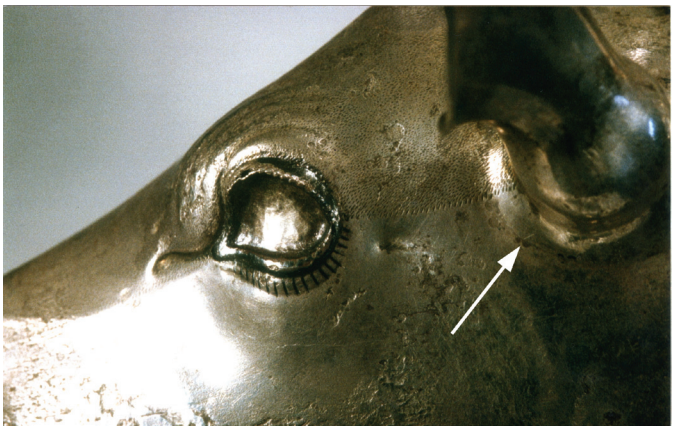

Fig. 9. An example of a join on a Classical *rhyton* in the Civici Musei di Arte e Storia, Trieste. The edges of the silver sheets have been hammered and the join is skillfully disguised, but the line of the seam can be easily recognized. The metal around the ears is very thick; the ear had also to be rivetted on the inside for better support (Civici Musei, Trieste).

Fig. 12. Tomography of Marcus Aurelius. The arrows indicate small daubs of solder applied on holes and cracks produced by intensive working on the metal structure (E. H. Lehmann, Paul Scherrer Institut).

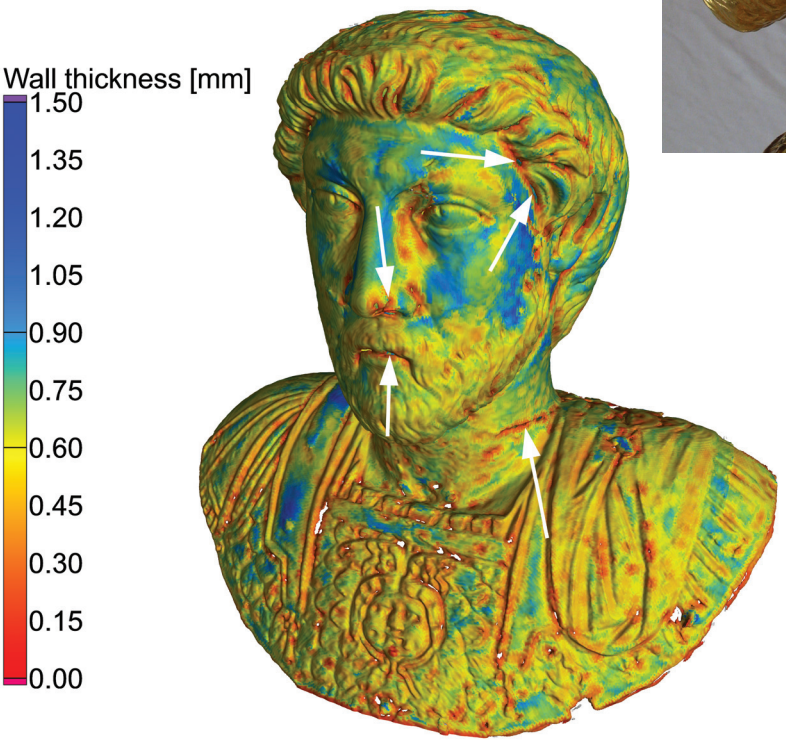

Fig. 11. Tomography of Marcus Aurelius. The horizontal red line with blue spots visible on the neck shows where the artisan begun his work on the gold disk. The blue spots are small repairs carried out from the inside of the bust (E. H. Lehmann, Paul Scherrer Institut).

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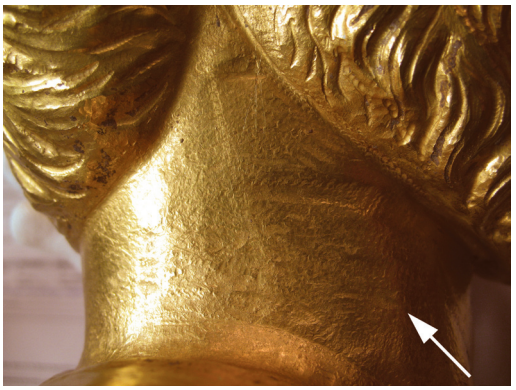

Fig. 13. (top) The surfaces representing the skin of Marcus Aurelius show a matte finish carried out by using a chisel with a thin circular point that produced many circlets next to one another. The white arrow points to tiny discoloured spots where some solder was applied. The gold solder contains higher amounts of copper and silver and tarnishes more easily (Musée Romain d'Avenches).

Fig. 14. (top, 2nd) The folds of the undergarment of Marcus Aurelius were shaped with a blunt thick chisel, and finished with a tool with a roughly triangular point to obtain a *chiaroscuro* effect (Musée Romain d'Avenches).

Fig. 15. Detail of the face of Marcus Aurelius showing realistic strands of hair of the beard on which three different tools have been used. The irises have been underlined with a thin point. The line on the proper right eye had to be re-drawn when the point slipped too far down. Note the small repair between the lips on his proper right side, more visible because of the effect of the light (Musée Romain d'Avenches).

Fig. 16. (right) Back of the bust of Marcus Aurelius. The hair strands at the back of the head are worked cursorily. Only one tool was employed both for the lines and for the matting of the surface. The centre of the head is almost smooth and unworked, probably because of the restoration undertaken in 1939 (Jürg Zbinden, Bern/Musée Romain d'Avenches).

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> Inscriptions, portraits and the army's standards proclaimed you Imperator, but in your self-effacement, activity and vigilance you were soldier, officer and commander in the field; striding ahead of the standards and eagles which were now your own you claimed no benefit from your adoption but the right to show the obedience and devotion of a son, and sought long life and lasting glory only for the name you now bore (transl. B. Radice).[25]

3. Who commissioned such busts, and where were they manufactured?

The acquisition of *imagines* in a civilian context was decided by high-ranking urban dignitaries and officials.[26] Less is known about the procedure in the army but we may assume that responsibility lay with the emperor.[27] Gold busts appear to have been popular in two distinct sizes: one of 5, the other of 3 Roman lbs of gold.[28] Our bust (5 lbs) and the one of Septimius Severus from Didymoteichon (3 lbs) correspond to each of the two 'standard sizes'.[29] Where might such objects have been made? We know very little about goldsmith workshops. The best known were located in Alexandria and, of course, at Rome, where such artists often moved. The stylistic peculiarities of individual goldsmith workshops cannot be defined since only a handful of pieces survive (and they span almost 250 years). But it is obvious, for example, that the busts dating to *c*.161-169 (Lucius Verus, silver), *c*.176-180 (Marcus Aurelius, gold), and *c*.193-197 (Septimius Severus, gold) are the products of different workshops, even though they follow the same typological canon of the cuirassed portrait.

Was the bust of Marcus Aurelius made in *Aventicum*? There are two indications that the working of gold will have been practiced in this region. The first lies in the fact that the territory of the *Helvetii* had some stream gold.[30] The second comes from an inscription found in Amsoldingen which attests the activities of two *aurifices* (goldsmiths), a father and son, in the 2nd c. at *Aventicum*.[31] Since the inscription does not mention any work executed by the *aurifices*, it does not prove that the bust was manufactured on site, as was suggested by P. Schazmann,[32] but this possibility cannot be entirely excluded either.[33]

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25 G. Lahusen, *Schriftquellen zum römischen Bildnis* I. *Textstellen* (Bremen 1984) at 120 no. 513 (with the incorrect citation as *Ep.* 10.3).

26 At least according to the inscriptions from Ephesos and Athens, cited above. Busts of gold had to be approved by the emperor: Cf. Oliver (supra n.23) 93, no. 11, letter of Marcus Aurelius and Lucius Verus to a member of the *gerusia* of Ephesos. We also learn from this letter of A.D. 162-163 that there was a practice of maintaining inventories of the busts of emperors stored in the *synhedrion*. Cf. Lahusen (supra n.9) 258; id. (supra n.1) 516.

27 Töpfer (supra n.22) 26-28.

28 E.g., *CIL* II 5265, concerning a gold portrait of 5 lbs of Titus in *Emerita*; Dio 79.12.7: gold portraits of 3 lbs in the reign of Macrinus. Cf. Lahusen (supra n.9) 255-56 and 259; id. (supra n.1) 514.

29 Bust of Marcus Aurelius: 1589.07 gm. Bust of Septimius Severus: 980 gm, see n.4 above (1 Roman lb = 327.45 gm. Small parts are missing from both busts. The small gold busts of Licinius I(?) (147.78 gm) and Licinius II (153.6 gm) weigh only about half a Roman pound.

30 L. Edelstein and I. G. Kidd (edd.), *Fragmenta. Posidonius* (Cambridge 1988) vol. 2, 931, frg. 272B, 40f (Strab. VII.2.1-2); Plin., *NH* 23.66. See F. Hofmann, "Gold, seine Lagerstätten und seine Gewinnung," in A. Furger and F. Müller (edd.), *Gold der Helvetier* (Zurich 1991) 35-39.

31 Camillius Polynices and Camillius Paulus: *CIL* XIII 5154 and G. Walser, *Römische Inschriften der Schweiz* II (Bern 1980) Nr. 117.

32 Schazmann (supra n.2) 89.

33 A. Kaufmann-Heinimann, "Römische Zeit: Einheimische Tradition — fremde Einflüsse," in Furger and Müller (supra n.30) 97-98.

4. How can we explain the strong stylistic heterogeneity of our bust?

Is the stylistic heterogeneity due to the impact of the raw material and its own particular properties? Is it a sign of an intrinsic lesser quality? Is the heterogeneity due to some artistic failing or lack of knowledge, and would that be a cause to consider the bust to be of "provincial" origin?[34] Did the goldsmith for some reason not follow the official standards for imperial portraits? And were all the larger pieces made by repoussé from a single sheet of metal, or was it possible to connect several parts? Gold has its own particular properties, and those can have an impact on the style. As far as we know, in Roman contexts only gold objects of large size worked by hammering have been found thus far. Smaller figures and objects made of silver were also cast. In hammering sheet gold, a goldsmith would encounter a special restriction because of the quantity of gold at his disposal. On the other hand, the relative softness of the material, the gold being of good quality, allowed for detailed work on the surface. Ancient texts discuss the reworking of the physiognomy of portraits.[35] Not only were the portraits of disgraced emperors and other personalities obliterated or their faces transformed;[36] the sources also mention the reworking of portraits of previous emperors into those of the current emperors. We see this in Marcus Aurelius and Lucius Verus' answer to a request made by an official at Ephesos who intended to transform older imperial portraits into those two emperors. The application was vehemently rejected:

> Imperator Caesar Marcus Aurelius Antoninus Augustus and Imperator Caesar Lucius Aurelius Verus Augustus Armeniacus to Ulpius Eurycles, greetings.
>
> --- The first question in your communication to us, the question of the silver images, has obviously furnished you with the occasion for the other inquiries, and it is a matter which requires our permission indeed. In regard then to the images of the emperors, old images which you say are stored in the synhedrion, in brief we think that all of them should be preserved under the names under which each of them came into existence, and that none of that material should be re-altered into representations of ourselves. But it has also occurred to you after considering the matter that as many of them [---] as retain the outlines, enough for the features to be recognized, ought to be preserved under the same names under which they came into existence. In regard, moreover to those so exceedingly battered as you report and no longer capable of exhibiting any outline, even their identifications might perhaps be supplied from inscriptions on the bases, or perhaps even from inventories, if there are any in this synhedrion [---] so that the honour might be renewed for our predecessors rather than disappear through the melting down of the images.[37]

This leads to some of the questions to be considered by our own scientific investigation: Was our gold bust not made from a single sheet of metal but perhaps was an older bust that had been reworked (without authorisation from the emperor) into a portrait of Marcus Aurelius? Is it not possible that the chronological and stylistic discrepancies mentioned above were caused by such a reworking process — i.e., that the bust received a new face with its curls framing forehead and temples, while the (earlier) hairstyle at the back of the head remained unchanged? These were the questions we hoped tomography would answer. Neutron tomography was also employed to measure the thickness of the sheet metal all over the bust. A further advantage of the technique is that it can provide a visualisation

34 "Provincial": Jucker (supra n.3) 9-10; Künzl (supra n.15) 394.
35 A. Massner, "Nicht Germanicus, sondern Drusus maior," *AntK* 34 (1991) 116-26.
36 G. Macchiaroli (ed.), *Domiziano/Nerva. La statua equestre da Miseno: una proposta di ricomposizione* (exh. cat., Napoli 1987).
37 Oliver (supra n.23) 93, no. 11, from Ephesos, ll. 11-15, with transl. on p. 95.

of the entire internal surface, which in turn will provide information on the goldworking techniques used.

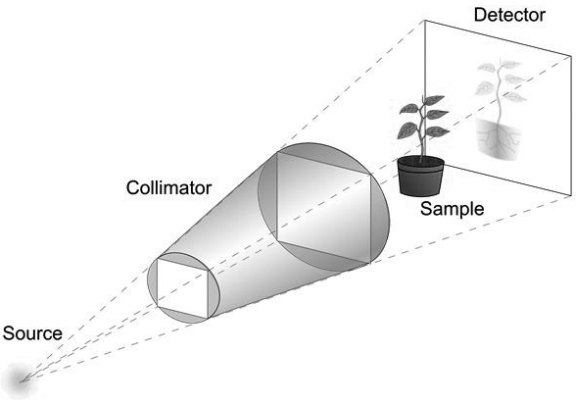

Fig. 2. Experimental set-up for transmission imaging experiments (X-rays or thermal neutrons). In the case of tomography, the sample has to be rotated around its vertical axis and projections are obtained over at least 180° (E. H. Lehmann, Paul Scherrer Institut)

2. Non-destructive analysis (neutron tomography) (E. H. Lehmann)

The investigation had to be performed in a non-destructive manner in order fully to protect the sculpture for future generations. For this there are a number of options. Optical scanning (e.g., with laser-based systems) can achieve a high precision in spatial resolution, but it delivers only information on the outer form and nothing about the wall thickness and inner structures. Even if the inner surfaces were accessible, the matching of positions inside and outside would not be possible with the desired precision (one-tenth of a millimetre). Traditionally, X-ray investigations are performed for such cases in transmission mode (fig. 2), but the attenuation coefficient of gold for X-rays (100 keV) is very high (35.94 cm-1) and penetration is to the order only of a few tenths of millimetre, as a result of which the images provide no clear information about the spatial distribution of the material gold, showing an object's outer surface only with little contrast inside the structure (fig. 3). Neutron transmission imaging is a better choice for gold, as the attenuation coefficient for thermal neutrons is 6.23 cm-1 only, and a penetration of a few millimetres is possible. The transmission images of the object (fig. 4) demonstrate this, showing that structural differences (e.g., the thickness of the wall) become visible. In radiography mode, a superposition of all layers in beam direction is achieved, and this renders the task of distinguishing front and rear features difficult. Therefore it was decided to run a tomography by using thermal neutrons at the NEUTRA facility of the Paul Scherrer Institut; this is a facility at the spallation neutron source (SINQ) for neutron imaging with thermal neutrons.[38]

Fig. 3. Overview of the gold bust using X-rays from the source running at 200 kV. Details of the structure and material distribution can hardly be distinguished due to the strong attenuation of the beam and the low transmission (E. H. Lehmann, Paul Scherrer Institut)

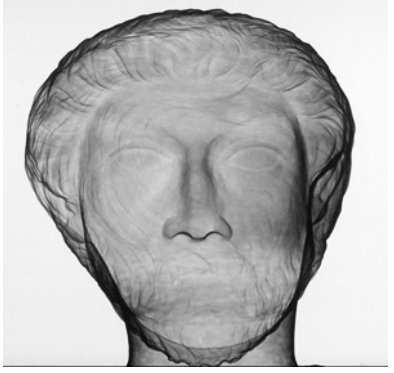

Fig. 4. The object as studied with thermal neutrons in radiography mode. The high transparency showed that application of neutron tomography was promising (E. H. Lehmann, Paul Scherrer Institut).

38 http://www.psi.ch/sinq/neutra/

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Fig. 5a. Virtual slice through the object along the centre line (E. H. Lehmann, Paul Scherrer Institut).

Fig. 5b. Perspective view in the 'semi-transparent' mode, which takes the effective thickness of the wall into account (E. H. Lehmann, Paul Scherrer Institut).

Neutron tomography begins with the acquisition of projections of the object over an angular range of at least 180° while it is rotated around its vertical axis in a few hundred equidistant steps. Each projection takes some 10 seconds in the digital detection system, and the whole investigation can be performed within a few hours of beam time. The number of projections, and the acquisition time per projection, will have a direct influence on the quality of the resulting tomography data.

In the case of gold, the risk of activation has to be discussed, as the captured cross-section is not negligible (98.7 barn). The captured cross-section is a measure of the probability that neutrons get absorbed by the irradiated material. With the half-life of Au-198 of 2.7 days, the normal environmental background level is reached after about 2 weeks of decay time.

On the basis of the projection data, we reconstructed the volume of the entire object. The evaluation could now be carried out in different ways, either by quantifying the material content and properties or by visualizing the data as several external or internal views, or as slices at arbitrary positions. Figures 5a-5b and fig. 11 present three different results of the tomography evaluation, based on the voxel data after the reconstruction of the volume.

The visualization of the tomography data is a separate image-processing step, performed to derive specific information from the volume information. We used the commercially-available software package from Volume Graphics.[39] The presentation of the outer surface in comparison to the photographs is given in figs. 6b and 7. A very good agreement was found. The number of voxels (1024*1024*1024) given by the detection system is a limitation, causing some surface roughness in the tomography data. Furthermore, the visualisation tool takes into account the material thickness in a way that thinner layers are presented as more transparent. Based on the data-set of the volume matrix, we are able to count the number of voxels which can be attributed to gold, namely 434.426. With

39 www.volumegraphics.com/

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the volume of the voxel (binned two times) as $(0.54\ mm)^3 = 0.1575\ mm^3$, we can calculate the gold volume as 68.22 cm^3. As the density is known to be 19.3 g*cm-3, we calculated the mass as 1.32 kg, which is an under-estimation by only 15%.

The visualization program used (Volume Graphics Studio) provides another useful tool — the "wall thickness measurement" — that was applied very efficiently on the bust. As the bust has a layer structure with thickness between 0 and 2 mm, the local thickness distribution provides valuable information on the manufacturing process and the techniques of working. Figure 8 provides an example of the representation of these data, where information on the thickness is given by a colour-coded thickness representation. The density of the data points corresponds to the resolution of the tomography (*c.*0.3 mm). The major thickness is found in regions of the upper face, particularly the sides of the nose. Several thin layers can be recognized between hair and neck. This is useful information for a discussion of the manufacturing process. The visualized volume data were then used to produce a film of the object, including outer views and vertical virtual slices based on the tomography, viewable at: https://www.youtube.com/watch?v=aOXsTn7It0I

3. The manufacturing process (A. Giumlia-Mair)

The manufacturing process of the bust has been a matter of debate among scholars ever since its discovery. The technical observations made by P. Schazmann, in particular his statement that the bust was produced by repoussé in one piece,[40] was doubted by many. As a result, the bust was X-rayed, but even this examination did not dispel the doubts.[41] Having resorted to tomography, we are now in a position to clarify this question and dispel all doubts.

The gold employed is a 22 carat gold — i.e., a gold with a purity of *c.*92%, the rest being a silver addition, perhaps with a little copper. Evaluation of the gold alloy has been performed in the past, apparently by using some goldsmith methods that can determine its purity but not the real composition. For the present study, regrettably it was not possible to carry out a reliable analysis — for example, with non-destructive but well-calibrated XRF equipment and adequate standards — to obtain more precise compositional data. It is worth mentioning that the small fragment of a probably similar gold bust from Kastell Dambach was recently analysed in the Archäologische Staatssammlung München by the conservation specialist of the museum.[42] He used a portable (handheld) Niton XL3t x-ray fluorescence (XRF) analyzer, the measured area was 3 mm, and the measurement time just 40 seconds, which means that the results must be considered merely indicative. Still, it seems that the results for copper and silver were below the detection limit, and for that kind of gold alloy there are no parallels in Roman times. The only explanation for the strange composition is the phenomenon of the depletion of gold during burial in the ground, by which the elements that are higher on the activity series of metals disappear from the alloy. The baser metals present in the alloy corrode at the surface, while the gold, as a precious metal, does not oxidize. Analyses of the surface give the impression that the gold is much purer than it is in reality. The degree of depletion also depends on the kind

40 Cf. Schazmann (supra n.2) 86.
41 Hochuli-Gysel and Brodard (supra n.3) 40.
42 Inv. 1985.2505, see n.5 above. We thank B. Steidl and P. Albert (Archäologische Staatssammlung München) for the results of the analysis and for permission to use them here.

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of soil in which the object is found and its humidity. This could account for analytical data that are quite anomalous for Roman times and for a bust that must have been rather similar to ours.

Our bust weighs 1589.07 gm; gold weighs 19.32 gm per cm^3 so that there are in total 82.25 cm^3. It is generally accepted that when Hellenistic and Roman goldsmiths and silversmiths had to produce a large object in repoussé, such as a decorated vessel with a narrow neck or a bust, they began their work by casting a disk of precious metal. The first part that had to be shaped on a stake is obviously the narrowest, in this case the neck of the portrait. There is no need to explain in much detail why the flaring lower part, with the breast and shoulders, had to be the last to be shaped: the wide hammered sheet representing breast and shoulders would have hindered the artisan when moving and turning the working piece to shape the head. While working on the bust — that is, while thinning down the metal sheet and working on different stakes to shape the various parts of the portrait — the goldsmith had repeatedly to anneal the gold. This means that he had to heat the metal to promote the softening of the material hardened by intensive hammering, and to achieve the re-crystallization of the gold. Thin metal sheets must be flash annealed (i.e., they must be heated at a high temperature for only a few seconds); while thicker pieces can be thermally treated at lower temperatures so as to be uniformly heated and be able completely to re-crystallize the grains of the metallographic structure. A thin gold sheet will break if it is not annealed between the various working stages. It is also important to anneal homogeneously the entire object, because areas that have been less heated will remain more fragile under the hammer, resulting in diffuse breaks all over the structure.

Methods for joining gold sheets

In antiquity there were not many methods for joining metallic parts made of sheet metal:
1. The sheets could be attached one to another by overlapping and fixing them with rivets. This is a rather crude method and easily recognizable since the rivets would always be visible; for example, on our bust the rivets at the lower edge, employed to fix the gold on a support, are very conspicuous.[43]
2. A better way, one that renders the join less evident, is to bend the edges together and hammer them so that they would hold the smaller part in place. This method is chiefly employed with precious metals. It too is easily recognizable because of the thickness around the edges and the joining lines which can never be completely disguised by hammering. A good example of this method, which became common in the Classical period, are the joins of the ears on silver *rhyta* from the region of the Black Sea: the seams around the ears are very skilfully made, but the joining lines are still visible and the sheet's thickness at the joins is quite noticeable (fig. 9).
3. A third method is attaching the two parts by means of a solder. In general, gold solders were gold alloys containing various amounts of silver and copper and having a melting point lower than that of the metal parts that had to be soldered, in order to avoid damaging the gold parts during the soldering process. Common gold solders contain *c.*15-20% of silver and 5-10% of copper in gold. The solder had to be applied between overlapping sheets, and the soldering operation had to be carried out as fast as possible because the metal freezes and solidifies quickly. Because of this, a rather abundant layer of solder had

43 Hochuli-Gysel and Brodard (supra n.3) 63, fig. 62.

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to be applied, and its thickness and distribution generally were rather irregular. The solder layer had to be distributed on the overlapping edges. In the case of a large object, the overlap had to be rather broad and measure at least a couple of centimeters. After application of the solder, the edges could not be hammered any more — if hammered, the join would break because of the different composition and structure of the gold and the solder. As a result, this method was mostly employed on small objects, such as jewellery,[44] or to fix the handles on silver vessels.[45]

4) There was another kind of join but it would not have been suitable for a large object such as our bust. Only one example of this technique has been identified in antiquity, on 4 small gold boxes from Ireland dating to the first half of the first millennium B.C., which had been assembled by pressing and heating the edges.[46] The overlap of the gold sheets is thus quite thick.

With all these methods, the joins turn out to be thicker than the metal sheet used for the object itself. Examination of the tomographies shows that none of these four methods was employed for our bust.

Evaluation of the tomography images

By keeping in mind Roman manufacturing processes and methods of joining, it is quite easy to tell from the tomography images that the bust of Marcus Aurelius was entirely produced by repoussé, and by hammering a single piece of gold. The coloured key on the left of the tomographies shows the different thicknesses of the gold in the various parts of the bust, which must be kept in mind as we discuss the details .

The most striking aspect of the tomography to catch one's eye is the even thickness of the face (fig. 8). Virtually only two colours — yellow (= *c.*0.6 mm) and blue (= 1.05-1.20 mm) — can be seen, while the hair and the cuirass look rather mottled (i.e., are irregularly thick); on them the full palette of reds, orange, yellow, green and blue can be seen, and the individual hammer blows are also rather apparent. The even thickness of the face bears witness to the great skill of the artisan.

A second striking detail is the red line (0.0-0.15 mm) that follows the contours of the face (fig. 10); it is coupled with a second, slightly less visible line on the hair, which looks almost parallel to the first line. The two lines would broadly correspond to lines resulting from joins if the face had been substituted with a new one, but the red indicates clearly that they are thinner than the average for the metal sheet. Thin lines can be recognized between the face and the hair too. From this it is easy to determine that at these places on the bust there cannot be any kind of join: the bust is made of a single piece of gold, shaped by hammering to form the portrait bust. The thinner line around the face is simply the common way in which *caelatores* underlined the various parts of their repoussé and separated different textures, such as, in this instance, the skin and the hair. This manner of working can be found on all repoussé work from Classical to Roman times.[47]

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44 Cf., e.g., R. Higgins, *Greek and Roman jewellery* (London 1980) 173-80.

45 Cf., e.g., J. Lang and M. J. Hughes, "Soldering Roman silver plate," *OJA* 3 (1984) 77-107, figs. 3-4 on pp. 86-87 and figs. 5-6 on pp. 88-89.

46 J. Ogden, *Jewellery of the ancient world* (London 1983) 59 and fig. 4.56 on p. 63.

47 Cf., amongst hundreds of examples, the repoussé work on the vessels from Berthouville (K. Lapatin [ed.], *The Berthouville silver treasure and Roman luxury* [Los Angeles, CA 2014] fig. opposite p. 1; 67, detail of fig. 34; D. E. Strong, *Greek and Roman gold and silver plate* [London

On the neck is a further interesting detail, an irregular horizontal red line with a couple of yellow and blue spots, which indicate that along a thinner line some small breaks or holes were repaired with a small quantity of solder. The state of the thinner line indicates that the entire area had undergone more stress than other parts, with the already-thinned metal being hit during the working process. This is the area that had to be raised first. The logical explanation for the stress cracking of the metal is that the various stakes that passed through the neck and were employed during the shaping of the head repeatedly hit the edge between the neck and the still quite thick section of the original disk (this was the part that had to be flattened by hammering and was the last to be finished) while the piece was being constantly turned around for shaping the various details of the head as repoussé. Later, when the front of the neck had to be formed from the remains of the original disk, the metal had to be stretched down to shape the throat and neck sinews. As the stress cracking could not be completely relieved by annealing, the result was this thinner horizontal line on the neck, which then needed some repairs with a solder applied from the inside of the bust. The solder is obviously thicker than the gold sheet; it appears blue on the tomography and is very evident on the red line (fig. 11).

Single thicker spots pointing to the use of solder are also visible in other areas of the bust. Three small daubs are recognizable above the proper right eye at the hairline, where the artisan, having to underline the distinction between skin and the mass of the curly hair, thinned the metal too much. A more noticeable repair is at the tip of the nose, above the left nostril. More spots indicating repairs with solder can be seen around the portrait — e.g., next to the proper left ear, along the hair line, on top of the head, behind the row of curls on the left side of the head, and under the chin (fig. 12).

Following the raising and repoussé work, the outer surface of the bust had to be finished. First, some pickling substance, such as alum or vinegar, was applied to the surface to remove the black staining caused by the repeated annealing of the gold.[48] The surface was then polished with a fine abrasive such as powdered marble or chalk.[49] Finally, it was worked with a large variety of tools, recognizable by the traces left on several areas of the outer surface. The surface of the facial skin was given a matte finish by a tool with a slightly concave, circular point that left many tiny circlets next to each other (fig. 13). The same tool was used on the leather shoulder strap. The inside of the head was cleaned to remove any blackish stains resulting from annealing, but it was not polished. The internal surface still preserves some slight and diffuse marks left by various tools, such as blunt hammers and broad chisels used during the shaping of the bust. A larger blunt chisel was employed on the texture of the undergarment. A tool with a thick elongated blade was used for the hair, together with a thicker tool used both vertically and at an oblique angle to obtain round impressions or curved lines (fig. 14). The strands of the beard and the locks over the forehead, both in high relief, were finished with a thin sharp chisel, with a round pointed tool,

1966] 142 and pls. 35A, 43A and 49); the figural vessels in the Sevso treasure [M. Mundell Mango and A. Bennett, *The Sevso treasure* vol. 1 [JRA Suppl. 12, 1994]); the Herakles and Auge phiale of the Rogozen treasure (A. Fol *et al.*, *Der thrakische Silberschatz aus Rogozen Bulgarien* [Sofia 1989] 67-69); or the Derveni krater (B. Barr- Sharrar, *The Derveni krater* [Princeton, NJ 2008] 34, figs. 27-28).

48 R. Halleux, *Les alchimistes grecs, t.* I. *Papyrus de Leyde – Papyrus de Stockholm – recettes* (2nd edn., Paris 2002).

49 Ogden (supra n.46) 87.

and with a stippling tool (fig. 15). The back of the head is quite flat and shows very little finishing with special tools. The hair is represented cursorily, almost graphically (fig. 16). The hair-do at the back is different from other portraits of Marcus Aurelius, and it is just possible that for the back of the head the artisan used or had in mind an older template (i.e., a model).

Conclusions (A. de Pury-Gysel)

The stylistic heterogeneity of the gold bust of Marcus Aurelius had prompted the question of whether it had been manufactured by repoussé with a single batch of gold (1589.07 g) or by joining several separately-produced parts perhaps deriving from different eras. We know from texts and from some marble and bronze works that the reworking of portraits in order to adapt one physiognomy to a new one was practiced. Neutron imaging was undertaken to obtain an answer. The results of the tomography, here performed for the first time on a large Roman gold artefact, provide strong evidence for manufacture in one piece. The neutron imaging also shows the different thicknesses of the gold in the various parts of the bust and reveals some of the difficulties the goldsmith encountered in producing a large bust in repoussé work and in the hammering and chiselling of the gold. Very small traces of soldering were noticed, along with tiny repairs in some areas. The question remains unresolved, however, as to why the goldsmith followed closely the last official portrait of A.D. 176-80 for the lower part of the face and first range of curls, but not for the general proportions of the head nor for the hairstyle of the back of the head nor for the type of cuirass, which in the second half of the 2nd c. was outdated. Whether the chronological discrepancies between these elements are due to a lack of skill and knowledge — in other words, if we can speak of a lower quality — remains unanswered, not least because of the very small number of works of gold that escaped remelting, leaving us with few comparisons.

anne.depury.gysel@gmail.com CH-4056 Basel
eberhard.lehmann@psi.ch Paul Scherrer Institut, CH-5232 Villigen PSI
giumlia@yahoo.it AGM Archeoanalisi, I-39012 Merano (BZ)

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