Casting Light on 20th-Century Parisian Artistic Bronze: Insights from Compositional Studies of Sculptures Using Hand-Held X-ray Fluorescence Spectroscopy

Emeline Pouyet 1,*, Monica Ganio 2, Aisha Motlani 3, Abhinav Saboo 4, Francesca Casadio 5 and Marc Walton 1

1 Center for Scientific Studies in the Arts, Northwestern University, Evanston, IL 60208, USA; marc.walton@northwestern.edu
2 The Getty Conservation Institute, 1200 Getty Center Drive, Suite 700, Los Angeles, CA 90049, USA; mganio@getty.edu
3 Department of Art History, Northwestern University, Evanston, IL 60208, USA; AishaMotlani2012@u.northwestern.edu
4 QuesTek Innovations LLC, 1820 Ridge Avenue, Evanston, IL 60201, USA; asaboo@questek.com
5 Art Institute of Chicago, Chicago, IL 60603, USA; fcasadio@artic.edu
* Correspondence: emeline.pouyet@northwestern.edu; Tel.: +1-847-467-6070

Received: 2 January 2019; Accepted: 12 February 2019; Published: 21 February 2019

Abstract: In the 19th and early 20th centuries, Paris was home to scores of bronze foundries making it the primary European center for the production of artistic bronzes, or bronzes d’art. These foundries were competitive, employing different casting methods—either lost-wax or sand casting—as well as closely guarded alloy and patina recipes. Recent studies have demonstrated that accurate measurements of the metal composition of these casts can provide art historians with a richer understanding of an object’s biography, and help answer questions about provenance and authenticity. In this paper, data from 171 20th-century bronzes from Parisian foundries are presented revealing diachronic aspects of foundry production, such as varying compositional ranges for sand casting and lost-wax casting. This new detailed knowledge of alloy composition is most illuminating when the interpretation of the data focuses on casts by a single artist and is embedded within a specific historical context. As a case study, compositional analyses were undertaken on a group of 20th-century posthumous bronze casts of painted, unbaked clay caricature portrait busts by Honoré-Victorin Daumier (1808–1879).

Keywords: hand-held X-ray fluorescence spectroscopy; semi-quantitative elemental composition; artistic bronze; 20th century; foundry fingerprints

1. Introduction

From the early 1900s, France was home to numerous foundries, with Paris being the dominant center for the production of artistic bronzes, or bronzes d’art. Scholars have only recently started to write the history of these foundries, unraveling the relationships between foundrymen, artists, and the 20th-century art market [1–4].

Casting modeled clay, wax, plasticine, and plaster sculptures into durable metals allowed artists and dealers to create multiples of individual artworks, increasing their longevity and profitability while also making them available to a growing audience of collectors. Material studies of bronzes d’art can provide a better understanding of their casting history. When correlated with historical
sources such as artists’ letters, art dealers’ catalogs, foundry invoices, purchase documents, or casting processes, material evidence can help to assign unmarked bronzes (bronzes that do not bear a foundry mark) to a specific foundry, ascertain casting dates, and shed light on the collaboration between artists, dealers, and foundrymen in the production of modern bronze sculpture. Ultimately, this information contributes to a better knowledge of the history and practices of 20th-century Parisian art foundries, and the relationship or competition between different firms [5].

Hand-held X-ray fluorescence (XRF) spectroscopy has been increasingly used in recent years for the semi-quantitative determination of major elements of modern bronzes, with alloy composition information occasionally being included alongside new art-historical scholarship in museum publications and exhibition catalogs [5–12]. Several recent studies not only have described the in situ quantification of the composition of metal objects using XRF [13–17], but they have also demonstrated comparable major compositional values with inductively coupled plasma (ICP) [9]. In comparison with micro-invasive methods (such as metallographic cross sections, electron microprobe, ICP, and isotope analysis), non-invasive XRF analysis has the advantage of allowing fast in situ investigation of several areas of a single sculpture, thus accounting for phase segregation, or separate casting steps, as may be required for large sculptures, whose base, body, and peripheral parts could be cast separately.

Drawing on a large database of alloy compositions for 20th-century bronzes with known foundry marks that have been assembled by the authors, this paper discusses how new material knowledge can enrich our understanding of an object’s biography. As a case study, we present here the results of our analysis of a group of posthumous bronze portrait busts by Honoré-Victorin Daumier (1808–1879) in the collection of the Art Institute of Chicago, which have an incomplete record of ownership, but can be assigned to foundries with some degree of certainty.

**Honoré Daumier’s Busts**

Twenty bronze sculptures from the Art Institute of Chicago (AIC) collection [18] were analyzed. These were caricatural portrait busts posthumously cast in the first half of the 20th century from a set of unbaked painted clay models (Figure 1a) made between 1832 and 1835 by the French artist Honoré Daumier. According to an article published in the weekly illustrated satirical magazine, *La Caricature*, these clay sculptures were intended to serve as models for a series of lithographic portraits of contemporary figures associated with the political regime of Louis Philippe (1773–1850) that were published in *La Caricature* and *Le Charivari* between 1832 and 1835 (*La Caricature* no.78 (26 April 1832): 2). Daumier sold the clays to Charles Philipon, the editor of these publications. In 1927, the Philipon family sold them to Maurice Le Garrec, an art dealer and publisher. Between 1927 and 1929, Le Garrec commissioned the sculptor Pierre-Félix Fix-Masseau (1869–1937) to repair the clay models and make molds of them [11]. The plaster positives and retainers were then given to the Barbedienne foundry to make wax positives for the lost-wax casting process [11]. In her study of nineteenth-century European Sculpture in the National Gallery of Art (NGA), art historian Suzanne Glover Lindsay has assigned cast dates of 1929–1930, 1929–1940, and 1929–1950 for the NGA’s collection of Daumier bronze busts [19]. At least 1 cast of each bust had been produced by 1948, when the Musée de Beaux Arts in Marseille (France), Daumier’s place of birth, acquired a full set of all 36 busts [11].

In 1954, the Barbedienne foundry closed down [2]. The plaster molds made by Fix-Masseau were returned to Madame Le Garrec, who commissioned the Valsuani foundry to make 3 sets of all 36 busts: 1 for herself and 1 for each of her daughters, Madame Heuyer and Madame Cordier (Figure 1b). These were marked LG (for Madame Le Garrec), Mme. H (for Madame Heuyer), and C (for Madame Cordier).

The AIC acquired one of the bronze busts as part of the Worcester bequest of 1947 (AIC 1947.64), and later acquired a full set through the Samuel and Marie Louise Rosenthal bequest of 1998. Perhaps as a reflection of different casting dates, foundry practices, and histories of ownership, the AIC busts vary greatly in terms of their surface condition, their weight and thickness, and the color, density, and opacity of their patina. Among the AIC busts analyzed, 18 were attributed to the Barbedienne
foundry and 2 were attributed to the Valsuani foundry. Those assumed to have been issued by Valsuani bore the known Valsuani mark, whereas none of the bronzes cast by Barbedienne displayed the Leblanc–Barbedienne mark that was customarily stamped on bronzes produced by this foundry since 1921. However, the bronzes tested in this study displayed cast marks that were consistent with Daumier’s bronze portrait busts with a well-established provenance in other museum collections, including those at the National Gallery of Art (NGA), Washington DC [19]. More particularly, both the NGA and the AIC busts thought to have been cast by Barbedienne carried Maurice Le Garrec’s monogram. They also bore one or two edition numbers, and in most cases, the inscription “BRONZE” was cold-stamped either below the monogram or on the underside rim.

As far as the date of casting for the bronzes was concerned three date ranges were proposed 1929–1935, 1935–1952, and 1953–1965 (These dates are based upon the date ranges Glover Lindsay had provided for the NGA busts but were expanded for the AIC busts due to the fact that most of the AIC busts displayed later edition numbers that might suggest later cast dates. Only the Dupin from the Worcester Collection (1947.64), which bore an edition number of 1, could be dated with greater precision to 1929–1930. The “BRONZE” inscription provided some chronological framework for the majority of the busts in the Art Institute’s collection proposed to be cast by Barbedienne. Following a decree issued in 1935, all art bronzes produced in France that were comprised of an alloy containing at least 65% copper had to be marked with the word “BRONZE” in order to distinguish them from brass [2]. This suggested that the bronzes bearing this inscription were cast after 1935 but before 1952 (1952 being the year in which the casting of Daumier’s bronzes in the Barbedienne foundry was said to have ended). For those bronzes that did not bear any foundry mark nor BRONZE inscription, we proposed a cast date between 1929, the year that the casting of the Daumier’s busts had begun at the foundry, and 1935.

With such a complex history that included the existence of multiple editions, and the availability on the market of many reproductions, it appeared that XRF analysis of the alloys of the AIC busts could shed additional light on their casting history, especially if an alloy similar to other known Barbedienne’s casts could be determined. Alloy composition information was available for comparison for 4 bronzes cast by the Barbedienne foundry bearing the foundry mark: 2 bronzes cast from busts by Daumier (cast in 1955) in the collection of the Philadelphia Museum of Art (PMA 1957.127.11 and PMA 1986.26.275) [20], a bronze cast of the Eternal Springtime by Rodin in the collection of the Cantor Arts Center, Stanford (1974.109), and a bronze cast of The Kiss by Rodin in the collection of the NGA (NGA 1942.5.15) [10]. Moreover, the composition determined by hand-held XRF of 6 Daumier’s busts that were part of the NGA collection were also available for comparison [19].

Figure 1. (a) Painted clay of André-Marie-Jean-Jacques Dupin, Ainé Modeled c. 1832/35 by H. Daumier, with the two bronze busts cast between 1929 and 1930 (Art Institute of Chicago (AIC) 1998.796 and AIC 1947.64). (b) Time line of the main steps involved in the process of posthumous Daumier’s bronzes casting.
2. Experimental

2.1. Hand-Held X-Ray Fluorescence Spectroscopy as a Semi-Quantitative Method to Determine the Elemental Composition of Bronzes

XRF analyses were performed using a Bruker TRACeR III-V X-ray fluorescence spectrometer. The instrument is equipped with a Rh tube (maximum voltage 40 kV), and a Si-Pin detector (typical resolution 190 eV at 10000 cps). For these experiments, the instrument was operated using a 40 kV voltage and 1.5 µA current, with an acquisition time of 180 s per spectrum. It is well known that maintaining consistent orientation of the hand-held instrument with respect to the analyzed surface is crucial in order to obtain reproducible results [21]. Thus, whenever possible, flat areas of metal were selected, covering the entire aperture of the instrument, ensuring good contact between the object and the instrument’s measuring head. For each of the Daumier’s sculptures, 10 points meeting these criteria were analyzed: 6 at the surface of the patinated surface (covering full height of the bronze), and 4 from the base where the patina was visually absent. All spectra were processed with PyMca [22] using fundamental parameters to measure and subtract the spectral background and to extract integrated peak areas for the major and minor X-ray lines.

An empirical calibration curve, based on the fitted peak areas, was created using the CHARM (Cultural Heritage Alloy Reference Material Set) copper reference material set produced by MBH Analytical, Barnet, UK [15]. While these reference materials were certified for 20 elements, a good calibration response was obtained only for a limited number of them. Elements such as aluminum (Al), silicon (Si), phosphorous (P), and sulfur (S) were not detected efficiently by the current analysis conditions due to their low characteristic X-ray energies, and were not considered in the calibration. Results from the calibration indicated that major constituents, namely concentrations higher than 1 wt % can be determined with a relative standard deviation (RSD) lower than 3%. Quantification of minor and trace elements (concentrations less than 1%) is not possible under the current analysis conditions.

2.2. Building a Compositional Database for Artistic Bronzes

The bronze alloy compositions reported in this study encompassed both published [5,9,10,20,23] and our own newly acquired results obtained using hand-held XRF instrument from a total 171 bronzes d’art produced in Paris between 1900 and 1981 with a known foundry provenance [24].

Published data included the metal composition of 41 sculptures from the Art Institute of Chicago (AIC), the Philadelphia Museum of Art (PMA), and the Rodin Museum (RM), measured by hand-held XRF and/or ICP-Optical Emission Spectroscopy [9,20], and hand-held XRF results from 9 sculptures from the permanent collection of the Smart Museum of Art at the University of Chicago [5], 20 bronzes from the Matisse collection of the Baltimore Museum of Art [23,25], and 11 bronzes from the Simpson collection of the NGA [10,19]. These data provided the alloy composition of 80 stamped bronzes from the 1900s to the 1960s, cast by the foundries of Alexis Rudier (17), Barbedienne (9), Bingen–Costenoble (3), Georges Rudier (3), Hebrard (6), Valsuani (36), Godard (4), and Susse Frères (2).

Compositional results newly acquired by hand-held XRF at the Center for Scientific Studies in the Arts over the last 3 years encompassed data from bronzes housed in 4 museum collections: (i) 55 sculptures among the 200 artworks that were part of the Cantor Art Center, Stanford University, mostly by the artist Auguste Rodin (cast after 1950); (ii) 18 sculptures by Malvina Hoffman, a former student of Auguste Rodin, part of the collection of the Field Museum of Natural History, Chicago; (iii) 16 sculptures by Pablo Picasso, part of the collection of the Musée National Picasso, Paris; and (iv) the 2 bust bronzes by Daumier at the AIC, further detailed in this paper. These newly acquired data provided 91 supplementary alloy compositions for the period between 1906 and 1986 for several foundries, bringing the total number of sculptures captured in the database for each foundry as follows: Alexis Rudier (42), Barbedienne (10), Bingen–Costenoble (4), Georges Rudier (36), Godard (14), Robecchi (4), Valsuani (50), Hebrard (6), and Susse Freres (5). In considering the relevance of this large database, a few observations must be made.
First, alloy compositions collected from certain foundries were more numerous than others in the database. To be more specific, the production of Alexis and Georges Rudier, together with Valsuani, accounted for almost 70% of the bronzes d’art analyzed. Extracting specific conclusions regarding other foundry practices apart from the 3 mentioned above was not possible, though compositional similarities could be highlighted.

Another important aspect to account for in constructing the database was the elemental quantification provided by hand-held XRF. In the publications mentioned above, the information provided per bronze was given as a single composition and was limited to the major elements relative to (i) the alloy: copper (Cu), tin (Sn), zinc (Zn), lead (Pb), occasionally nickel (Ni), and arsenic (As) and (ii) to the patina: iron (Fe) and chromium (Cr). Thus, in this study Cu, Sn, Zn, Pb, and Ni were used to describe the composition of the alloy and normalized to 100% to ease data comparison. In the context of bronze, semi-quantitative values were usually acquired from flat and homogeneous areas from (i) the surface of the bronze, (ii) the base area where unpatinated alloy was accessible [9,20], or (iii) on both [5,23]. Only one publication [23] presented both patinated and unpatinated alloy composition on the same object. Moreover, none of the publications provided the standard deviation of the composition when multiple points were collected at the scale of the sculpture, although a large variation can be expected for some elements, such as Zn. The reader should then keep in mind that the compositions given in literature are often a single average value of the unpatinated and/or patinated surface of a bronze d’art, and that the results can present around 1% standard deviation, thus reinforcing the notion that XRF analysis of metal alloys of artistic bronzes is only semi-quantitative in nature.

3. Interpreting Compositional Data: First Steps in Determining Foundry Fingerprints

In order to help visualize the large compositional dataset, box-and-whisker representations were used to show the distribution of Zn values associated with a given foundry (Figure 2a,b). The box-and-whisker plot is a standard graphical representation which describes variation of a single variable by its extrema (whiskers), its lower and upper quartiles (consisting of rectangle bounding boxes), its median demarcated by a central line, and its mean represented by a red plus sign [26]. Analysis of the data highlighted that Zn is the element that best discriminates the casting technique among the different foundries.

Summarizing the variation in Zn associated with the different foundries in this manner and combining it with available information on the casting method of the sculptures that were surveyed demonstrated that sand casts predominantly displayed low Zn content down to 5 wt %, with little alloy variability observed at the foundry scale (Figure 2).
Among the 42 casts from the Alexis Rudier foundry (1874–1952), a relatively low content of Zn with an average of $1 \pm 0.6$ wt % was observed for 40 pieces (Figure 2b). Only two sculptures (Cantor Arts Center 1983.204, Smart Museum 1974.217) present higher Zn contents, respectively, 8.1 and 18.7 wt %. The bronze from the Cantor Arts Center is currently under exhibition and cannot be accessed for further observation of the cast; however, 1974.217 from the Smart Museum presents remnant core material very similar to a plaster-based material.

Similarly, the Georges Rudier foundry pieces presented a relatively low amount of Zn content in their alloy composition. The 31 out of the 36 sculptures discussed here, cast between 1955 and 1981, presented Zn contents below 5 wt %, with 20 sculptures presenting a similarly low Zn content of $2.0 \pm 1$ wt % (Figure 2b). The remaining 5 Georges Rudier’s casts had a much higher concentration of Zn, with an average concentration of $13.2 \pm 2.4$ wt %. For these sculptures, a strong decrease of the Sn content compared to the other 31 sculptures was observed, possibly pointing to a modification of the copper alloy composition that is more typical of a lost-wax process (as detailed hereafter). The Georges Rudier foundry is known to have performed only the sand cast process. When it was considered the most cost-effective, some pieces were sub-contracted to lost-wax foundries (e.g., Scuderi) [2], while they were still stamped as “Georges Rudier”. A closer look at the structures of these objects helps to confirm the hypothesis of different casting techniques. For example, the Cantor Art Center 1974.70, *Hanako, Type F*, part of the 5 high Zn G. Rudier sculptures, has been examined and presents clear remnant plaster from core material, clearly pointing toward the use of lost-wax casting instead of the expected sand casting.

The 4 bronzes sand cast around 1910 by Bingen (lost-wax founder) and Costenoble (sand caster) presented a very homogeneous composition with a Sn average value of $2.4 \% \pm 0.2$ and Zn values that were similar to the G. Rudier production of $3.0 \pm 0.4$ wt % (Figure 2b).

Similarly, a characteristically low Zn-content copper alloy was observed for the Florentin or Désiré Godard (1922–1923) foundries ($4.3 \pm 0.4$ wt %). Compared to the alloy composition of the Rudier and Bingen-Constenoble foundries, a slightly higher Zn content was used for the Florentin or Désiré Godard foundries (Figure 2b).

The foundries presented above share an overall constant and reproducible copper alloy composition, with a Zn content lower than 5 wt % that seems to be characteristic of their similar sand casting method.

Conversely, the lost-wax casts presented higher Zn alloy compositions (Figure 2a) that were also more variable at the scale of the individual foundry’s production, as exemplified by the casts from Emile Godard, Claude Valsuani, Hebrard, Susse Frères, and Robecchi foundries (Figure 2b). Amongst
these, the Susse Frères, Robecchi, and E. Godard foundries were characterized by the highest degree of variability in their copper alloy composition. These three foundries showed the highest Zn contents, often above 14 wt %. The Robecchi’s production analyzed was limited to a few bronzes produced during World War II, suggesting that the variabilities observed in the final alloy composition of the sculptures could depend on the access to, and storage of metal and plaster, highlighting the importance of taking these factors into account when examining the casting process. The Susse and E. Godard foundries both produced sand cast and lost-wax sculptures simultaneously during their activity and may have used different alloy compositions and storage methods, which may explain the broader alloy compositions observed in their casts.

Even in light of a relatively wide range of Sn and Zn content for lost-wax casts, fewer examples contained Zn in comparable amounts to the Valsuani’s, Barbedienne’s, and Hebrard’s typical composition. These last three foundries presented an average range of Zn content in their composition that were rather similar—10.8 ± 1.7 wt % for Valsuani, 9.8 ± 1.8 wt % for Hebrard, and 9.8 ± 2.4 wt % for Barbedienne. Hebrard’s production differed by a higher Sn content (5.3 ± 0.8 wt %). While previously a time dependency in the Valsuani’s alloy composition had been proposed in the literature [9], our expanded study indicated that, in fact, the variation did not seem to correlate to any time scale. Thus, further study is needed to ascertain whether Valsuani may have adapted its alloy composition to the type of object (size, bronze thickness, final rendering color, etc.) produced, or whether the alloys have been adjusted in response to specific workers’ preferences, fluctuation in the market price, and availability of raw materials.

Young et al. [20] suggested that the casting method had a great impact on the composition of the metal alloy. The expanded database presented here confirms the importance of specific alloy composition in relation to casting technology.

This observation seems to corroborate the modern founder adage: “la fonte au sable coule du rouge, la cire perdue coule du jaune,” (Private communication with Jean Dubos, first founder chief at the Coubertin Foundry, and Elizabeth Lebon, Art Historian, author of several essays and books on sculptures and casting techniques of bronzes d’art, October 2017) meaning that the sand cast process casts a red alloy, and the lost-wax process casts a yellow alloy. Indeed, the color of a common brass is golden yellow, the alloy becoming darker and richer when the Cu amount increases. An example, an alloy containing more than 20 wt % of Zn would resemble gold in color, whereas an alloy of 90% Cu for 10% Zn would have a reddish-yellow color [27]. Whereas the final color is not the result of the choice of the Zn ratio alloy composition here, it seems to correlate with current foundry practices and knowledge. It was also likely that it provided foundrymen with an easy visual clue to assess the composition of their alloys in operando.

Looking at the historical reasons for the low Zn tenor of sand casts, E. Lebon [28] pointed out that a number of the first generation of art sand casters were either themselves involved in military operations during the French Revolution, in particular cannon production, or were the sons of men trained to work in that field. They redirected their skills to the civil- and art-oriented branches of the industry when the demand for guns was met by booty captured in Napoleon’s campaigns. The subsequent invention of new techniques to counteract the build-up of explosive gases in sand molds made it a dependable means for the production both of monumental statuary and for the supply of smaller serial bronzes to a market which expanded dramatically after 1830. Interestingly, cannon alloy was known to present a very low Zn content, i.e., 3 parts Zn for 100 parts of bronzes in the early 1800s, in order to maintain both hardness and resistance of the metal [29]. Here, the likelihood that alloy compositions from the cannon casts were transposed to sand casting production of bronzes d’art cannot be excluded, traditions being part of the daily life of workshop recipes.
Looking at the results with a modern, materials-by-design lens, the composition of the alloy can be related to its castability, the ease of forming a quality casting. The castability of an alloy can be related to the fluidity of the melt which in turn is related to the freezing range, given by:

$$\Delta T_{\text{freezing}} = T_{\text{liquidus}} - T_{\text{solidus}}$$

where $T_{\text{liquidus}}$ is defined as the lowest temperature at which an alloy is completely liquid and $T_{\text{solidus}}$ is defined as the highest temperature at which an alloy is completely solid. Castability of an alloy is inversely related to $\Delta T_{\text{freezing}}$, i.e., the lower the freezing range, the better the melt fluidity [30] and the greater the castability. Recent advances in material science have made it possible to calculate the freezing range of an alloy based on its composition. Several commercial computational tools utilizing the CALPHAD (CALculation of PHAse Diagram) approach [31,32] have enabled such calculations. One such tool, ThermoCalc [33] was used in the present work to perform calculations of freezing range over a range of compositions with varying Zn and Sn content in Cu (Figure 3a). The calculation was performed using TCCU2 thermodynamic database on ThermoCalc 2017a version.

It was observed that for similar Sn content, an increase in Zn resulted in a larger freezing range and hence poorer castability. Thus, with the classical low Zn sand cast, an enhanced castability should be expected.

Sand cast molds resist high temperature melts, easily allowing the casting of low Zn bronze alloy, characterized by a slightly higher melting temperature (~1100 °C) than high Zn alloy composition (<1000 °C) (Figure 3b). Using low Zn alloy composition to cast in sand mold is also preferred as alloy richer in Zn would “eat” into the molding sand, leading to a rough and blemished casting [27]. These last aspects are additional criteria that can justify the low-Zn composition of alloys typically used by sand cast foundries. On the contrary, the major drawback of the lost-wax process is that it can only be used with lower melting temperature non-ferrous materials, such as zinc. The maximum working temperature of plaster is 1200 °C, so higher melting temperature materials would melt the plaster mold. More importantly, the fluidity of the melt and ductability of the metal after casting increase with the amount of Zn used—additional criteria that can motivate the use of brass-like composition for lost-wax techniques, in opposition to the sand cast approach. If brass composition is favored, it also represents a more economical solution as Zn has a lower cost than Cu.

![Figure 3](image.png)

**Figure 3.** Biplot representing average Sn versus Zn contents of the sculptures part of the database with (a) overlapping Cu–Sn–Zn freezing ranges and (b) overlapping Cu–Sn–Zn liquidus and solidus lines.
4. In Focus: Honoré Daumier’s Bust Series

4.1. The Alloy Composition: The Fingerprint of the Foundry

Figure 4a,b present the Cu, Sn, and Zn contents for each sculpture as determined from XRF analysis performed on the base of the bronzes (characteristic of the alloy composition with the least or no interference from patina). The production attributed to the Barbedienne foundry was divided into two groups, based on the presence or absence of the mention of “BRONZE” dated from 1935.

Focusing on the major elements of the alloy—namely Cu, Sn, and Zn—the busts cast by the Valsuani foundry can be easily distinguished from others, with Cu, Sn, and Zn contents of 78.8 ± 1.2 wt %, 4.4 ± 0.4 wt % and 13.3 ± 0.8 wt %, respectively. Regarding the bronzes attributed to Barbedienne, their alloy is characterized by a lower Sn (2.9 ± 0.5 wt %) and Zn (9.4 ± 1.2 wt %) content, together with higher Cu (86.8 ± 1.2 wt %). The presence of lead (around 1 wt %) limited to the Valsuani’s casts of the Daumier’s busts further support the existence of specific alloy fingerprints at each foundry. The variations reported in Appendix A between bronzes coming from the same foundry (Barbedienne) are too small to be considered relevant and represent real differences of composition.

4.2. Patina Technique and Materials as Supplementary Criteria of Differentiation between Foundries

The use of hand-held XRF allowed us to probe both the alloy and patinated alloy composition of all bronzes. For each of the Daumier’s sculptures, 10 points were taken—6 from the surface with patina and 4 from the base where the patina was absent. The composition of the patinated surface of all bronzes compared to their base shows little difference except for a higher concentration of Zn in the base, as shown in Figure 5a, which reports the weight percent of elements in the base versus weight percent of elements in the patina. Interestingly, the Valsuani’s busts present the strongest depletion of Zn in the patinated surface compared with the base alloy.

Zn has a melting temperature of 420 °C, and a boiling temperature of 908 °C. However, at atmospheric pressure, Zn sublimes at 343 °C [34]. Sublimation is the transition of a substance directly from a solid to a gas phase without passing through an intermediate liquid phase. This endothermic phase transition occurs at temperatures and pressures below the substance’s triple point in its phase diagram. Two possible mechanisms might be responsible for the loss of Zn from the surface of the sculptures—casting or patination. During casting, the molten metal is likely to interact with the casting molds. Among the major constituents of bronze, Zn is the most volatile, therefore the most likely to leave the alloy and interact with the molds, resulting in a greater Zn depletion on the surface compared to the bulk composition [35]. The extent to which Zn is released in the mold fabric probably relates to the length of time the cast metal remains molten. This also depends upon the dimension of the
sculpture, since a bigger mold would remain hot longer than a smaller one, with a consequent larger volatilization of Zn [36].

![Graph](image_url)

**Figure 5.** (a) Biplot representing the average content of Zn, Sn, and Pb in patina and base for each Daumier’s bronzes; (b) A.A. Hebrard (1904) applying hot patina on a bronze [37]; and (c) bar plot representing for each bust—(i) T-predicted: the temperature at which the observed amount of Zn loss is seen and (ii) T-start: the temperature at which the volatilization starts. The busts cast by Valsuani are the last two values represented (1998.781 and 1998.783).

On the other hand, patination plays a major role in the surface changes of a bronze sculpture (Figure 5c). Patina could be applied in a variety of ways, mainly through cold (no heat) or hot (with heat) processes [38]. Hot patination methods involve the use of a torch to heat the bronze surface prior to the application of the patination solution. In the early 20th century, two types of torch were available—chalumeau à gaz (probably oxyacetylene torch) and the lampe à souder (probably a gasoline torch) [39] (Figure 5b). A temperature not higher than 100 °C [40] is recommended for hot patina application. However, the heating of the bronze surface using a torch is not a controlled process, and temperatures around 3000 °C can easily be reached; thus volatilization due to the torch is worth considering.

Thermodynamic calculations can be used here again, to calculate the formation of gas phase at higher temperatures for a given composition of the alloy. Using the same thermodynamic TCCU2 database previously described, calculations were performed for the starting temperature of gas phase formation using the composition measured in the bronze base. It was observed that the gas phase was primarily composed of Zn, suggesting that Zn would be the first element to volatize. Further, it is also possible to calculate the predicted temperature at which the Zn content in the alloy would be expected to drop to the level observed in the patina. Figure 5c shows a bar chart of the start temperature and the predicted temperature for the observed Zn loss across the different alloys.

The minimum temperature for the volatilization of Zn for the alloy composition of the Valsuani’s busts (1998.781 and 1998.783) is 1410.60 ± 32.93 °C. This value is much lower than what is expected for the rest of the bronzes, for which the minimum temperature value for Zn volatilization is 1526.79 ± 44.92 °C. In other terms, the application of a heat source at a given temperature would lead to larger Zn depletion at the surface of the Valsuani’s bronzes compared with the other bronzes (Figure 5c);
a result consistent with the greater decrease of Zn content observed for the patinated surface of the Valsuani’s casts.

Whereas the heat application of patina in both Valsuani’s and Barbedienne’s busts seems to modify the Zn content of the characteristic composition of the alloy, other metallic elements (Figure 6) detected on the patinated surface but not on the sculpture’s base seem to suggest a voluntary addition related to the patination process itself. It is the case for Cr, Pb, and Fe, which were detected in the patinated surface of the Valsuani’s bronzes, leading to the interpretation that the foundry used mainly two heated patina compositions: (i) Pb = 2 wt %, Fe = 1 wt %, and Cr = 2–7 wt %, (ii) Fe/Cr = 1/1 (2–4 wt %) and Pb = 0–3 wt %. None of the Barbedienne’s casts has Fe, Cr, or Mn in the patinated surfaces, a finding that is also consistent with the NGA Daumier’s busts. Regarding Pb, only one sculpture (1998.800) presents a high amount of Pb attributed to patina in the order of about 5 wt %.

4.3. The Daumier’s Casts in the Larger Context of the Production of the Valsuani and Barbedienne Foundries

When specific results from the focused study of the Daumier’s busts were examined within the larger database of compositional ranges for the Barbedienne and Valsuani foundries described in Section 2.2, the following conclusions can be drawn (Figure 6a,b).

Overall, the alloy composition identified for the bronzes believed to have been cast by Barbedienne correlates with values of Barbedienne’s cast in our expanded compositional database, confirming the attribution based on the markings described above. Only one Rodin bronze from the Cantor Museum of Art bore a Barbedienne mark (1974.109: Eternal Springtime, no. 4 reduction, 1898–1918, first modeled c. 1881, gift of the Iris and B. Gerald Cantor Foundation -foundry mark: “F BARBEDIENNE Fondeur”), 1974.109. The Eternal Springtime no. 4 reduction presented a very different alloy composition. Interestingly, its foundry mark presented a different typography than the marks published for this specific foundry, in particular, for the cast of the Eternal Springtime bronzes part of the Musée Rodin collection [2]. Importantly, our findings correlated well with the data published for the NGA Daumier’s busts with well-known provenance that were thus assumed to have been cast by Barbedienne and, which reported alloy compositions with Cu ranging from 86% to 90%, Sn from 3% to 4%, and Zn from 6% to 9% [19].

The two Valsuani’s bronzes from the AIC collection also fit in the compositional ranges of our Valsuani production database, but it should be noted that this prestigious foundry of lost-wax bronze d’art had a long history, a large staff, and, consequently, a very wide spread of Cu, Zn, and Sn compositions for its casts.

This explains why, when plotting all the data points accumulated to date on the alloys used for the Valsuani and Barbedienne, differentiating between the two foundries solely based on the determination of alloy composition is impossible, since both present overlapping fingerprints as shown in Figure 6b.
However, in the context of the Daumier’s casts, a clear distinction between the two foundries involved in the casting of the artworks can be proposed (Figure 4). Both alloy and patina give first trends and criteria to differentiate one from another.

5. Conclusions

This work highlights the new information provided by an increased body of knowledge on the major element composition for 19th/20th-century fine art bronzes acquired using hand-held XRF on a series of 171 bronzes with known foundry origins.

Whereas the results of analysis can only be considered semi-quantitative due to the sculptures’ chemical and physical heterogeneities, the expanded database demonstrates the strong potential of the approach based on specific trends in the alloy composition to reveal part of the objects’ biographies. In particular, the amount of Zn content in the sculptures appears to be related to the casting process: Zn values lower than 5 wt % correlate with sculptures produced with the sand cast technique, while higher Zn levels are indicative of a lost-wax approach. Determining if this correlation is related to the tradition or practical casting limitations (temperature, fluidity, mold type, etc.) remains an open question as both factors can be related. The database also confirms first trends regarding the best documented foundries, such as Rudier (both Alexis and Georges) which present a characteristic fingerprint and a rather limited range of compositions, likely representing tight control of raw material supplies or highly standardized foundry practices, or both. On the other hand, the Valsuani foundry shows higher variability in the composition of its alloys, and this is possibly linked to changes within the supply chain of raw materials or a process of adaptation of its alloy to specific sculptures, and to the final rendering expected. However, in order to provide an accurate overview of Parisian bronze d’art production at the beginning of the 20th century, more efforts are needed to collect further data for the less represented foundries. For future work, databases should be enhanced by adding information such as time of casting, price, thickness, sculpture size/color/weight, buyer, etc. in addition to the artist and foundry name. This information could play an important role in the casting attribution. Similarly, assuming the casting technique based on the foundry mark and expected casting period might not be sufficient, and when uncertainties exist they should be specified more clearly.

When this type of material analysis is coupled with art-historical research, and the focus of comparison against the database is limited to a specific artist or time period, this method of inquiry can be very powerful. As an example, this project found several distinctions between Barbedienne’s and Valsuani’s casts of Daumier’s busts. Among the 20 Daumier’s bronzes analyzed, the Valsuani’s alloys presented the highest concentration of Zn (13 wt %) and Sn (5 wt %), and the lowest Cu content. They also presented high levels of Fe and Cr, which seemed to be related to the salt composition used for the patina. This patina was most likely applied using a heat treatment that had led to a strong depletion of Zn on the surface of the bronzes, another peculiarity of Valsuani’s casts. Regarding objects that were not stamped with the Valsuani mark and were suspected of being Barbedienne’s casts based on their interior and exterior marks, this analysis had shown a pretty consistent casting recipe with regards to the amount of Sn that was used (around 3 wt %), and displayed a strong linear correlation between Zn (~11 wt %) and Cu (~87 wt %). This composition was in very good agreement with the alloy composition of the Daumier’s bronzes from the NGA with known provenance from the Barbedienne foundry. Thus, these results confirm similarities of the bronzes for their alloy composition as well.

In summary, the present study constitutes a solid foundation for further in situ investigation of artistic bronzes cast in Paris during the 20th century. The material studies together with rigorous historical research have proven to enhance our general knowledge of the secretive foundry operation (from raw material supply and recipe to casting process) and of its relationship with the artists. Nonetheless, analyses of more sculptures are needed to dissipate some of the ambiguities and open questions that still remain.

Acknowledgments: The Andrew W. Mellon Foundation is acknowledged for its support of both NU-ACCESS and the Chicago Objects Study Initiative (COSI), which were essential to carry out this project. NU-ACCESS also received supplemental support from the Materials Research Center, the Office of the Vice President for Research, the McCormick School of Engineering and Applied Science, and the Department of Materials Science and Engineering at Northwestern University. The authors would like to thank Jane Neet, Collection Manager and Research Assistant at the Department of European Painting and Sculpture of the Art Institute of Chicago (Chicago, USA), for facilitating non-invasive analyses on the Daumier’s bronzes; Gloria Groom, Chair of European Painting and Sculpture and David and Mary Winton Green Curator at the Art Institute of Chicago, for encouraging this interdisciplinary study; and Suzanne Glover Lindsay, Adjunct Associate Professor in the History of Art, University of Pennsylvania, for providing valuable guidance in the study of lost-wax bronze casts. Seth Young is gratefully acknowledged for his help in performing the hand-held XRF measurements on the Daumier’s bronzes as part of his undergraduate studies at the Northwestern University (Evanston, USA). Susan Roberts-Manganelli, Director of the Art and Science Learning Lab, and Oliver Wang, Fellow student of the program at Stanford University are also thanked for acquiring the hand-held XRF measurements on the Cantor collection hereby presented.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. Elemental composition of base (4 points analyzed) and surface (6 points analyzed) of the Daumier’s bust bronzes analyzed by hand-held XRF for this study. M.L.G is the abbreviation for Maurice Le Garrec (standard deviations are provided for both bases and surfaces in italic).

<table>
<thead>
<tr>
<th>AIC Accession Number</th>
<th>Cast Period</th>
<th>Cast Marks</th>
<th>Composition</th>
<th>Cu (%)</th>
<th>Zn (%)</th>
<th>Sn (%)</th>
<th>Pb (%)</th>
<th>Cr (%)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947.64</td>
<td>c. 1929</td>
<td>MLG (Maurice Le Garrec) on proper left near base, E2 1/25 on underside rim, 1/25 on inside front</td>
<td>Patina</td>
<td>89.1</td>
<td>7.1</td>
<td>3.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.7</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>88.0</td>
<td>7.9</td>
<td>3.4</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>0.2</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1998.796</td>
<td>1935-1952</td>
<td>MLG on proper left near base; BRONZE underside rim proper right; 7/25 inside front proper right</td>
<td>Patina</td>
<td>88.1</td>
<td>8.2</td>
<td>3.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.0</td>
<td>1.3</td>
<td>0.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>85.8</td>
<td>10.6</td>
<td>3.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
### Cont.

<table>
<thead>
<tr>
<th>AIC Accession Number</th>
<th>Cast Period</th>
<th>Cast Marks</th>
<th>Composition</th>
<th>Cu (%)</th>
<th>Zn (%)</th>
<th>Sn (%)</th>
<th>Pb (%)</th>
<th>Cr (%)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998.785</td>
<td>1935–1952</td>
<td>MLG on back proper left near base with BRONZE beneath partially visible; 18/25 inside front</td>
<td>Patina</td>
<td>86.8</td>
<td>9.1</td>
<td>2.8</td>
<td>0.6</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>86.6</td>
<td>10.0</td>
<td>2.4</td>
<td>0.6</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>1998.786</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper left; 17/25 inside front proper left</td>
<td>Patina</td>
<td>86.6</td>
<td>9.0</td>
<td>3.5</td>
<td>0.3</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>86.3</td>
<td>9.8</td>
<td>3.1</td>
<td>0.3</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>1998.805</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper left; 10/25 inside front</td>
<td>Patina</td>
<td>87.7</td>
<td>8.6</td>
<td>2.9</td>
<td>0.2</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>85.2</td>
<td>11.3</td>
<td>2.7</td>
<td>0.3</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>1998.809</td>
<td>1935–1952</td>
<td>MLG and BRONZE on proper left shoulder near base; 15/30 inside front</td>
<td>Patina</td>
<td>86.5</td>
<td>8.2</td>
<td>3.8</td>
<td>0.6</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>86.3</td>
<td>9.9</td>
<td>3.2</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>1998.811</td>
<td>1935–1952</td>
<td>MLG back proper left near base; BRONZE underside rim; 7/30 inside front</td>
<td>Patina</td>
<td>89.8</td>
<td>6.3</td>
<td>3.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.5</td>
<td>8.7</td>
<td>3.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>1998.795</td>
<td>1935–1952</td>
<td>M.L.G. and BRONZE on back, proper right; 11/25 on inside front, proper right; 11/25 on underside rim, proper right</td>
<td>Patina</td>
<td>85.9</td>
<td>9.9</td>
<td>2.6</td>
<td>1.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>85.2</td>
<td>10.6</td>
<td>2.6</td>
<td>0.7</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>1998.782</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper right near base; 10/25 inside front</td>
<td>Patina</td>
<td>88.7</td>
<td>6.9</td>
<td>3.6</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.5</td>
<td>8.7</td>
<td>3.2</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>1998.784</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper left near base; 17/25 inside front</td>
<td>Patina</td>
<td>84.7</td>
<td>10.5</td>
<td>3.5</td>
<td>0.4</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>85.4</td>
<td>10.5</td>
<td>3.3</td>
<td>0.4</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>1998.788</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper right near base; 15/25 inside front proper right</td>
<td>Patina</td>
<td>90.6</td>
<td>5.5</td>
<td>1.7</td>
<td>0.9</td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>89.4</td>
<td>7.3</td>
<td>2.2</td>
<td>0.4</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>1998.794</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper left near base; 7/25 inside front proper right</td>
<td>Patina</td>
<td>91.1</td>
<td>6.8</td>
<td>0.6</td>
<td>1.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>88.4</td>
<td>8.7</td>
<td>2.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>1998.800</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back near base; 15/25 inside front proper right</td>
<td>Patina</td>
<td>83.5</td>
<td>5.1</td>
<td>4.7</td>
<td>4.9</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.4</td>
<td>7.0</td>
<td>4.0</td>
<td>0.9</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>1998.779</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back center near base; 10/25 inside proper right</td>
<td>Patina</td>
<td>88.8</td>
<td>7.4</td>
<td>3.1</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.0</td>
<td>9.3</td>
<td>3.0</td>
<td>0.3</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>1998.787</td>
<td>1935–1952</td>
<td>Indecipherable stamp (may be MLG) and BRONZE on back; 11/25 on underside rim and stamped inside</td>
<td>Patina</td>
<td>86.0</td>
<td>9.8</td>
<td>2.5</td>
<td>1.3</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>85.3</td>
<td>11.0</td>
<td>2.4</td>
<td>0.8</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>1998.799</td>
<td>1935–1952</td>
<td>MLG on back proper right; BRONZE underside rim proper right; 8/25 inside proper left</td>
<td>Patina</td>
<td>88.4</td>
<td>7.6</td>
<td>3.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.6</td>
<td>8.8</td>
<td>3.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Table A1. Cont.

<table>
<thead>
<tr>
<th>AIC Accession Number</th>
<th>Cast Period</th>
<th>Cast Marks</th>
<th>Composition Patina</th>
<th>Cu (%)</th>
<th>Zn (%)</th>
<th>Sn (%)</th>
<th>Pb (%)</th>
<th>Cr (%)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998.808</td>
<td>1935–1952</td>
<td>MLG and BRONZE on back proper right, 11/25 underside rim front, 11/25 inside front proper right</td>
<td>Patina</td>
<td>86.7</td>
<td>9.5</td>
<td>2.4</td>
<td>0.9</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>86.1</td>
<td>10.3</td>
<td>2.3</td>
<td>0.8</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1998.813</td>
<td>1935–1952</td>
<td>MLG proper right near rim, BRONZE underside rim proper left, 7/30 inside front proper left</td>
<td>Patina</td>
<td>90.3</td>
<td>5.6</td>
<td>3.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>87.6</td>
<td>8.8</td>
<td>3.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1998.781</td>
<td>1953–1965</td>
<td>Cire Perdue Valsuani back proper right near rim, MLG back proper right and C incised</td>
<td>Patina</td>
<td>81.1</td>
<td>7.9</td>
<td>4.2</td>
<td>1.0</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>79.7</td>
<td>12.7</td>
<td>4.1</td>
<td>0.0</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>0.4</td>
<td>0.4</td>
<td>0.0</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>1998.783</td>
<td>1953–1965</td>
<td>Cire Perdue Valsuani back proper left near rim, MLG back proper right and Mme. H. incised</td>
<td>Patina</td>
<td>79.3</td>
<td>7.5</td>
<td>5.6</td>
<td>1.9</td>
<td>4.2</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Base</td>
<td>78.0</td>
<td>13.8</td>
<td>4.7</td>
<td>1.7</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

References and Note

1. Finn, C. Rumours of war: Rudier and art bronze casting during the Second World War. *Sculpt. J.* 2013, 22, 128–133. [CrossRef]


37. Vautel, C. Un fondeur artiste. La Vie Illustrée 1904.


© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).