The Unique History of *The Armorer's Shop*

AN APPLICATION OF CONFOCAL X-RAY FLUORESCENCE MICROSCOPY

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This article presents a multidisciplinary case study of The Armorer's Shop *(North Carolina Museum of Art), a seventeenth-century panel painting attributed to David Teniers the Younger of Flanders. The study was motivated, first, by visual and X-ray radiographic observations suggesting an atypical construction, and second, by the discovery that the depiction of armor in this painting is nearly identical to that in several other works. All but one of these paintings are attributed to Jan Brueghel the Younger, a contemporary Flemish painter related to Teniers by marriage. Stylistic analysis strongly supports the hypothesis that Brueghel completed the armor, whereas Teniers painted the background, figures and objects depicted around the armor. A broad range of materials analysis techniques, particularly cross-sectional analysis, dendrochronology and confocal X-ray fluorescence microscopy (CXRF), were used to establish whether the panel construction and palette composition are consistent with this hypothesis. Dendrochronology shows that the panel was fabricated from three distinct wood planks, and suggests that the smallest of these, the armor plank, was painted approximately 20 years before the other two. CXRF provides direct evidence that this plank was painted before the three planks were combined. To the authors' knowledge, this is the first evidence of the work of a seventeenth-century Flemish painter being re-used in this fashion by a second contemporary painter.*

INTRODUCTION

In 1952, the North Carolina Museum of Art (NCMA) purchased *The Armorer's Shop*, by David Teniers the Younger (1610–1690). The painting, shown in Figure 1, depicts a seated armorer at the bottom right and a richly detailed pile of parade armor in the foreground. A 1946 article identifies most of this armor, some of which is still exhibited today in Vienna, Brussels and Krakow [1]. The middle ground depicts several workers surrounding a forge, above which hangs a dragon, a symbol for alchemy. The painting is signed *D. Teniers* on the log upon which the armorer sits. During an examination of the painting in 2001, the panel was found to have an unusual construction. Specifically, joins detected as raised edges in raking light suggested that the parade armor in the lower left corner of *The Armorer's Shop* was painted on its own distinct plank. These joins are clearly visible in the X-radiograph in Figure 2. Careful inspection of the panel edges in preparation for dendrochronological analysis, described below, revealed that *The Armorer's Shop* is in fact constructed from three distinct planks, as shown in Figure 3. The plank containing the parade armor is inserted into a second, wide plank evidently planed down expressly for this purpose, and on which is painted the worker in the foreground. This composite plank is attached to a third plank on top, which depicts additional workers and a forge.

This atypical panel construction prompted further study of the painting and of Teniers, and eventually led to the discovery that the armor pile in Figure 1 is nearly identical to armor in several other paintings, most of which are attributed to Jan Brueghel the Younger (1601–1678). It is well known that collaboration among two or more painters was common practice among northern European painters in the seventeenth century [2, pp. 2–4]. In addition, there are examples of seventeenth-century works being incorporated into other panels in a manner similar to Figure 3 [3]. But in these cases, the additions were evidently executed much later than the original painting. Thus, *The Armorer's Shop*, apparently constructed by the incorporation of one seventeenth-century panel into that of a second, contemporary painter, would be extremely rare if

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Figure 1 The Armorer's Shop, *attributed to David Teniers the Younger, 56.5 × 80.7 cm, oil on cradled panel, NCMA, Inv. No. 52.9.116.*

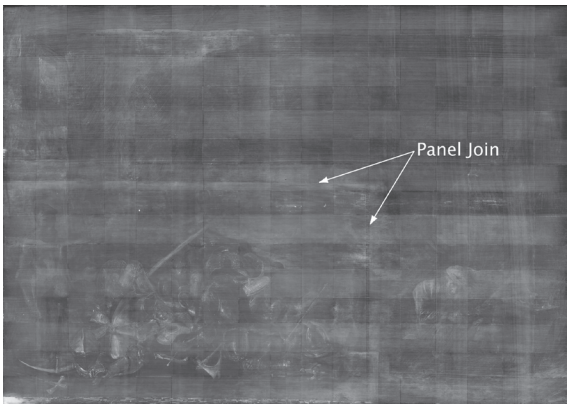

Figure 2 X-radiograph of the painting shown in Figure 1, revealing extra features at the joins between the rectangular portion and remainder of the painting. The light cross-hatch pattern throughout the radiograph arises from a mahogany cradle attached to the rear of the painting. This pattern has been digitally reduced. The radiograph reveals that the helmet on the left-hand table of the painting was originally part of a full suit of armor, and a lance or spear laying diagonally across the armor that was later painted out.

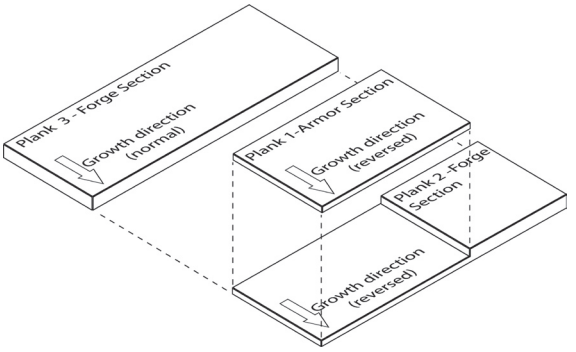

Figure 3 Construction of The Armorer's Shop, *as revealed by optical microscopy. Arrows indicate the growth direction of each of the wood planks. For the bottom two planks, this growth direction is reversed compared to conventional practice, according to which adjacent planks are joined with opposing growth directions, and are oriented so that older, harder wood faces outward.*

not unique. Moreover, it is unclear whether the term 'collaboration' would apply to this painting.

This paper presents a multifaceted study of the construction, composition and palette of *The Armorer's Shop* to address questions about its origins and history. The paper starts with a discussion of visual, holistic and art historical evidence in support of the hypothesis that Jan Brueghel the Younger painted the armor pile, and that Teniers painted the remainder of the work. This is followed by results of a dendrochronological study of the individual wooden planks used in the panel. Next, cross-sectional microanalysis and X-ray fluorescence spectroscopy (XRF) of the paint and ground composition and structure are described. Finally, results obtained using synchrotron-based 3D, or confocal, XRF (CXRF) are presented. Dendrochronological analysis suggests that the plank containing the armor was painted before being joined with two other planks. The CXRF results strongly support this conclusion by revealing the presence of an additional, buried paint layer on the armor plank near the joins between it and the other two planks. These results establish CXRF as a non-destructive technique for studying the composition and application sequence of different layers in a painting. The paper concludes with a summary of the results, and a discussion of remaining questions regarding *The Armorer's Shop.*

VISUAL AND STYLISTIC EXAMINATION

In general, the composition and execution of *The Armorer's Shop* fits quite well into Teniers' compositions of the 1640s. A typical element of his work is the division of foreground and background into different areas of activity. Also, the figures, palette and spatial configuration are typical of Teniers' work [4]. Moreover, both the armor and forge sections of the painting depict

Table 1 *Paintings sharing one or more identical armor pieces with* The Armorer's Shop

Title, location, group	Attribution	Circa
Venus in the Forge of Vulcan, location unknown. Catalogue no. 383. Oil on panel, 73.1 × 127 cm. Group one.	Jan Brueghel the Elder and Hendrik van Balen	1623
Allegory of the Elements, Collection of Baron de Coppée, Brussels, Belgium. Catalogue no. 204. Material, dimensions not available. Group one.	Jan Brueghel the Younger and Hendrik van Balen	1630
Allegory of Touch, Musée Calvet, Avignon, France. Catalogue no. 227. Oil on panel, 53 × 89 cm. Group two.	Jan Brueghel the Younger	1648
Allegory of War, Private collection, Lucerne, Switzerland. Catalogue no. 229. Oil on panel, 41 × 59 cm. Group three.	Jan Brueghel the Younger and a follower of Rubens	1647
Allegory of Discord, Staatliches Lindenau-Museum, Altenburg, Germany. Catalogue no. 228. Oil on canvas, 84 × 115 cm. Group three.	Jan Brueghel the Younger and a follower of Rubens	1648

The catalogue number for Venus in the Forge of Vulcan *is from [7]. All others are from [8]. Group number corresponds to degree of compositional similarity with* The Armorer's Shop.

common elements found in other Teniers compositions, including the earthenware jug in the top left window and the tables in the bottom right and bottom left corners. These observations support the attribution to Teniers. However, although several works of Teniers include depictions of armor, that of *The Armorer's Shop* stands out in its execution style and quality. For example, the armor is very finely painted, contrasting both with the irregular, coarsely painted brushstrokes of the surrounding forge and with armor and other metallic objects in paintings[1] confidently attributed to Teniers. Such observations suggest that Teniers may not have painted the armor in *The Armorer's Shop*, and motivated a thorough comparison with contemporary works for evidence that the armor panel was painted either by a different painter or at a different time than the remainder of the painting.

Remarkably, five paintings were found, listed in Table 1, that have nearly identical depictions of armor to that in *The Armorer's Shop*. Four of these are attributed to Jan Brueghel the Younger[2] and one to his father, Jan Brueghel the Elder (1563–1625). During an in situ examination at the Musée Calvet, an overlay from *The Armorer's Shop* was used to compare precisely compositional and stylistic elements with those of *Allegory of Touch*. *The Armorer's Shop* and *Allegory of Touch* have very similar dimensions, and are both painted on oak panels. Most of the armor pieces in the two paintings were found to match precisely in size, palette and execution, suggesting that the same artist painted both piles of armor.

A conspicuous discrepancy between the two paintings is that *Allegory of Touch* shows a full suit of armor at the far left foreground, where *The Armorer's Shop* depicts only a helmet on a table. However, the X-radiograph shown in Figure 2 shows that this difference is superficial. The helmet was at one time part of a full suit of armor similar to that in *Allegory of Touch*, and the table represents a change to the composition. Figure 2 and the infrared reflectogram shown in Figure 4 reveal a number of other changes to the armor section, possibly representing an attempt to integrate a pre-existing image of the armor with the surrounding composition. In contrast, there are no indications of compositional changes to the painting outside the armor section. Finally, between the armor pile and the armorer in the right-hand foreground, Figure 4 shows what appears to be a layer of paint or filling material extending from the forge section across the vertical join into the armor section. Like the compositional changes, this feature appears to indicate an attempt to integrate two images.

Figure 4 was also examined for the presence of an underdrawing or sketch that is often applied with charcoal or black chalk prior to the application of paint [9, 10]. While no underdrawing could be identified with certainty, its presence cannot be ruled out. Such a sketch might be obscured in the infrared image by bone black, which, as described below, is found throughout the

[1] *See, for example,* Soldiers Playing Dice, *oil on copper, laid on canvas, laid on panel, signed D. Teniers, c. 1642, 54 × 73 cm, Sarah Blaffer Foundation, Houston, TX, Inv. No. 1978.9 [5] and* Guardroom with the Deliverance of Saint Peter, *oil on panel, signed D. Teniers, c. 1645–1647, 55.2 × 75.9 cm, Metropolitan Museum of Art, New York, NY, Inv. No. 64.65.5 [6].*

[2] *A fifth painting by Brueghel the Younger, catalogue no. 230 in [8], is listed as being nearly identical to catalogue no. 228,* Allegory of Discord, *and presumably includes the same depiction of armor. However, since no photograph of the painting is included or has been found, this painting is not included in the table.*

Figure 4 *Infrared reflectogram of* The Armorer's Shop. *The reflectogram shows the same compositional changes to the armor section of the painting as revealed by the X-radiograph, in addition to an amorphous contour in the vicinity of the vertical join between the armor plank and the remainder of the painting.*

painting and also absorbs infrared light. Alternatively, an underdrawing may have been executed using identical pigments to the painting [2, pp. 222–223].

Teniers and Brueghel the Younger were both active in the Antwerp art guild in the early seventeenth century, and were also related through Teniers' marriage to Brueghel the Younger's half-sister. Woollett [2, p. 33] makes reference to collaborative projects between Teniers and Brueghel the Younger, and Ertz [8, p. 385] suggests that Teniers 'possibly' contributed to *Allegory of Might and Right*. Historically, then, it is feasible that Brueghel the Younger painted the armor in *The Armorer's Shop*. However, the first painting listed in Table 1, *Venus in the Forge of Vulcan,* casts doubt on this interpretation. Unfortunately, the current location of this painting is unknown, and the analysis is necessarily based on a poor quality reproduction. Nevertheless, it is listed in [7] as being signed Brueghel the Elder, 1623, a year after Brueghel the Younger is known to have left Antwerp for Italy, where he remained until his father's death in 1625 [2, pp. 32–33]. Moreover, Brueghel the Elder would have had more opportunity than his son to examine and paint this specific armor as he was court painter for Archduke Albert (d. 1621), and it is Albert's armor on the right that is depicted in *The Armorer's Shop* [1].

In order to further compare *The Armorer's Shop* with the paintings in Table 1, reproductions of all of these paintings were digitally scaled and overlaid using *Adobe Illustrator*. All images were scaled according to their real painting dimensions except for *Allegory of Elements*, for which neither the material nor size are known. In this case, the image was scaled so that the armor pile matched as closely as possible to that in Figure 1, corresponding to a real painting size of approximately 59 × 92 cm. This exercise reveals that the paintings in Table 1 can be placed into three groups, indicated in the table, according to the relative positions of the two foremost suits of armor. Increasing group number corresponds to decreasing similarity to *The Armorer's Shop*. As noted above, individual elements in *The Armorer's Shop* match very precisely in size with those in *Allegory of Touch*. However, the right-hand suit of armor in *Allegory of Touch* is translated left and down relative to its position in *The Armorer's Shop*. In contrast, the entire armor piles in the first two paintings of Table 1, assigned to group one, overlay that in *The Armorer's Shop* almost perfectly. Furthermore, these two paintings share many more compositional elements with *The Armorer's Shop* than the remaining paintings in the table. For example, these three paintings all depict a quiver directly above the right-hand suit of armor. What appears to be the same quiver is also present in *Allegory of Touch*, but in a different location. In the last two paintings in Table 1, *Allegory of War* and *Allegory of Discord*, the two foremost suits of armor are even closer to each other than in *Allegory of Touch*, and there are numerous compositional discrepancies with *The Armorer's Shop*, both additions and omissions. *Allegory of Discord* also contrasts with both *Allegory of War* and the other paintings in Table 1 in terms of scale. Its armor is significantly larger than that in the remaining paintings. It is also the only painting in Table 1, other than possibly *Allegory of Elements*, executed on canvas rather than wood.

Close inspection shows that the two paintings in group one of Table 1 are not equally similar to *The Armorer's Shop*; there at least four objects in *The Armorer's Shop* and *Venus in the Forge of Vulcan* but not in *Allegory of Elements*. These include the long, narrow-bladed axe at the far left and the lance or spear lying across the armor pile that is evident in Figure 4. Even so, this does not prove that Brueghel the Elder painted the armor in *The Armorer's Shop*. Ertz suggests that Brueghel the Younger was perhaps the best copyist of his father's work [8, p. 98], and that his best works were a result of such imitation. Thus, on the basis of the compositional similarity between these two paintings alone, *The Armorer's Shop* might equally well have been a study by Brueghel the Elder, possibly in preparation for *Venus in the Forge of Vulcan*, or a copy by Brueghel the Younger

of his father's composition, perhaps in preparation for *Allegory of Elements*.

Without further examination, the precise degree of similarity in execution between the armor in *Venus in the Forge of Vulcan* and that in *The Armorer's Shop* cannot be ascertained. Here, it may be observed that comparisons of *The Armorer's Shop* to the work of Teniers and to the paintings in Table 1 suggest that Teniers painted the principal elements on planks 2 and 3, but that either Brueghel the Elder or Brueghel the Younger painted the armor. To date, there have been no comprehensive, scientific studies of the working methods of either Brueghel the Younger or Teniers, and hence there is no material or conservation science basis for assessing these particular attributions. In lieu of this ideal, the first goal of this paper is to show evidence that both parts of *The Armorer's Shop* were painted using materials consistent with northern European practice in the early seventeenth century. The second and principal goal of this paper, independent of the first, is to demonstrate the sequence in which the planks in Figure 3 were painted and joined. As suggested by the composition changes discussed above, it is found that the armor plank was painted prior to being joined to planks 2 and 3, at which point these planks were painted and merged with plank 1 to form the completed work.

DENDROCHRONOLOGY

In preparation for dendrochronological analysis of *The Armorer's Shop*, a careful examination of the structure and tree-ring patterns on each of its sides was performed. The reverse sides of the planks, which might reveal sawing techniques or a panel signature, were not accessible due to the addition of a 3.5 mm thick oak panel covering the entire reverse side of the painting. Two surprising features of the overall construction were found. The first observation, described above, is that the panel is comprised of three separate planks as illustrated in Figure 3. The second unusual feature of *The Armorer's Shop*, indicated by the arrows in Figure 3, concerns the orientation of the individual planks relative to their growth direction. The orientation of these planks departs from conventional practice in two ways. First, planks are generally placed with their *older* rings at the *outer* edges of a painting panel due to the stronger structural support of the older, inner rings, or heartwood [11, p.154]. In this painting, only the top plank follows this convention: the youngest rings of both bottom planks face the outer, bottom edge of the panel. Another element of panel-making convention is that when two planks are joined edge to edge, they are arranged so that the oldest (or youngest) rings of two neighboring planks are adjacent [11, p. 154]. In other words, the growth directions of adjacent planks are typically opposed. As indicated by the arrows in Figure 3, this is not the case in *The Armorer's Shop*.

A natural explanation for the construction shown in Figure 3 is that *The Armorer's Shop* was created to make deliberate use of plank 1. The orientation of plank 2 was then chosen to match that of plank 1 to reduce warping, overruling the convention of placing older wood at the outer edge. This choice forced a second convention to be broken when attaching plank 3, since the 'older wood at outer edge' rule and the 'like next to like' rule dictate opposite orientations and so could not both be followed.

An alternative explanation is that *The Armorer's Shop* represents a cleverly constructed mosaic of two pre-existing paintings, executed by a third person. This hypothesis is motivated both by construction technique indicated in Figure 3 and by the question of why Teniers would re-use a pre-existing image when he was perfectly capable of painting armor himself. However, a key piece of evidence that Teniers himself completed *The Armorer's Shop*, as opposed to an unknown third painter, is the blue table in the left-hand foreground of Figure 1. As mentioned briefly above, this table was clearly added to the composition to replace an original suit of armor visible in Figures 2 and 4, and is nearly identical to tables found in several other paintings by Teniers, for example *The Seven Acts of Mercy*[3] and *The Prodigal Son*.[4]

Figure 3 provides a subtle, additional counter-argument to the idea that *The Armorer's Shop* was created from two pre-existing paintings. The orientations of planks 1 and 2 relative to their growth directions are *opposite* to the convention of placing heartwood at the outer edge of a painting. If planks 2 and 3 originally comprised a complete, independent painting, it is unlikely that plank 2 would have the orientation shown in Figure 3. Instead, it would have the opposite orientation, in accordance with both of the construction conventions described above.

[3] *Teniers, David the Younger,* The Seven Acts of Mercy, *c. 1644, 57 × 77 cm, Louvre, Paris, Inv. No. 1879 [12].*

[4] *Teniers, David the Younger,* The Prodigal Son, *oil on copper, c. 1640, 57.15 × 77.47 cm, Minneapolis Museum of Art, Minneapolis, MN, Inv. No. 45.8 [13].*

The orientation of plank 1 is also significant in relation to its similarity with the paintings in Table 1. In all of these paintings, the armor appears in the foreground, or lower portion of the painting. Thus, if the armor plank in *The Armorer's Shop* had originally been part of a separate, larger painting with a composition similar to the others in Table 1, one would still expect the lower edge of this plank to coincide with the lower edge of the hypothetical, larger painting. Since this painting would also be expected to conform to the 'older wood at outer edge' convention described above, the orientation of plank 1 would still be expected to be opposite that shown in Figure 3. In other words, the growth direction of the armor plank 1 suggests, if indirectly, that it was not cut out from an earlier, separate composition. Alternatively, it may have been a study, possibly in conjunction with one of the paintings in group one of Table 1.

The motivation for performing dendrochronological analysis on *The Armorer's Shop* was to obtain an estimate of when it was painted. Dendrochronological estimates of painting dates are obtained by first determining the date of the outermost ring of the wood, then adding estimates of the number of sapwood rings in oaks and the number of years between felling and painting. Implicit in this approach is the assumption that, in accord with typical practice [9, 11, pp. 151–152], only sapwood rings were removed from planks before use. Estimates and probabilities of the number of sapwood rings and the years between felling and painting are well established from a growing dendrochronological database. Based on modern and archaeological oak samples collected in the Baltic region [14], the median number of sapwood rings in these oaks is 15, with 90% of samples having between 9 and 23 [15]. For seventeenth-century paintings, the period of time between the felling and painting is typically 5 ± 3 years, again with ~90% certainty [16]. This range includes the time needed for splitting the timbers into boards, for transportation and sale, for seasoning the wood, and for preparation and finishing of the panels.

Each of the three planks in *The Armorer's Shop* contains over 140 tree rings, and none contain any sapwood. All were found to match sufficiently with other oaks from the Baltic region that their tree-ring sequences could be dated, the results of which are shown in Figure 5. The outer rings of the two forge planks (planks 2 and 3 in Figure 3) date to 1620 and 1624. Since these two planks were presumably painted at the same time, the later date is used to estimate the painting date. The average of 15 sapwood rings (range of 9–23) plus 5 years between felling and painting (range of 2–8) gives a most likely date of 1644 or after for the completed work, with a statistically likely range of 1638–1652.

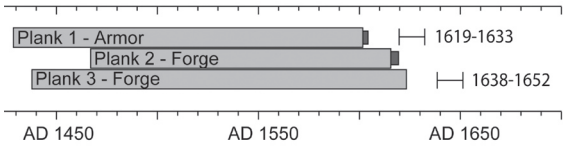

Figure 5 *The span of tree-ring sequences of the three panels of* The Armorer's Shop. *The smaller rectangles at the ends of the upper two sequences represent rings that were added by measurements from the opposite side or that could be counted but not reliably measured for width determination. The statistically likely ranges of painting dates for the armor plank and the two forge planks (based on plank 3) are indicated.*

In contrast, the outer ring of the armor plank dates to 1605, yielding a most likely painting date of 1625 and a probable range of 1619–1633. In this case, the range of likely paintings dates was narrowed by the discovery that its ring sequence is particularly similar to those of two previously studied paintings. The degree of dendrochronological correlation among the armor plank and these two paintings, *The Art Cabinet of Crowned Prince Vladislav IV*[5] and *Lamentation*,[6] both attributed to unknown Antwerp painters, is high enough to conclude that the wood in these three panels originated from trees in the same forest stand. The first of these is signed 'Here[?] fecit 1626', while the second has been dendrochronologically and art historically dated to c. 1628. The practice of woodcutters in the Baltic region at that time was clear-cutting, with no known forest management. Thus, the fact that the trees used for these three paintings came from the same stand indicates that the armor plank was painted very close to 1626–1628.

To summarize, the orientation of the planks used in *The Armorer's Shop* suggest that planks 2 and 3 were prepared specifically to make use of plank 1. Dendrochronological analysis suggests that the armor plank was most likely painted in the mid-to-late 1620s, approximately 20 years before the remaining two

[5] *The Royal Castle in Warsaw, Inv. No. ZKW 2123. Vladislav IV became king of Poland in 1632.*

[6] *The Royal Museums of Fine Arts of Belgium in Brussels, Inv. No. 678. Painting belongs to the very large group (more than 70) of versions of this fifteenth-century Lamentation, seventeenth-century sub-group [17].*

planks, which were likely completed between 1638 and 1652. The second range of dates fits very well into the career of Teniers. The earlier range, while supporting an attribution to Brueghel the Younger, does not rule out Brueghel the Elder.

MICROANALYSIS

Conventional microanalysis methods were used on both sections of the painting to identify any distinctions in their elemental and molecular compositions and microstructures. A clear difference in the pigments and binders used in one of the two parts of the painting might suggest that the painting was executed at two different times or by two different artists. Energy dispersive XRF was applied to numerous locations in both sections of the painting to determine the elemental composition of the palette and ground. In addition, seven cross-sections were taken from the painting, the locations of which are indicated in Figure 6.

XRF analysis suggests a traditional seventeenth-century northern European palette for both sections of the painting: vermilion and iron oxide reds, lead-tin and iron ochre yellows, lead white, azurite blues, umber browns, and flesh tones created by mixing lead white, vermilion, iron oxide reds and umber [18–21]. A translucent copper-containing green was used to represent the interior fabric of the armor, possibly powdered verdigris [22]. Calcium was found in each spectrum, suggesting the presence of a chalk ground as would be expected for seventeenth-century northern European panel paintings [10, 18, p. 28]. The chalk particle morphologies in the armor panel and the remaining panel were similar but not identical. Coccoliths were not readily observed in the ground on either side of the painting, and the calcite ground from the armor panel was quite monodisperse with particle sizes consistently under 5 μm. However, the ground layer from the forge panel exhibited a broader particle size distribution, with some individual particles as large as 10 μm. Similar strontium concentrations were identified in the grounds from both parts of the panel. Both lead and copper were found in virtually every spectrum regardless of the color of the presentation surface (defined as the topmost paint layer), suggesting that lead white and a copper-containing pigment such as azurite were used in a lower-lying paint layer such as the imprimatura [10, 23, pp. 205–210]. No significant difference was observed between the palettes of the two sections.

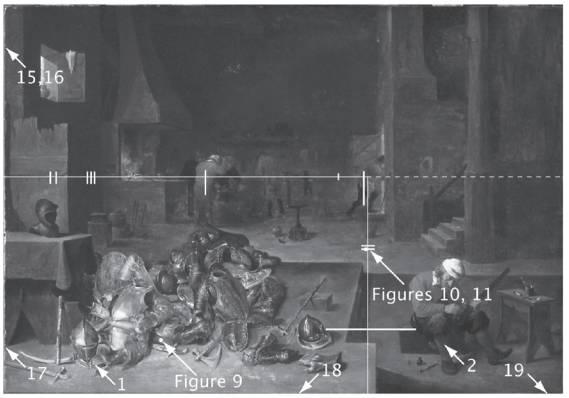

Figure 6 *An annotated reproduction of* The Armorer's Shop. *The solid white rectangle surrounding the armor pile indicates the interface between the armor-containing plank and the remainder of the panel. The dashed line indicates a third join between planks 1 and 2 (see Figure 3). The short solid lines indicate the locations of scans across the interface, performed with CXRF, showing that the armor plank was painted before being joined with the other two planks. The numbered, white arrows show the location of the samples obtained for cross-section analysis. The positions of scans shown in Figures 9–11 are indicated.*

Fourier transform infrared spectroscopy (FTIR) and dispersive Raman spectroscopy were applied to five cross-sections (samples 1, 15–18) taken from the painting in order to verify the presence of compounds inferred from XRF. FTIR revealed characteristic absorbances for lead white in a drying oil [24]. Strong absorbances were observed for both the carbonyl stretching bands for hydrocerussite and lead carboxylate soaps. A drying oil binding medium was suggested by the presence of characteristic C–H stretching, carbonyl and O–H bands. The major carbonyl band, at 1530 cm^{-1}, was due to the presence of lead carboxylates. The formation of such metal carboxylate soaps has been observed for many paintings of this age prepared with a lead-white-based palette [25, 26]. The presence of a calcium carbonate ground was confirmed by FTIR analysis for all five samples and also by dispersive Raman spectroscopy on sample 18. The FTIR spectra exhibited intense carbonate stretching and bending absorption bands associated with calcite. Four of the five samples exhibited only strong fluorescence when examined by dispersive Raman spectroscopy, but sample 18 revealed moderate scattering bands at 1084, 708 and 278 cm^{-1}, all three of which are due to the presence of calcite.

Cross-sectional samples were also studied with optical microscopy and scanning electron microscopy–energy dispersive X-ray microanalysis (SEM-EDX), the results

Table 2 *A summary of results from cross-section samples from* The Armorer's Shop

Sample number/location	Composition Ground	Presentation	Imprimatura	Paint layer thickness (range)
1/Armor section: armor	Ca, tr. Al, Si	Al, Si, P, Pb, K, Ca, Fe, Cu (bone black)	Cu present but no distinct layer	16 (10–20)
17/Armor section: brown/gray foreground	Ca	Pb, Ca, Si, P (bone black)	No distinct layer	20 (10–31)
18/Armor section: gray foreground	Ca	Pb, Ca, Al, Si, K	Yes (Al, Si, P, Ca, Pb, Fe, Cu)	25 (19–33)
2/Forge section: armorer's leg	Ca	Al, Si, P, Pb, Ca, Fe (bone black)	Yes (Al, Si, P, Ca, Pb, Fe)	16 (8–20)
15/Forge section: gray wall	Ca	Pb, Si, Ca, Fe, Cu, Al, K	Cu present but no distinct layer	37 (19–48)
16/Forge section: gray wall	Ca, tr. Pb	Pb, Ca, Si, Fe (iron ochre)	No distinct layer	29 (25–34)
19/Forge section: brown foreground	Ca	Pb, Ca, P, Si, Fe (bone black)	Yes (Al, Si, P, Ca, Pb, Fe)	33 (30–36)

Sample locations are shown in Figure 6. tr. = trace. Paint layer thicknesses are given in micrometers, and include the imprimatura and presentation layers, but not the ground. FTIR and dispersive Raman spectroscopy results are described in the text.

of which are summarized in Table 2. Optical micrographs and backscattered electron images of two of these samples are shown in Figures 7 and 8. In visible light, all of the cross-sections contain an off-white, calcium-based ground with very fine granularity. Above this layer, Figure 7 clearly shows a 2–10 μm layer consisting primarily of lead, identified as lead white on the basis of FTIR results discussed above. The topmost layer shown in Figure 7 contains elements that suggest the presence of lead white, iron ochre, bone black and calcite, consistent with the palette inferred from the XRF data. Bone black is indicated by high concentrations of both calcium and phosphorus found in numerous dark particles.

All of the cross-section samples show a lead-rich region directly above the ground. In several samples, as in Figure 7, this region is clearly distinct from the presentation layer, and can thus be identified as a lead-white-based imprimatura as suggested by the XRF data described above. In addition to lead, SEM-EDX analysis of samples 1, 15 and 18 directly above their ground layers all revealed the presence of small amounts of copper, occasionally associated with dark blue particles such as those in Figure 8. These data, combined with the ubiquitous observation of copper in XRF spectra, suggests that the imprimatura layer is interspersed with small amounts of azurite. An azurite-containing imprimatura would create a cool-toned gray ground, and the addition of copper-containing pigments to imprimatura layers to facilitate rapid drying is well known [10].

The identification of calcium and phosphorus together in the gray particles of the imprimatura and presentation layer in Figure 7 is suggestive of bone black, and the identification of aluminum and silicon in low atomic number particles with plate-like habits in this layer is suggestive of the clay minerals associated with iron ochre. The scumbled background of both the armor and forge sections appear to be prepared from a mixture of pigments that includes lead white, bone black, iron ochres and calcium carbonate.

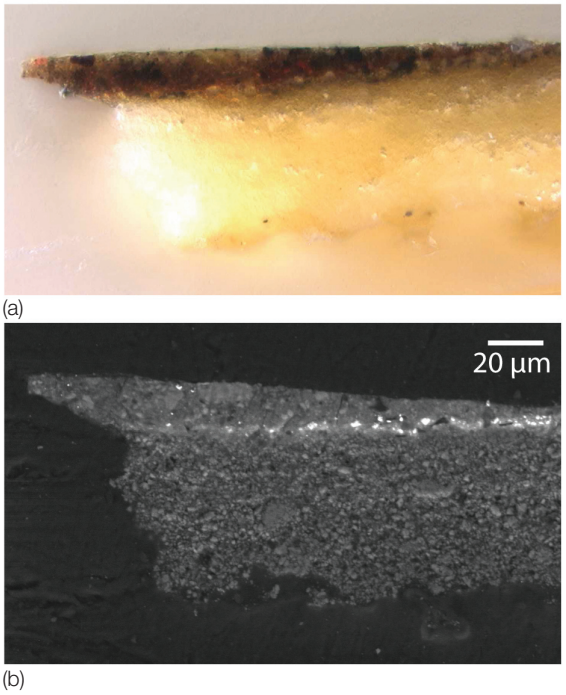

Figure 7 *Sample 2, taken from the armorer's right leg (see Figure 6): (a) optical and (b) backscattered SEM images. The SEM image shows a thin, lead-white-based imprimatura layer between the ground and pigment layers. Magnification: 2000×; accelerating voltage: 20 kV; working distance: 22 mm.*

The consistent identification of copper in the imprimatura layer on both sections of the painting by

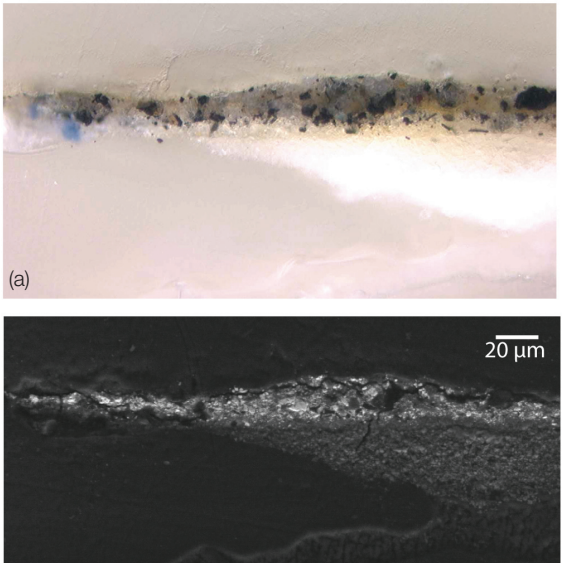

Figure 8 *Sample 1, taken from a gauntlet in the armor pile (see Figure 6): (a) optical and (b) backscattered SEM images. The optical micrograph shows a variety of pigment particles, including several bright blue particles thought to be azurite. Magnification: 2000×, accelerating voltage: 20 kV, working distance: 22 mm.*

X-ray fluorescence but not by SEM-EDX is of interest. It is noted, however, that SEM-EDX samples a much smaller area of a particular layer than the ArtTAX XRF, which employs a spot diameter of approximately 75 µm. Further, in the cases where copper particles are visible in SEM-EDX, the variation in layer composition and thickness, as in samples 1 and 15 (see Figure 8, Table 2), makes it difficult to definitively assign these particles to a particular layer. Brueghel the Elder is known to have used both cool gray and warm brown imprimatura layers, the former being comprised of lead white and carbon black [2, p. 221]. However, detailed, comprehensive scientific analyses of the imprimatura layers employed by Jan Brueghel the Younger and Teniers have not been published.

In summary, it is found that the composition, number and thickness of paint layers in *The Armorer's Shop* are consistent with seventeenth-century northern European painting practice, but do not reveal any substantive differences between the armor and forge sections outlined in Figure 6.

CONFOCAL X-RAY FLUORESCENCE

To obtain direct evidence pertaining to the chronology of the paint layers, a recently developed non-destructive technique, confocal X-ray fluorescence microscopy (CXRF), was employed. CXRF, or 3D scanning XRF, combines two X-ray focusing optics to resolve X-ray fluorescence from a particular 3D volume in space, the confocal volume [27–32]. When X-rays of sufficient energy are incident on a layered sample, they will, if the layers are sufficiently thin, penetrate to and stimulate fluorescence from all layers simultaneously. In CXRF, the second optic allows fluorescence only from material within the confocal volume to arrive at the detector. The size of this volume defines the resolution of the instrument, and typically depends on the choice of X-ray source and optics in addition to the fluorescence energy. If this resolution is sufficiently small compared to the thicknesses of layers in a painting, then it is possible to directly resolve the fluorescence signal from each layer, resulting in a compositional depth profile of the painting.

The Armorer's Shop was transported to the Cornell High Energy Synchrotron Source for two separate experimental runs of approximately three days each. In a typical scan, the painting is translated perpendicular to its painted surface in a series of steps, so that different layers are sequentially translated through the confocal volume. At each position, or depth, a fluorescence spectrum is collected and subsequently analyzed to obtain integrated intensities for each peak. Figure 9 represents one of approximately 1000 such depth scans that were performed. Increasing values on the abscissa correspond to increasing depth. Each line represents integrated intensities of a particular fluorescence peak. The points are separated by approximately 5 µm, and fluorescence spectra at each point were collected for 2 s. Each profile has been normalized by its maximum value to allow visual comparison of the relative peak positions.

The scan in Figure 9 was performed just below the armor pile, as indicated in Figure 6. The plot clearly indicates a top layer that contains lead, copper and iron. The widths of these peaks correspond closely to the instrumental resolution of the measurement (see Appendix), indicating that the layer thickness is no greater than approximately 15 µm. The actual intensities of the copper Kα and iron Kα peaks in Figure 9 (see caption) are approximately 40 times weaker than the lead Lα line, indicating that lead is the predominant constituent of this layer. Thus, in terms of both thickness and composition, this layer resembles the imprimatura

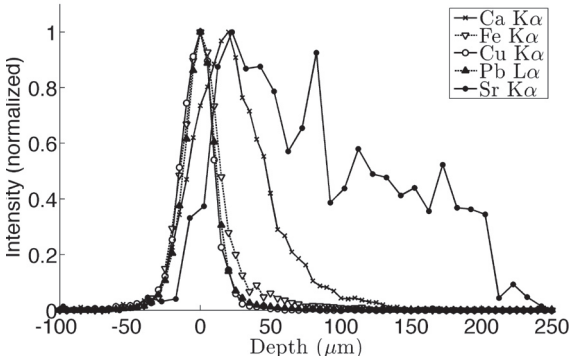

Figure 9 Intensity versus depth of several elemental fluorescence lines obtained from a single depth scan using CXRF performed just below the armor pile as indicated in Figure 6. The intensities have been normalized to their maxima for visual comparison. The intensity maxima of the Ca Kα, Fe Kα, Cu Kα, Pb Lα and Sr Kα lines are 195, 400, 490, 20600 and 17 counts, respectively. The scan shows a top pigment layer, compositionally similar to the imprimatura layer found using SEM-EDX, above a thick calcium-based ground that also contains strontium.

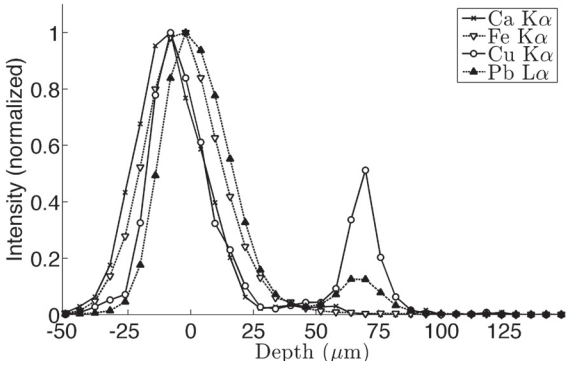

Figure 10 Intensity versus depth of several elemental fluorescence lines obtained from a single depth scan near the join between planks 1 and 2 as indicated in Figure 6. The intensities have been normalized with respect to their maxima for visual comparison. The intensity maxima of the Ca Kα, Fe Kα, Cu Kα, and Pb Lα lines are 190, 2500, 160 and 25700 counts, respectively. The top layer consists of calcium-, iron- and copper-based pigments on a lead-based imprimatura layer. A second lead- and copper-containing layer is visible approximately 75 μm below the presentation layer, and is indicative of a second, subsurface pigment layer.

layer identified in Figure 7. At this location in the painting, this layer serves as the presentation surface. This is consistent with seventeenth-century northern European painting practice, where an imprimatura layer was often used as a middle-toned ground from which the painter could build up highlights.

Figure 9 also shows calcium and strontium fluorescence peaks that are located to the right of, or below the lead, copper and iron peaks. These peaks arise from the ground layer, as discussed in the Microanalysis section above. The calcium signal decreases rapidly with increasing depth due to strong self-absorption by the ground layer itself. The strontium signal is much weaker than that of calcium, resulting in increased scatter due to poor counting statistics. However, because it occurs at 14.1 keV, much higher than the calcium Kα line at 3.7 keV, it decays much less rapidly with depth. Despite the increased scatter, the left and right edges of the strontium signal are easily discerned in the plot, and indicate that the ground layer is approximately 200 μm thick.

A general feature of the data is that, despite the fact that the ground layer throughout the painting consists primarily of calcium carbonate, calcium is nevertheless not always detected. This absence is caused by the fact that the calcium Kα line, at 3.69 keV, is strongly absorbed by overlying heavy elements such as lead.

Figure 10 is a depth scan similar to that in Figure 9, but obtained very close to the join between planks 1 and 2, as indicated in Figure 6. This scan differs from that in Figure 9 in several ways. One difference is that there appears to be no clear signature of the ground layer. No strontium Kα signal was detected, and the calcium Kα signal is dominated by calcium arising from the top pigment layer, most likely from bone black. The calcium Kα fluorescence from the ground is evidently completely absorbed by the pigment layers.

A second difference between Figures 9 and 10 is that, unlike the lead, iron and copper peaks in Figure 9, the left-hand peaks in Figure 10 are not coincident with one another. Instead, the centroid of the lead Lα peak occurs slightly below those of iron Kα, copper Kα and calcium Kα. In this regard, Figure 10 is much more representative of depth scans taken throughout the painting than Figure 9. Specifically, virtually all scans show a set of overlapping, but not coincident fluorescence peaks at the presentation surface. These peaks generally span less than 50 μm in total depth, and indicate the presence of lead in addition to varying amounts of calcium, iron, manganese, copper, mercury and tin. Both the composition and widths of these peaks are consistent with the pigment layers in cross-section samples listed in Table 2.

Overlap of adjacent peaks as in Figure 10, which is tantamount to a blurring of signal from adjacent layers, can arise either from real non-uniformities in the layers or as a result of finite instrumental resolution. Since the range of pigment layer thicknesses of *The Armorer's Shop*,

5–40 μm (see Figures 7 and 8 and Table 2), is similar to the measured depth resolution of 15–30 μm, finite resolution definitely contributes to this effect in the CXRF data. Despite this overlap, when absorption effects are sufficiently small or the layers are thin, the locations of fluorescence peaks still represent the locations of peaks in elemental concentration [27, 31–32]. In Figure 10, the different peak positions in the left-hand group of peaks are interpreted as indicating the presence of at least two layers: a top pigment layer consisting primarily of iron, copper and calcium, above a lead-rich imprimatura layer, similar to that in Figure 7.

The most conspicuous difference between Figure 10 and Figure 9 is the presence in Figure 10 of additional lead Lα and copper Kα fluorescence peaks approximately 75 μm below the top layer of paint. As stated above, the scan in Figure 10 was taken very close to the join between planks 1 and 2, and these buried peaks appear to indicate the presence of an additional layer of pigment. Figure 10 is just one of a series of 21 depth scans taken at 1 mm intervals, and spanning the interface between planks 1 and 2 as indicated in Figure 6. In Figure 11, the data from all of these scans are combined to form cross-sectional representations of elemental concentration across this interface. Each plot in Figure 11 shows the 2D distribution of integrated intensity of a particular fluorescence peak.

Figures 11a and b clearly show that the extra lead Lα and copper Kα peaks towards the right-hand side of Figure 10 correspond to a buried layer that slopes downward as it approaches the interface between the two planks, then abruptly stops. This layer is only clearly

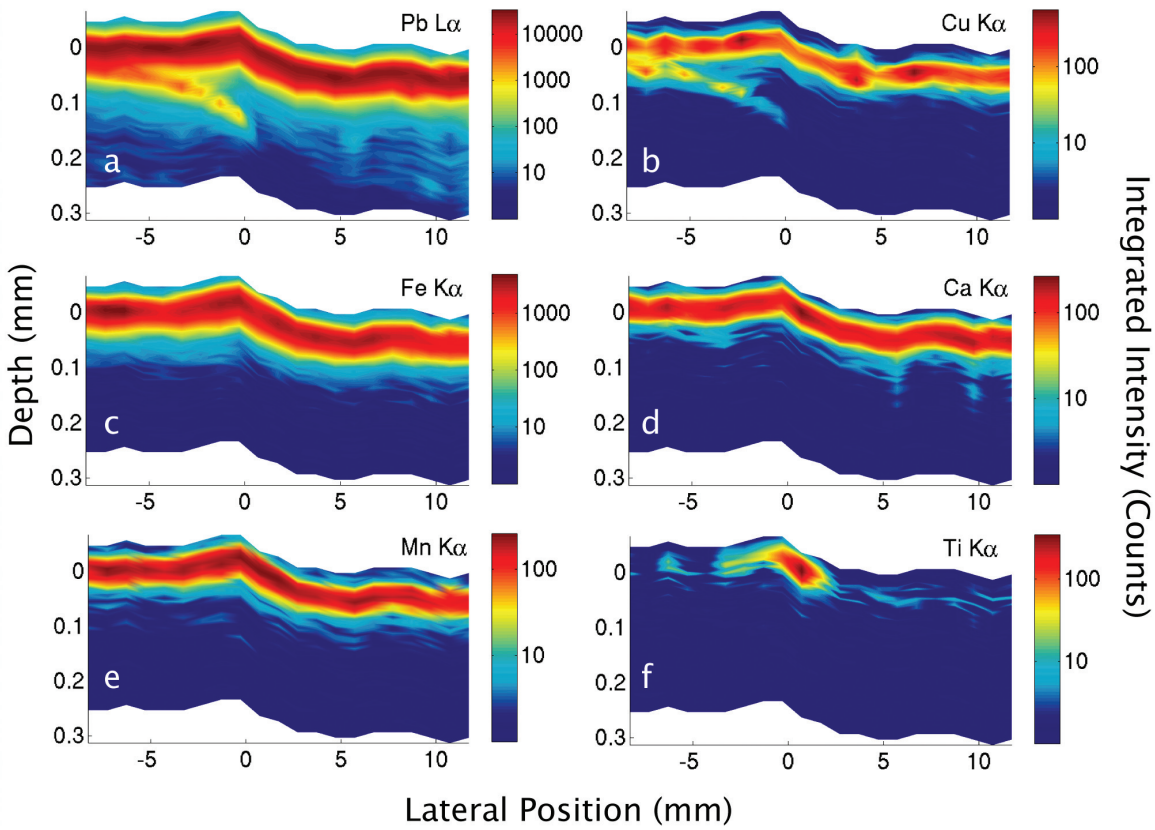

Figure 11 *Virtual cross-section across the interface between the armor and forge sections of the painting (scan position is indicated in Figure 6). The Pb Lα and Cu Kα cross-sections reveal the presence of an additional, buried imprimatura layer on the armor section of the painting. Iron, calcium and manganese are present only in the top layer. The presence of a titanium-based pigment used during restoration near the location of the join between the two panels is indicated in (f).*

resolved within approximately 3–4 mm of the join. The location of the join, in this scan, is indicated both by the abrupt termination of this buried layer and by the sudden change in slope and height of the surface that make the join visible under raking light. This buried layer is evidently a layer that was painted onto the armor plank, possibly in conjunction with the armor, before the plank was joined to the remainder of the panel. The small, 50–75 μm separation between the top and buried layers may be understood by considering the accuracy with which plank 2 could have been planed down to accept plank 1 as shown in Figure 3. Even with exceptional craftsmanship, one would expect small height differences in the two planks along their mutually adjacent edge. The space between the two layers in Figures 10 and 11 may be associated with new ground, added as a filler material to smooth these differences in height. This new ground material was then painted with imprimatura and paint layers, corresponding to the upper layers in Figures 10 and 11, which clearly span across the join.

In addition to the scan in Figure 11, ten additional scans across the joins between planks 1, 2 and 3, indicated by the white line segments in Figure 6, show the same key feature: a lead-based buried layer near the interface between plank 1 and the other two planks. Away from the join, the buried layer merges with the top paint layer as at the far left Figure 11. In all of these scans, the buried layer is located on the armor side of the join. The fact that 11 separate scans across the joins between plank 1 and planks 2 and 3 show evidence of a buried, lead-rich layer on plank 1 strongly support the idea that plank 1 was painted, at least with an imprimatura layer, before being joined with planks 2 and 3. Although this layer cannot be directly associated with the armor itself, it may be noted that the imprimatura layer was typically applied by a member of the artist's studio, as opposed to the panel maker [9, 10, 11, pp. 167–168]. In contrast, the *absence* of a buried layer on the forge side of the join is consistent with the hypothesis that unlike plank 1, planks 2 and 3 were *not* painted until after all three panels were joined. Thus, the CXRF results, in accord with the observations regarding the plank orientations discussed in the Dendrochronology section above, support the hypothesis that planks 2 and 3 were prepared specifically to make use of plank 1.

A final feature of Figure 11 is the map in Figure 11f, showing a localized titanium-containing region above and to the right of the join. The CXRF scans were performed after a recent conservation treatment, and this peak may be associated with in-painting done in the course of that treatment. It is noted that the depth information provided by CXRF allows one to confidently separate this titanium peak from the buried layer to the left of the join. The fact that it is positioned above the top band of fluorescence peaks from lead, copper, iron, calcium and manganese means that it was added after these pigments.

DISCUSSION

In this article, results have been presented from a wide variety of analysis techniques, each of which adds insight to the construction and history of *The Armorer's Shop*. Holistic examination alone suggests that:

1. the painting is a seventeenth-century work;
2. the armor is contained on a small, rectangular plank that was incorporated into a larger composition; and
3. the armorer and forge sections of the work were painted by Teniers, while the armor plank was most likely painted by a different artist, probably either Jan Brueghel the Elder or his son, Jan Brueghel the Younger.

The scientific analysis indirectly supports each of these inferences, while providing a wealth of new detail concerning this work. Microanalysis shows that all of the construction materials used throughout the painting, including altered regions identified by IR-reflectography and X-radiography, are consistent with those known to be used in seventeenth-century Flemish oil painting. Dendrochronological dating shows that all three planks forming the panel were felled in the early 1600s, and that the armor plank was most likely painted 20 years before the other two planks. Furthermore, the growth orientations of individual planks in *The Armorer's Shop* suggest that planks depicting the armorer and forge were constructed specifically to make use of the armor-containing plank. Finally, confocal XRF provides direct evidence that the armor plank was painted before the complete panel was constructed. In view of Brueghel the Elder's death on 13 January 1625 [2, p. 33], the range, 1624–1630, of likely dates for the completion of the armor plank supports Brueghel the Younger as the artist of the armor pile, but does not rule out Brueghel the Elder.

There is evidence for collaboration between Teniers and Brueghel the Younger [2, p. 33, 8, p. 385]. However, no examples of such collaboration have been firmly identified. *The Armorer's Shop*, then, could represent one of the few known collaborations between these two important seventeenth-century painters. In view of these

results, in 2005 the attribution of *The Armorer's Shop* was changed to David Teniers the Younger and Jan Brueghel the Younger.[7]

A remaining question raised by this analysis concerns the nature of the collaboration that produced *The Armorer's Shop*. If Brueghel the Younger and Teniers did indeed collaborate on other works, and if Brueghel the Younger did paint the armor in *The Armorer's Shop*, why would Teniers go through the trouble of re-using an existing painting rather than inviting Brueghel the Younger to participate in a traditional collaboration? It is hoped that such questions may be addressed by further research.

Each of the analytical techniques described here provides distinct, yet complementary information that both supports and enriches the original hypotheses suggested by holistic and visual analysis. Although the dendrochronological results provide the most specific information regarding the dates each plank was originally felled, CXRF provides the only direct evidence that the armor plank was in fact painted before being joined to the rest of the panel. Similarly, neither the dendrochronology nor the CXRF results could be meaningfully interpreted without both the results of conventional analysis techniques and the stylistic and art historical observations made during the initial examination. Although CXRF is becoming an increasingly well-established technique, there are few examples of its application towards problems in conservation science [27]. This work demonstrates the feasibility and utility of using synchrotron-based CXRF to probe complex microstructural features on large works of art that are not accessible through conventional holistic and microanalytical methods.

APPENDIX: EXPERIMENTAL DETAILS AND INSTRUMENTATION

X-ray radiography was performed using a Picker Hotshot unit at an operating voltage of 20 kV and a tube current of 3 mA, with an exposure time of 90 s. Individual X-ray and IR images were combined using Adobe Photoshop 6.0. Infrared images were captured using an FLIR Systems (North Billerica, MA) SWIRcam camera using a pass-through filter of 1.5–1.8 μm.

For dendrochronology, one end of each plank in the support panel was prepared, and the widths of all rings were measured to 0.05 mm precision. The outer growth rings of the opposite ends were also prepared and measured, both to be sure that each plank's outermost ring was counted and to determine whether any sapwood rings were present. Sapwood consists of the outer rings next to the bark: those rings are generally removed due to low durability, leaving just the heartwood rings. In addition, all edges of the panel were examined for structural and wood anatomical features. The data from each plank were compared with several established Baltic, German and Dutch oak chronologies to determine the source of the wood and the outer ring dates of the planks, using standard dendrochronological statistical and visual techniques [33].

FTIR, conventional energy dispersive XRF, Raman microspectroscopy, SEM-EDX and cross-sectional analysis were employed to identify the paintings' pigments and overall paint layer structure. FTIR was performed using a Thermo-Nicolet (Waltham, MA) Magna 560 IR spectrometer with a Nicolet Nic-Plan microscope in transmission mode. For each sample, 120 scans were acquired from 4000 to 650 cm^{-1} at a spectral resolution of 4 cm^{-1}. Spectra were collected with Omnic ESP 6.1a software and analyzed using the Infrared and Raman Users Group (IRUG) database and commercial polymer and organic chemical libraries. Non-destructive, qualitative energy dispersive XRF was performed using a Bruker/Roentec (Carlisle, PA) ArtTAX micro-XRF spectrometer using a molybdenum tube operated at 50 kV, 600 μA and 200 s collection time. A polycapillary focusing optic was used to achieve an approximately 75 μm incident beam size, and Intax version 4.5.18.1 software (Bruker AXS, Madison, WI) was used to interpret spectra. The ArtTAX system is used for simultaneous multi-element analysis from Na(11) to U(92). In the element range for which the instrument is primarily designed, K(19) to U(92), the detection limits range from a minimum of 18 $\mu g \cdot g^{-1}$ for cobalt to 120 $\mu g \cdot g^{-1}$ for uranium [34]. Scanning electron microscopy was conducted with a Topcon ABT 60 SEM (Paramus, NJ) operated at 20 kV, a 22 mm stage height and a 20° sample tilt. Paint layer thicknesses from SEM images were calibrated and measured using ImageProPlus software (Media Cybernetics, Bethesda, MD). Energy dispersive X-ray spectra were collected using an EDX (Mahwah, NJ) X-ray detector, an Evex pulse processor and multi-channel analyzer and Evex Nanoanalysis software (Princeton, NJ). Raman spectroscopy was performed using a Renishaw (Hoffman Estates, IL) inVia Raman spectrometer using a 785 nm diode laser, a 50× objective, 1200 lines per mm grating, a laser

[7] *The change in attribution was made by the NCMA's Curator of Northern European Art, Dr Dennis P. Weller.*

power of 3 mW at the sample, a spectral range of 100 to 3200 cm^{-1} and a spectral resolution of 1 cm^{-1} per CCD pixel (functional resolution of 3 cm^{-1}). Data were also collected using a JY Horiba (Edison, NJ) LabRAM Aramis Raman spectrometer with a 50× objective, 785 and 633 nm lasers, a laser power of 8 mW at the sample, a 1200 lines per mm grating, a spectral range of 200 to 1600 cm^{-1} and a spectral resolution of 1 cm^{-1} per CCD pixel.

CXRF measurements were carried out at the D1 station of the Cornell High Energy Synchrotron Source (CHESS), using monochromatic radiation at 18 keV, selected using a 1% bandpass multilayer monochromator. A single-bounce monocapillary, fabricated at CHESS [35], was used to provide a focused incident beam of approximately 3×10^9 photons per second into a focus spot of approximately 20 (H) × 45 (V) μm. In a previous study of an oil-based painting on canvas painted using traditional pigments such as lead white, no evidence of radiation damage was detected even after a ten-minute exposure to a more intense X-ray beam than used for scanning: approximately 1×10^{11} photons per second in a 30 μm diameter spot at 17 keV. Nevertheless, as a rule, *The Armorer's Shop* was exposed to X-rays only while data collection was in progress. A double-focusing polycapillary lens (Xray Optical Systems, Albany, NY) with an input acceptance angle of 25° was used to collect X-ray fluorescence from the sample and direct it onto a Rontec Xflash silicon drift detector. The detector resolution is approximately 0.16 keV. The two optics define a 3D sample volume as described previously [31]. The energy-dependent depth resolution with the setup used for the scans presented here was measured using a variety of thin metal films, approximately 100 nm thick each, and varied smoothly from 31 μm at 4.5 keV to approximately 15 μm at 16 keV. These thin films were also used to estimate the sensitivity of the CXRF setup to different elements of interest. For the calcium Kα, iron Kα, copper Kα, lead Lα and strontium Kα fluorescence lines, the estimated fluorescence yields are approximately 2.6, 24, 28.5, 9.2 and 4.64 counts per second per picogram, respectively. It is noted that these yields are somewhat smaller than, but commensurate with, the results obtained by Vincze et al. if differences in incident energy, intensity and spot size are taken into account [30]. The painting was mounted on a large-area, high-resolution, 3D scanning stage equipped with an easel-style mount [32]. To increase the distance between the painting and polycapillary lens, the sample surface was oriented at 32° from the incident beam, rather than 45°, as in prior experiments. Integrated intensities of particular fluorescence lines were obtained by fitting peaks to a Gaussian line shape with a constant background.

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Résumé — *Cet article présente une étude pluridisciplinaire du tableau* The Armorer's Shop *(North Carolina Museum of Art), un panneau peint du XVIIe siècle attribué à David Teniers le Jeune, des Flandres. L'étude était motivée, premièrement, par des observations faites à partir de l'examen visuel et de celui des radiographies qui suggéraient une construction atypique, et deuxièmement par la découverte du fait que la représentation de l'armure dans ce tableau est presque identique à celles de plusieurs autres œuvres. Toutes les peintures, sauf une, sont attribuées à Jan Breughel le Jeune, un peintre flamand contemporain parent de*

Teniers par alliance. L'analyse stylistique soutient fortement l'hypothèse que Breughel a peint l'armure, alors que Teniers peignait l'arrière-plan, les personnages et les objets dépeints autour de l'armure. Un large éventail de techniques d'analyse, notamment l'analyse de coupes stratigraphiques, la dendrochronologie et la microscopie confocale de fluorescence des rayons X, a été utilisé pour déterminer si la construction du panneau et la palette sont compatibles avec cette hypothèse. La dendrochronologie a montré que le panneau a été fabriqué avec trois planches et suggère que la plus petite de celles-ci, la planche de l'armure, aurait été peinte environ 20 ans avant les autres. De plus, la microscopie confocale de fluorescence des rayons X a démontré que cette planche a été peinte avant que les trois planches soient assemblées. Pour autant que le sachent les auteurs, ceci est le premier témoignage du travail d'un peintre flamand du XVIIe siècle réutilisé de cette façon par un autre peintre contemporain.

Zusammenfassung *— In diesem Artikel wird eine multidisziplinäre Studie zu dem flämischen Gemälde* The Armorer's Shop *(North Carolina Museum of Art) von David Teniers dem Jüngeren präsentiert. Die Studie wurde durch die bei der Betrachtung unter dem Mikroskop und bei Radiographischen Untersuchungen sichtbar werdende, ungewöhnliche Konstruktion motiviert sowie dadurch, dass die Darstellung der Waffen nahezu identisch mit zahlreichen anderen Werken ist. Mit Ausnahme eines sind alle diese Werke Jan Brueghel dem Jüngeren zugeschrieben, einem zeitgenössischen flämischen Maler, der mit Teniers durch Heirat verwandt war. Eine stilistische Analyse unterstützt die Hypothese, dass die Waffen von Breughel gemalt worden sind, während Teniers Hintergrund, Figuren und andere Objekte gemalt hat. Die Ganze Breite materialanlytischer Techniken wie Dendrochronologie oder Confocale Röntgenfluoreszenzmikroskopie (CXRF) wurden insbesondere an Querschliffen durchgeführt, um die Frage zu klären, ob die Konstruktion der Tafel und die verwendete Palette mit dieser Hypothese in Übereinstimmung gebracht werden kann. Die Holzuntersuchungen zeigen, dass die Tafel aus drei Brettern besteht, deren kleinstes, das Waffen-Brett, etwa. 20 Jahre älter ist als die anderen. CXRF zeigte dementsprechend, daß dieses Brett bemalt wurde, bevor die Tafel zusammengefügt wurde. Nach Wissen des Autors ist dies der erste Beleg einer Wiederverwendung eines Flämischen Werkes des 17. Jahrhunderts in dieser Art.*

Resumen *— Este artículo presenta el caso del estudio multidisciplinar de* La tienda del armero *(North Carolina Museum of Art), una pintura sobre tabla del siglo XVII atribuida al artista flamenco David Teniers el Joven. El comienzo de estudio estuvo motivado, en primer lugar, por observaciones visuales y radiográficas que sugerían una construcción atípica, y, en segundo lugar, por el descubrimiento de que la representación de la armadura en este cuadro es casi idéntica a la existente en muchas otras obras. Todas, con una única excepción, son atribuidas a Jan Brueghel el Joven, un pintor contemporáneo, también flamenco, vinculado a Teniers por matrimonio. El estudio estilístico mantiene con seguridad la hipótesis de que Brueghel terminó la armadura, mientras que Teniers realizó el fondo, las figuras y los objetos representados alrededor de la armadura. Un amplio abanico de técnicas analíticas, especialmente estratigrafías, dendrocronología y microscopía confocal de fluorescencia de rayos X (CXRF), fueron empleadas para el análisis de esta obra con el fin de confirmar si la construcción del panel y la paleta usada pueden ser relacionados con la mencionada hipótesis. La dendrocronología muestra que el panel se fabricó a partir de tres planchas distintas, y sugiere que la más pequeña de ellas, la que corresponde a la armadura es, aproximadamente, veinte años más antigua que las otras dos. La CXRF, además, demuestra que este panel fue pintado antes de que se uniesen las tres piezas. Para los autores esta es la primera evidencia de la reutilización de una obra pictórica flamenca del siglo XVII por un segundo artista contemporáneo.*