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Collaboration or Appropriation? Examining a 17th c. Panel by David Teniers the Younger and Jan Brueghel the Younger Using Confocal X-ray Fluorescence Microscopy

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ABSTRACT

This paper presents the results of a multidisciplinary investigation of *The Armorer's Shop* (North Carolina Museum of Art), a 17th century painting on panel attributed to David Teniers the Younger of Flanders. The study was motivated by x-radiographic observations suggesting an atypical panel construction and by the discovery that the armor depicted in this painting is nearly identical to that of several other works, all but one of which are attributed to Jan Brueghel the Younger, a contemporary Flemish master and relative of Teniers. Stylistic analysis strongly supports the hypothesis that Teniers painted the background, figures and objects depicted around the armor, and that Brueghel completed the armor itself. A broad range of materials analysis techniques, including cross-section microanalysis, 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 twenty years before the other two. CXRF demonstrates that this plank was painted before being attached to the other two. To the authors' knowledge, this is the first report of a painting being re-used in this way, and the first evidence of collaboration between these two painters.

INTRODUCTION

The Armorer's Shop, by David Teniers the Younger (figure 1) depicts in its foreground a seated armorer and a richly detailed pile of parade armor. 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 at 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 a visual examination of the painting, the panel was found to have a highly unusual construction.

Figure 1. *The Armorer's Shop,* attributed to David Teniers the Younger, 56.5×80.7 cm^2, oil on panel, NCMA. The long solid lines indicate the interface between the armor-containing plank and the remainder of the panel. The dashed line indicates a third join discovered during dendrochronological analysis. The short lines indicate the locations of confocal XRF scans across the interface. The numbered arrows show the locations of samples used for conventional microanalysis. The unnumbered arrow highlights the particular CXRF scan shown in Figs. 4-5.

Typically when a large panel is constructed from multiple planks, the planks are assembled such that the joins are all parallel to the grain. In *The Armorer's Shop*, the parade armor in the lower left corner is painted on its own distinct plank, which is attached to the remainder of the painting along two perpendicular joins indicated by the solid white lines in figure 1. There is increased paint loss along the right-hand, vertical join because it is perpendicular to the grain. Both joins are visible as raised ridges in raking light, and are corroborated by the transmission x-radiograph in figure 2.

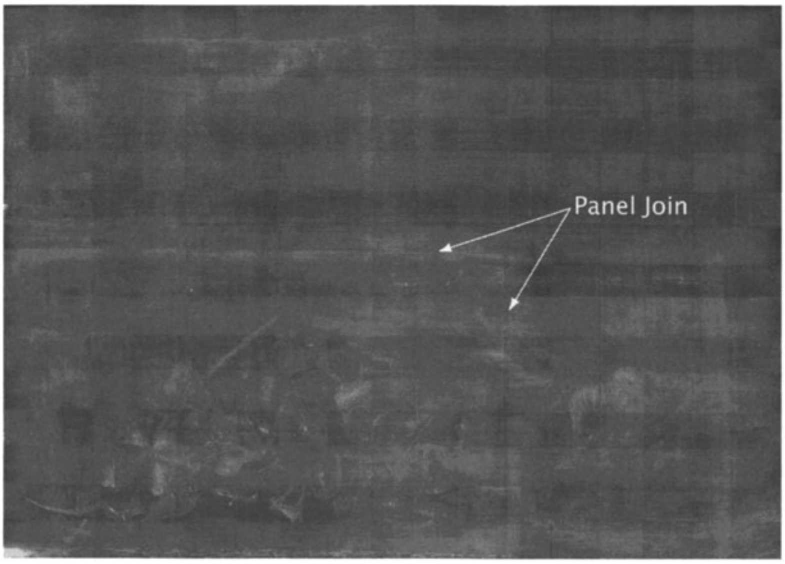

Figure 2. Transmission x-ray radiograph of the painting shown in Fig. 1, revealing the joins between the rectangular portion and remainder of the painting. The light cross-hatch pattern throughout the radiograph arises from a mahogany cradle. The radiograph reveals that the helmet on the left-hand table of the painting was originally part of a full suit of armor.

This atypical panel construction prompted further study and analysis of the painting, and eventually led to the discovery that the armor pile in figure 1 is nearly identical to armor depicted in six other paintings, all but one of which are attributed to Jan Brueghel the Younger. Although collaboration among two or more painters was common practice among Northern European painters in the 17th century [2], this painting, constructed by the incorporation of an already-painted single plank into a larger scene, is unique. Moreover, it is unclear whether the term 'collaboration' should be applied to this work at all.

This paper presents a study of the construction, composition, and palette of *The Armorer's Shop*, to determine the origin and history of this uniquely constructed painting. It presents a discussion of the visual, holistic and art historical evidence pertaining to the hypothesis that Jan Brueghel the Younger painted the armor pile, and that Teniers painted the remainder of the work. This is followed by the results of the conventional microanalysis of the painting, including Raman spectroscopy and x-ray fluorescence spectroscopy (XRF). Results obtained using synchrotron-based 3D, or confocal XRF (CXRF) are presented that unambiguously reveal the chronology of construction, and these are followed by results of a dendrochronological analysis of the panel components. In accord with the CXRF results, the dendrochronology data suggests that the plank containing the armor was painted approximately twenty years before being joined with two other planks to complete the work.

EXPERIMENT

X-ray radiography (figure 2) 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 seconds. Fourier transform infrared microspectroscopy (FTIR) was performed using a Thermo-Nicolet Magna 560 IR spectrometer with a Nicolet Nic-Plan microscope in transmission mode. For each sample (mounted on a diamond half-cell) 128 scans were acquired from 4000 cm^{-1} to 650 cm^{-1} at a spectral resolution of 4 cm^{-1}. Spectra were collected with Omnic E.S.P. 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 ArtTAX µXRF spectrometer with a molybdenum tube operated at 50 kV, 600 microamps, and 200s collection time. A polycapillary focusing optic was used to achieve an approximately 70 micron incident beam size, and Intax version 4.5.18.1 software was used to interpret spectra. Scanning electron microscopy was conducted with a Topcon ABT 60 SEM operated at 20 kV, a 22 mm stage height and a 20 degree sample tilt. Paint layer thicknesses from SEM images were calibrated and measured using ImageProPlus software (Media Cybernetics). Energy dispersive x-ray spectra were collected using an EDAX x-ray detector, an Evex pulse processor and multi-channel analyzer, and Evex Nanoanalysis software. Raman spectroscopy was performed on a Renishaw inVia Raman spectrometer using a 785 nm diode laser, a 50x objective, 1200 l/mm grating, a laser power of 3 mW at the sample, a spectral range of 100 cm^{-1} to 3200 cm^{-1}, and a spectral resolution of 1 cm^{-1}/CCD pixel (functional resolution of 3 cm^{-1}). Data was also collected using a JY Horiba LabRAM Aramis Raman spectrometer with a 50x objective, 785 and 633 nm lasers, a laser power of 8 mW at the sample, a 1200 l/mm grating, a spectral range of 200 cm^{-1} to 1600 cm^{-1}, and a spectral resolution of 1 cm^{-1}/CCD pixel.

The CXRF experiments were carried out at CHESS station D1, using monochromatic radiation at 18 keV, selected using a 1% bandpass multilayer monochromator. A single-bounce monocapillary, fabricated at CHESS[3], was used to provide a focused incident beam of approximately 5×10^9 photons/second into a 20 µm-diameter spot. A double-focusing polycapillary lens (X-ray Optical Systems) 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 [4]. The energy-dependent depth resolution with the setup used for the scans presented here varied smoothly from 31 µm at 4.5 keV to approximately 15 µm at 16 keV. The painting was mounted on a large-area, high resolution 3D scanning stage equipped with an easel-style mount [5]. To increase the distance between the painting and polycapillary lens, the sample surface was oriented 32° from the incident beam, rather than 45°, as in prior experiments.

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: these rings are generally removed due to low durability, leaving just the heartwood). 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,

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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 [6].

RESULTS and DISCUSSION

Visual & Stylistic Examination

After the initial observation of *The Armorer's Shop's* unusual construction, the painting was examined for corroborating evidence that the armor panel was painted either by a different painter or at a different time than the remainder of the painting. The armor is finely painted, contrasting with the irregular, coarsely painted brushstrokes of the surrounding forge. However, this difference alone does not constitute evidence of a second artist, since the depiction of armor would require much more detail compared to the rather rough elements in the rest of the composition. The difference could also indicate an increased degree of importance placed upon the pile of armor.

Compositional changes might also indicate that more than one artist contributed to the work. Infrared reflectography (data not shown) and x-radiography reveal possible attempts to integrate the pre-existing image of the armor with the surrounding composition. Figure 2 shows that the helmet on the table to the left was originally part of a full suit of armor. The question of whether a different painter might have painted the armor section was addressed by comparing *The Armorer's Shop* to other works by Teniers and his contemporaries. Remarkably, five paintings attributed to Jan Brueghel the Younger (1601-1678) have nearly identical depictions of armor as in *The Armorer's Shop* [7,8]. During an *in situ* examination of the *Allegory of Touch*, (Musée Calvet, Avignon, France) an overlay from *The Armorer's Shop* was used to precisely compare compositional and stylistic elements with those of the Avignon painting. 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. The biggest difference between the two is a full suit of armor at the far left of the *Allegory of Touch*, where *The Armorer's Shop* shows only a helmet on a table. However, as noted above, x-radiography revealed this helmet to have originally been part of a full armor suit until it was painted over with a table.

The correspondence between *The Armorer's Shop* and the armor in five paintings attributed to Brueghel the Younger suggest that *The Armorer's Shop*'s armor was painted by Jan Brueghel the Younger. Teniers and Brueghel the Younger were both active in the Antwerp art guild in the early 17^{th} century, and were also related through Teniers' marriage to Brueghel's half sister. Woolet [2] and Ertz make reference to collaborative projects between Teniers and Brueghel, yet no examples of such work have been firmly identified.

In general, the composition and execution of *The Armorer's Shop* fits quite well into Teniers' compositions of the 1640s. The figures, palette and spatial configuration are typical of Teniers' work. Moreover, both parts of the panel depict common elements found in other of Teniers' compositions, including the earthenware jug in the top left window and the tables in the bottom right and bottom left corners. Although several works of Teniers include depictions of armor, that of *The Armorer's Shop* stands out in both its execution style and quality. Other paintings that are confidently attributed to Teniers show his armor and other metallic objects having a rectangular quality to the contour and application of the highlight, not defining shape or curve. In comparison, Brueghel's armor paintings reveal that he applied highlights in a well-planned manner, always accentuating form as well as illustrating the reflective quality of the armor. These qualities apply to the armor in *The Armorer's Shop*, and suggest that Jan Brueghel the Younger contributed to this section of the work.

Conventional Microanalysis

Conventional microanalysis was carried out on both sections of the painting to identify any distinctions in their compositions and microstructures. A clear difference in the chemical composition of the two parts of the painting could support the hypothesis that the painting was executed at two different times or by different artists. Conventional 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 1.

Results from conventional XRF analysis suggest a traditional 17th century palette for both sections of the painting: vermilion and iron oxide reds, lead-tin and iron ochre yellows, lead white, azurite blue, umber browns, and flesh tones created by mixing lead white, vermilion, iron oxide red, and umber [9-11]. A translucent copper-containing green was used to represent the interior fabric of the armor, possibly verdigris or copper resinate (sampling for further analysis was not possible in these areas) [12]. Calcium could be found in each spectrum, suggesting the presence of a chalk ground as should be expected for 17th c. Northern European painting on panel [9,11,13,14]. Both lead and copper were found in virtually every spectrum regardless of the color of the presentation surface, suggesting that lead white and a copper-containing pigment such as azurite were used in a lower-lying paint layer such as an imprimatura [11,14,15]. No significant difference was observed between the palettes of the two sections. Fourier transform infrared spectroscopy and dispersive Raman spectroscopy were applied to five cross-sections from the painting to verify compounds inferred from conventional XRF. FTIR on all samples revealed characteristic absorbances for lead white in a drying oil. Strong bands were observed at 1407 and 1530 cm^{-1}, the carbonyl stretching bands for hydrocerussite and lead carboxylate soaps respectively. Bands at 2928 cm^{-1} and 2854 cm^{-1} (C-H stretching bands), at 3365 cm^{-1} (O-H stretching band), and 1711 cm^{-1} (carbonyl stretching band) were due to a drying oil binding medium. The major carbonyl band, at 1530 cm^{-1}, was due to the presence of lead carboxylates. The formation of such metal carboxylate salts are expected for a painting of this age prepared with a lead white-based palette [16]. Dispersive Raman spectroscopy of sample 18 revealed strong scattering bands at 1084 cm^{-1}, 708 cm^{-1}, and 278 cm^{-1}. All three of these bands match the reference spectrum for calcite, confirming the phase identification of the ground.

Cross-section samples were also studied with SEM-EDS to evaluate paint layer thicknesses and microstructures. Figure 3 shows a backscattered electron image of one of the cross-sections (sample 1). Above the Ca-rich ground layer, figure 3 clearly shows a 2-10 micron layer consisting primarily of lead, identified as lead white on the basis of FTIR results discussed above. The topmost layer shown in figure 3 contains significant Pb, Fe, Al, Si, Ca, and P, elements that suggest the presence of lead white, iron ocher, bone black, and calcite, consistent with the palette inferred from the conventional XRF data.

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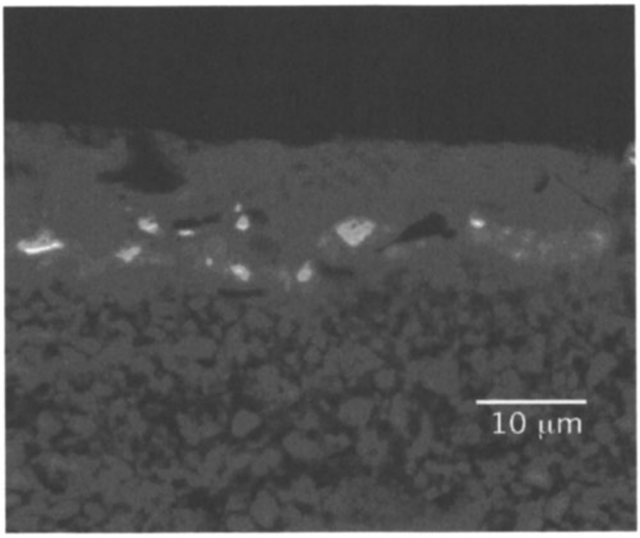

Figure 3. Backscattered SEM image of sample 1 (see Fig. 1), taken from the grey area from the armor pile, showing the presence of a lead white-containing imprimatura layer. Magnification 2000X.

The lead-rich layer immediately above the ground in figure 3 is identified as the imprimatura layer that was suggested by the conventional XRF data described above. The cross-section samples all show a lead-rich region directly above the ground, which corroborates the application of a lead white-based imprimatura to the ground before additional paint layers were applied. In addition to lead, SEM-EDS analysis of samples 2, 15, and 18 directly above their ground layers all revealed the presence of small amounts of copper. This data, combined with the ubiquitous copper observed in the ED-XRF data and the occasional presence of dark blue particles directly above the ground observed by visible-light microscopy, suggests that the imprimatura layer is interspersed with small amounts of a copper-containing blue pigment such as 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 [11].

The identification of calcium and phosphorus together in the grey particles of the imprimatura layer in figure 3 is suggestive of bone black, and the identification of aluminum and silicon in the dark (low-Z) particles that have platey habit in this layer is suggestive of the clay minerals typically associated with iron ochres. 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 ochers and calcium carbonate. The identification of copper in the imprimatura layer on both sections of the painting is notable. The composition, number and thickness of paint layers in *The Armorer's Shop* are consistent with 17th century northern European painting

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practice, but do not reveal any substantive differences between the armor and forge sections outlined in figure 1.

Confocal X-Ray Fluorescence

To obtain direct evidence for the chronology of the paint layers throughout the painting, a new, non-destructive technique, confocal x-ray fluorescence microscopy (CXRF) was applied. CXRF, or 3D scanning XRF, combines two x-ray focusing optics to resolve x-ray fluorescence from a particular, 3D volume in space [4,17-20]. By scanning the sample through this volume, the composition of a layered sample as a function of depth is determined.

Figure 4 shows intensity versus depth profiles of several fluorescence lines obtained from a single depth scan using CXRF, taken on the armor panel adjacent to the join between the armor and forge sections. The panel was translated by 6 µm between each point (moving the confocal volume deeper into the painting), and the data collection time at each point was 2 seconds. Each profile has been normalized by its maximum value to allow visual comparison of the relative peak positions. The data indicate a top layer (between 25 and 75 microns depth) consisting of Ca, Fe, Mn (not shown), Cu, and Pb. Within the layer, the Ca, Fe, and Cu peaks are approximately 5-10 microns to the left, or above the Pb peak. This implies an increasing Pb concentration immediately below the presentation surface, consistent with the observation of a lead-rich imprimatura layer in figure 4.