



REMBRANDT?: COOPERATIVE TECHNICAL EXAMINATIONS OF FIVE *TRONIES* BY REMBRANDT AND HIS CIRCLE

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ABSTRACT Five *tronies* (character studies) painted by Rembrandt and artists in his circle, which are or have been attributed to Rembrandt, from three collections were examined using complementary technologies. Dendrochronology of the panel of *Head of a Bearded Man* (c.1630, Oxford, Ashmolean Museum) connects it to paintings by both Rembrandt and Jan Lievens, while infrared reflectography revealed black underdrawn lines beneath the painted surface that suggest a spontaneous creative process at an early stage. Macro-X-ray fluorescence analysis (MA-XRF) of three paintings allowed conservators at the Mauritshuis (The Hague) to identify a copper-containing pigment in the midtones of the flesh (*Portrait of Rembrandt with a Gorget*, c.1629), differentiate original paint from later additions in the background (*Tronie of an Old Man*, c.1630–31), and determine where the ground was left exposed at the surface to act as shadows of the skin (*Study of an Old Man*, 1650). High-resolution digital microscopy of *Head of an Old Man in a Cap* (c.1630, Kingston, Canada, Queen's University) revealed the order in which layers were applied, and visualised Rembrandt's brushstrokes, paint handling and use of a tool to scratch into the wet paint. These technologies have developed or improved significantly since the Rembrandt Research Project published their research (1982–2015), advancing our technical knowledge about the five *tronies*.

Introduction

Character studies, also known by the Dutch term *tronies*, form a significant part of the oeuvre of Rembrandt van Rijn (1606–1669), including early in his career when his studio was located in Leiden (1625–31). Some of these paintings may depict a specific person, but most are studies of an anonymous model or generic type with interesting physiognomy, facial expression or costume.¹ *Rembrandt?* is an international research project involving conservators, scientists and art historians from the Mauritshuis (The Hague, The Netherlands), Ashmolean Museum of

Art and Archaeology (Oxford University, United Kingdom) and Agnes Etherington Art Centre (Queen's University, Kingston, Canada), which was established to share technical information about five *tronies* that are, or have been, attributed to Rembrandt, and are currently being re-examined and/or restored.

The attribution of paintings to Rembrandt and his studio has been an ongoing challenge. Between 1968 and 2014, Rembrandt attribution and connoisseurship was dominated by the Rembrandt Research Project (RRP), based in Amsterdam. In the six-volume *A Corpus of Rembrandt Paintings*,² ultimately only one of the *tronies* in the current

Table 1 Technical examination methods used to examine five *tronies*.

Title / Date/ Support / Size / Figure number	Institution / Inventory number / Number from <i>Corpus of Rembrandt Paintings</i>	Recent technical examination methods (Date is specified if the most recent examination was before 2018)				
		Dendro- chronology	IRR	XRF	High- resolution digital microscopy	Other
<i>Head of a Bearded Man</i> , c. 1630, oak panel, 16 x 13.7cm (figs. 1, 2)	Ashmolean Museum, Oxford, UK / WA1951.8 / vol. 1, C31	Andrea Seim (2018); Ian Tyers (2020); Peter Klein (2020)	Apollo InGaAs (900-1700nm), Opus Instruments	Bruker Crono μ -XRF scanning spectrometer	—	Technical photography; UV; X-radiography
<i>Portrait of Rembrandt with a Gorget</i> , c. 1629, oak panel, 37.9 x 28.9cm (fig. 3)	Mauritshuis, The Hague, The Netherlands / MH148 / vol. 1, A21; vol. 4 corrigenda I A 21; vol. 6 copy after no. 30	Peter Klein (1994)	Osiris InGaAs (900-1700nm), Opus Instruments	Bruker M6 Jetstream	HRX-01 10x and 30x magnification	Technical photography; UV; X-radiography; samples mounted as cross-sections (1999)
<i>Tronie of an Old Man</i> , c. 1630–31, oak panel, 46.9 x 38.8cm (fig. 4)	Mauritshuis, The Hague, The Netherlands / MH565 / vol. 1, B7; vol. 6, 46	Peter Klein (1995)	Osiris InGaAs (900-1700nm), Opus Instruments	Bruker M6 Jetstream; Elio μ XRF scanning spectrometer	HRX-01 30x magnification	Technical photography; UV; X-radiography; samples mounted as cross-sections
<i>Study of an Old Man</i> , 1650, canvas, 80.5 x 66.5cm (fig. 5)	Mauritshuis, The Hague, The Netherlands, MH560 / not included in <i>Corpus</i>	—	Osiris InGaAs (900-1700nm), Opus Instruments	Bruker M6 Jetstream; Elio μ XRF scanning spectrometer	HRX-01 10x–90x magnification	Technical photography; UV; X-radiography; samples mounted as cross-sections
<i>Head of an Old Man in a Cap</i> , c. 1630, oak panel, 24.3 x 20.3cm (figs. 6, 7)	Agnes Etherington Art Centre, Queen's University, Kingston, Ontario / 46-031 / vol. 1, C22; vol. 4 Corrigenda I C22; vol. 6, 44	Peter Klein (1996)	Apollo InGaAs (900-1700nm), Opus Instruments	Bruker M6 Jetstream; Bruker Tracer 5g portable XRF	Hirox-RH 2000 35x–1000x magnification	Technical photography; UV; X-radiography; samples mounted as cross-sections

study was considered by the RRP to be an authentic work by Rembrandt; the others were determined to be products of Rembrandt's workshop or circle, or not enough information was available to make a secure attribution. The research

team's early conclusions were based mainly on visual observations and informed by technologies that were available at the time, including stereomicroscopy, ultraviolet fluorescence (UV), and sometimes infrared (photography

and/or reflectography) and X-radiography. From *Corpus IV* (2005) onwards, dendrochronology and sampling techniques – which remove tiny amounts of materials from the paintings – were included. Since then, many new examination technologies have been developed or have improved significantly. Non-invasive imaging methods have been especially helpful for identifying artists' materials, visualising their distribution, discovering underlying compositions and tracking stages of production. A full understanding of the material-technical composition of paintings requires that the results of complementary technologies are considered together.

In this article, we focus on four non-invasive scientific technologies that enabled researchers to gather new information about the *tronies* from the participating institutions: dendrochronology, infrared reflectography (IRR), macro-X-ray fluorescence analysis (MA-XRF) and high-resolution digital microscopy.³ These technologies not only provided evidence about the materials and techniques that were used by Rembrandt and artists from his circle – they also informed conservation treatments. Until now, the international collaboration between the three institutions has focused on documenting and comparing the results from these new technologies, and how they have advanced our technical knowledge about these *tronies*. As more data are made available and collaborative research continues, this may eventually lead to (re)considered, or more secure, attributions, and to a clearer understanding of the materials, stylistic development and experimentation of Rembrandt and unidentified artists in his circle. Table 1 summarises the technologies that have recently been used by the various institutions to examine these paintings and their results to date.⁴

Dendrochronology

Head of a Bearded Man (c.1630) entered the collection of the Ashmolean Museum in Oxford in 1951 as an autograph work by Rembrandt (Figure 1a).⁵ Two other painted versions of this *tronie* have survived, now in the Museum of Fine Arts in Houston and a French private collection. In 1982, the Ashmolean painting was assessed by the RRP, who endorsed Horst Gerson's opinion of 1969 that it was *not* an autograph Rembrandt.⁶ There is no evidence that any scientific examination had been undertaken prior to the current study.

Dendrochronology, or tree-ring dating, examines and compares the spacing of annual growth rings on timber to determine the earliest felling date of the tree from which it originated. It can also provide information about the tree's geographic origin. As part of the recent technical investigation at the Ashmolean, the panel of *Head of a Bearded Man* was examined by three dendrochronologists, each using different reference databases (Figure 1b). Andrea Seim (2018) and Ian Tyers (2020) independently from each other concluded that the timber was oak from northeastern France, with earliest felling dates of 1568 and 1569, and plausible first use in 1570 and 1577, respectively. Prof Dr Peter Klein, who had previously contributed to the RRP, examined the panel in 2020. Klein determined that the timber was oak from the Polish/Baltic Region, with an earliest felling date of 1618 and a plausible first use date of 1626. This panel is technically challenging for dendrochronology because it is thin (10 mm, decreasing to 5 mm at the edges), tangentially sawn, and the left and right sides with end grain are short (160 mm). Reference datasets will vary, and the models for location and dating based on statistical matches

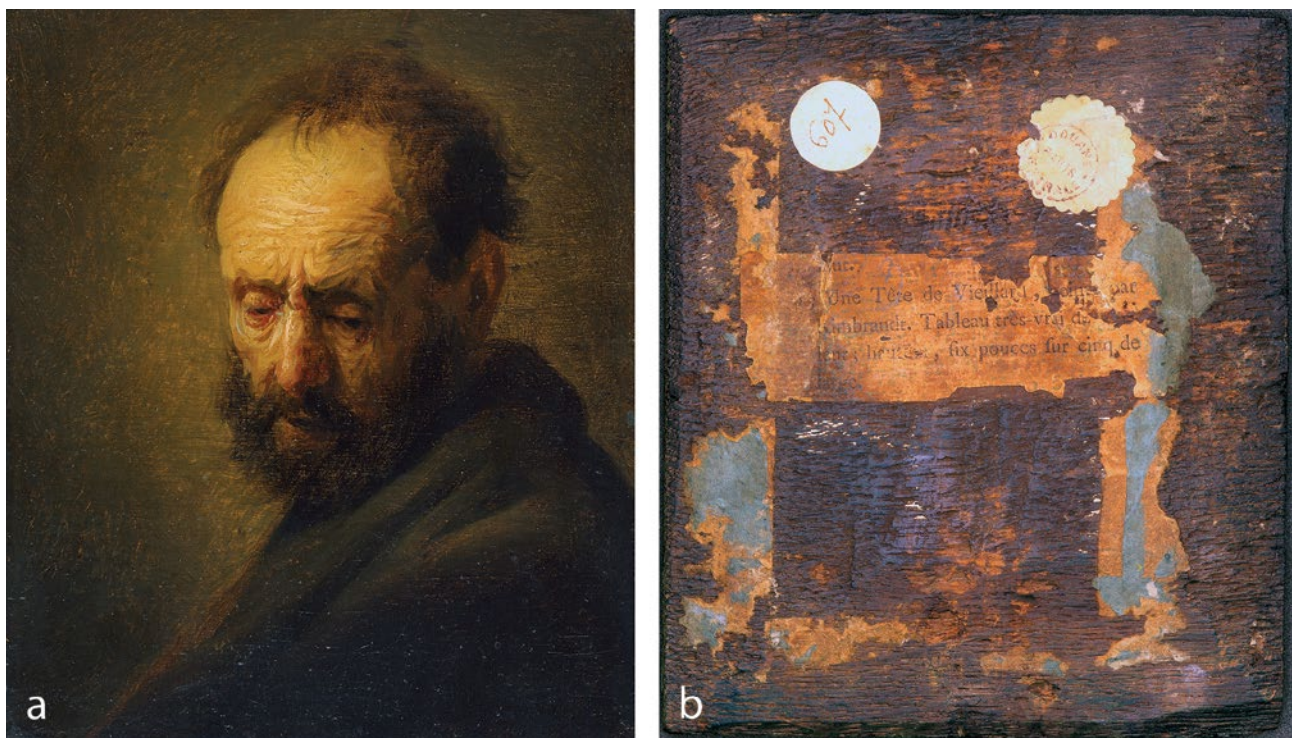


Figure 1 Workshop of Rembrandt, *Head of a Bearded Man*, c.1630, oil on oak panel, 16 × 13 cm, Ashmolean Museum, Oxford, inv. no. WA1951.8: (a) recto; (b) verso. © Ashmolean Museum, University of Oxford (images: Jevon Thistlewood).

cannot account for the effects of microenvironments on growth patterns.⁷ Even so, the variability in locations and dates by the three experts raises caution about using dendrochronology results from one source on panels, which pose particular challenges to this technique.

In his assessment, Klein took his opinion further by stating that the panel originated from the same tree as used in two paintings he had previously examined, namely Rembrandt's securely attributed *Andromeda* (1630, The Hague, Mauritshuis) and *Elderly Woman with a Coat* attributed to a follower of Jan Lievens (c.1630, Dresden, Staatliche Kunstsammlungen Dresden, Gemäldegalerie Alte Meister).⁸ According to Klein's conclusions, the *Head of a Bearded Man* could be placed in Rembrandt's Leiden workshop around 1630, but a date alone cannot confirm its authorship. For example, the Ashmolean panel could have been used by Rembrandt or by another artist in his circle, such as Jan Lievens, who probably shared a studio with Rembrandt between about 1624 and 1631.⁹

This situation – where several panels originating from a single tree are connected to Rembrandt's workshop – is not unique to these specific paintings. Klein determined that the panel of *Tronie of an Old Man* (c.1630–31, The Hague, Mauritshuis, described below) came from the same tree as two works in German collections with secure attributions to Rembrandt: *Minerva in her Study* (c.1631, Berlin, Gemäldegalerie) and *Simeon in the Temple* (1627, Hamburg, Hamburger Kunsthalle).¹⁰ Furthermore, Klein's dendrochronological examination of *Head of an Old Man in a Cap* (c.1630, Kingston, Canada, Agnes Etherington Art Centre, described below) indicated that the panel came from the same tree as *Self-Portrait(?) at an Easel* (c.1628–9, New York, Leiden Collection) attributed to Gerrit Dou: Rembrandt's first documented pupil in Leiden.¹¹ It should be noted that the data on which these historical assessments were based are not available for independent review.¹²

Infrared reflectography

The use of infrared technologies to examine artworks – including IR photography and infrared reflectography (IRR) – began in the 1930s and has undergone significant improvements in resolution and responsivity over the decades. IRR is often (but not exclusively) used to detect and reveal carbon-containing underdrawing applied during a preparatory stage.

The RRP did not use infrared imaging systematically, and none was used to examine *Head of a Bearded Man* (c.1630, Oxford, Ashmolean Museum) in 1982.¹³ The recent IRR of *Head of a Bearded Man* revealed roughly sketched dry lines, positioned on top of the ground and beneath the paint layers (Figures 2a and b). The lines repeat as the artist attempted to establish contours (such as those around the cheek and along the nose), and to place facial features (for instance, the nostrils), which were later redrawn in a slightly different location. The artist also made changes between the underdrawing and painting stages. Hatching

under the left eye indicates an area that should be in shade but was later painted as being in the light (Figures 2c and d). Rather than assuredly laying out a finalised composition, the underdrawing indicates a spontaneous sketching phase being developed directly onto the prepared panel. As such, this would lean more towards an original composition, rather than a copy based on an existing work.

All five paintings in the current study have been (re-) examined using state-of-the-art IRR equipment (see Table 1). Three of the works seem to have been planned with broad brushstrokes at an early stage, but no underdrawn outlines or hatching were detected. In contrast, IRR revealed sketchy underdrawing lines in a carbon black-containing material beneath the paint layers of two paintings: the Ashmolean panel (described above), and *Portrait of Rembrandt with a Gorget* (The Hague, Mauritshuis, described below). Linear underdrawing is seldom reported in works securely attributed to Rembrandt, who typically brushed an initial lay-in of the composition with translucent brown paint.¹⁴ Thus, the presence of a sketched underdrawing – contours, lines or hatching, perhaps applied using a dry material – could have been a reason to question an attribution to Rembrandt. However, as more paintings are examined with modern infrared cameras, a more nuanced picture has been emerging as recent research has shown that underdrawing does feature in selected works linked to Rembrandt's practice and those of his assistants, but further studies are required to clarify the extent of its use.¹⁵

Macro-X-ray fluorescence analysis

Following a 2019 exhibition to commemorate 350 years since Rembrandt's death, the Mauritshuis initiated a project called *Rembrandt?* to investigate and carry out conservation/restoration treatments on three *tronies* that, at one time, had been attributed to the master. Two were painted on panel – *Portrait of Rembrandt with a Gorget* (c.1629) and *Tronie of an Old Man* (c.1630–31) – and the third, *Study of an Old Man* (1650), is a signed work on canvas painted approximately two decades later than the other *tronies* in this study.

During the technical examination and conservation/restoration treatments, all three paintings were examined with XRF, both point measurements and macro-X-ray fluorescence analysis (MA-XRF).¹⁶ MA-XRF was used to detect and identify the chemical elements present in different layers of the painting, and to map their distribution, thus helping to identify pigments and other materials. For the three *tronies* from the Mauritshuis collection, the analytical technique shed further light on the original materials in preparatory and paint layers and helped to identify and distinguish later additions.

Portrait of Rembrandt with a Gorget was acquired in 1768 by Stadtholder Willem V (Figure 3a). Between 1774 and 1795, it was displayed in his gallery in The Hague, the first museum in the Netherlands that was open to the public. At the time, it was described as 'a portrait, being



Figure 2 Workshop of Rembrandt, *Head of a Bearded Man* (Figure 1): **(a)** infrared reflectogram (900–1700 nm) and **(b)** with underdrawing lines traced in orange; **(c)** detail of the face in visible light and **(d)** in IRR (images: Jevon Thistlewood).



Figure 3 Rembrandt (studio copy), *Portrait of Rembrandt with a Gorget*, 1629, oil on panel, 37.9 × 28.9 cm, Mauritshuis, The Hague, inv. no. 148: **(a)** recto; MA-XRF maps for **(b)** lead (Pb-L), **(c)** iron (Fe-K), **(d)** manganese (Mn-K), **(e)** mercury (Hg-L), **(f)** calcium (Ca-K), **(g)** potassium (K-K) and **(h)** copper (Cu-K). © Mauritshuis, The Hague.



Figure 4 Rembrandt (?), *Tronie of an Old Man*, c.1630–31, oil on panel, 46.9 × 38.8 cm, Mauritshuis, The Hague, inv. no. 565: (a) recto; (b) MA-XRF map for copper (Cu-K); (c) mercury (Hg-L); (d) potassium (K-K). © Mauritshuis, The Hague.

the head of a young man, on panel, by Rembrandt'. It was not recognised as a self-portrait by the master until 1874.¹⁷ Over the years, the attribution has been questioned by a few authors; however, from the inauguration of the Mauritshuis in 1822 until 1998, the museum considered it as an autograph painting by Rembrandt. The RRP included the painting in the first volume of the *Corpus* as a work by him, while noting that it was somewhat different in execution from other self-portraits from the same period.¹⁸

In 1998, *Portrait of Rembrandt with a Gorget* was examined in the Mauritshuis conservation studio.¹⁹ When an IR image revealed an extensive and detailed underdrawing, the sketchy quality of the costume and the loose, fluid character of the curls was deemed uncharacteristic of Rembrandt. This was followed by additional research

into this painting and the related self-portrait in the Germanisches National Museum in Nuremberg. The outcome was an agreed shift in attribution first proposed by Grimm in 1991: the Mauritshuis painting was judged to be a studio copy, and the Nuremberg version as being by Rembrandt.²⁰ The reassessment of the two paintings was incorporated by the RRP into the fourth and sixth volumes of the *Corpus*.²¹

Some researchers have suggested that the Mauritshuis painting was made by Gerrit Dou, who worked in Rembrandt's studio between 1628 and c.1632–3, or a copy made by Rembrandt himself,²² but so far, the attribution is inconclusive.²³ Recently, both the Mauritshuis and Nuremberg paintings have been re-examined as part of the *Replicating a Rembrandt Study* project, in collaboration with Vrije Universiteit Amsterdam.²⁴

An MA-XRF scan of the Mauritshuis painting has helped to determine the elemental composition and distribution of the pigments in the skin tones. Specific pigments were identified based on the elements that were detected: lead white (containing lead: Pb), vermilion (mercury: Hg), earth pigments (iron: Fe, with manganese: Mn indicating umber), bone black (co-presence of calcium: Ca and phosphorus: P) and red lake (potassium: K). The skin tones of the Mauritshuis *Portrait of Rembrandt with a Gorget* were smoothly blended into one another, with carefully selected pigment mixtures. The light areas of the face contain lead white with the addition of a little vermilion, red lake and earth pigments. Extra vermilion was incorporated in the left cheek and on the tip of the nose, the earlobe and the eyelids (Figure 3e). The shadows were mostly achieved with earth pigments, bone black and possibly organic lakes (Figure 3c).²⁵ The lips were carefully modelled with four distinct tones: vermilion and lead white for the lighter part of the lower lip, vermilion and red lake in the mid-tones (Figure 3g), red lake mixed with umber in the darker upper lip, and red lake, umber and a little bone black for the dark line between the lips. Apart from the lips, umber was used specifically for the outlines of the eyelids, and in combination with bone black for the dark areas in the hair (Figures 3d and f).

The most striking MA-XRF map is the one for copper (Figure 3h: Cu), which shows its distribution within the frown lines of the forehead, the outline of the face on the right, and around the mouth and jaw on the left. Examination of these areas with a stereomicroscope revealed distinct blue particles of azurite pigment, which were incorporated to provide the cool midtones of the face. While copper pigments such as azurite have been identified in other paintings by Rembrandt, their role in building up the skin tones is unusually pronounced in this particular painting.²⁶ MA-XRF also detected some copper in the clothing; however, no distinct blue particles were apparent under the microscope. It was likely incorporated there to accelerate drying of the dark paint (containing bone black and red lake).

As MA-XRF becomes used more frequently to examine Rembrandt's portraits and *tronies*, it is hoped that patterns of elemental distribution can help shed light on practices used by Rembrandt and artists in his circle. This initial research indicates that the use of azurite for the midtones in the depiction of flesh specifically could reveal characteristic applications which may help to distinguish the techniques of specific artists in the workshop from one another.

When *Tronie of an Old Man* (c.1630–31, Figure 4a) was purchased in 1892 by Abraham Bredius, the director of the Mauritshuis, it was thought to depict Rembrandt's father, Harmen Gerritsz van Rijn.²⁷ After examining the painting in 1973, the RRP linked some features of the figure study with Rembrandt's Leiden works from around 1630; however, in the first volume of the *Corpus*, they concluded that 'it presents stylistic features that prevent the authors from pronouncing judgment on its authenticity'.²⁸ In the sixth *Corpus* volume, Ernst van de Wetering reconsidered the

painting in the context of oil studies painted in the workshop, with the pronouncement that 'one can now once again confidently attribute this painting to Rembrandt'.²⁹

During the recent technical examination, which included MA-XRF, the tonality of the background and touches of red paint on the ears and eyes became the focus, as these were mentioned specifically by the RRP in the first volume of the *Corpus*.³⁰ The 'scattered accents of bright red' they described are mainly visible on the left side of the man's face. The opaque red touches on the top of the ear and around the eye correspond to the highest concentration of mercury (Hg-L) detected using MA-XRF (Figure 4c), indicating that the red pigment vermilion was used. In other areas of the face, the vermilion-containing paint lies slightly below the surface – for instance, on the right side of the nose – and is also present in the mixtures used to paint the skin tones.

Another chemical element present in the red touches of the ear and eye is potassium (K), which is likely related to the manufacturing method of the red lake used in the glaze.³¹ In the left ear, its distribution is more localised than the vermilion (Figure 4d). Potassium-containing paint partially covers the opaque red highlight at the tip of the ear, creates the shadow for the ear canal, and establishes the smaller position of the earlobe. A translucent red glaze on top of an opaque vermilion underlayer would have deepened the colour to create a shadow. Over time, the red lake has degraded, presumably faded in response to light. It appears hazy and cracked under the microscope, giving a blanched appearance to the areas that would have had the most intense shadow.³² Furthermore, the broad distribution of potassium-containing glazes on the right side of the face would have provided a darker intensity, but their degradation has now resulted in a loss of modelling and definition.

Another point raised by the RRP in the *Corpus* is that the background of *Tronie of an Old Man* is difficult to assess, and that its tonality and colour – opaque light brown with a greenish tint – seem atypical. The surface is flat and even, but there is evidence of some textured brushstrokes beneath. Recent research shows the background was almost completely overpainted in the past, and therefore its current appearance should not be a factor in attribution. The extent of the overpaint is revealed in the MA-XRF map for the element copper (Cu: Figure 4b). It was painted around the contour of the figure, avoiding delicate brushstrokes such as the fur collar, and circumventing the shadow on the left. The source of the copper in the background was determined by examining cross-sections using a light microscope which showed two distinct phases separated by an unpigmented organic layer (probably varnish). The lower layer of original paint contains mostly earth pigments, and the upper layer of overpaint contains a variety of pigments, including verditer, a copper-containing synthetic malachite or azurite that was available in the 17th and 18th centuries.³³ This suggests that the background was overpainted relatively early in the painting's history.

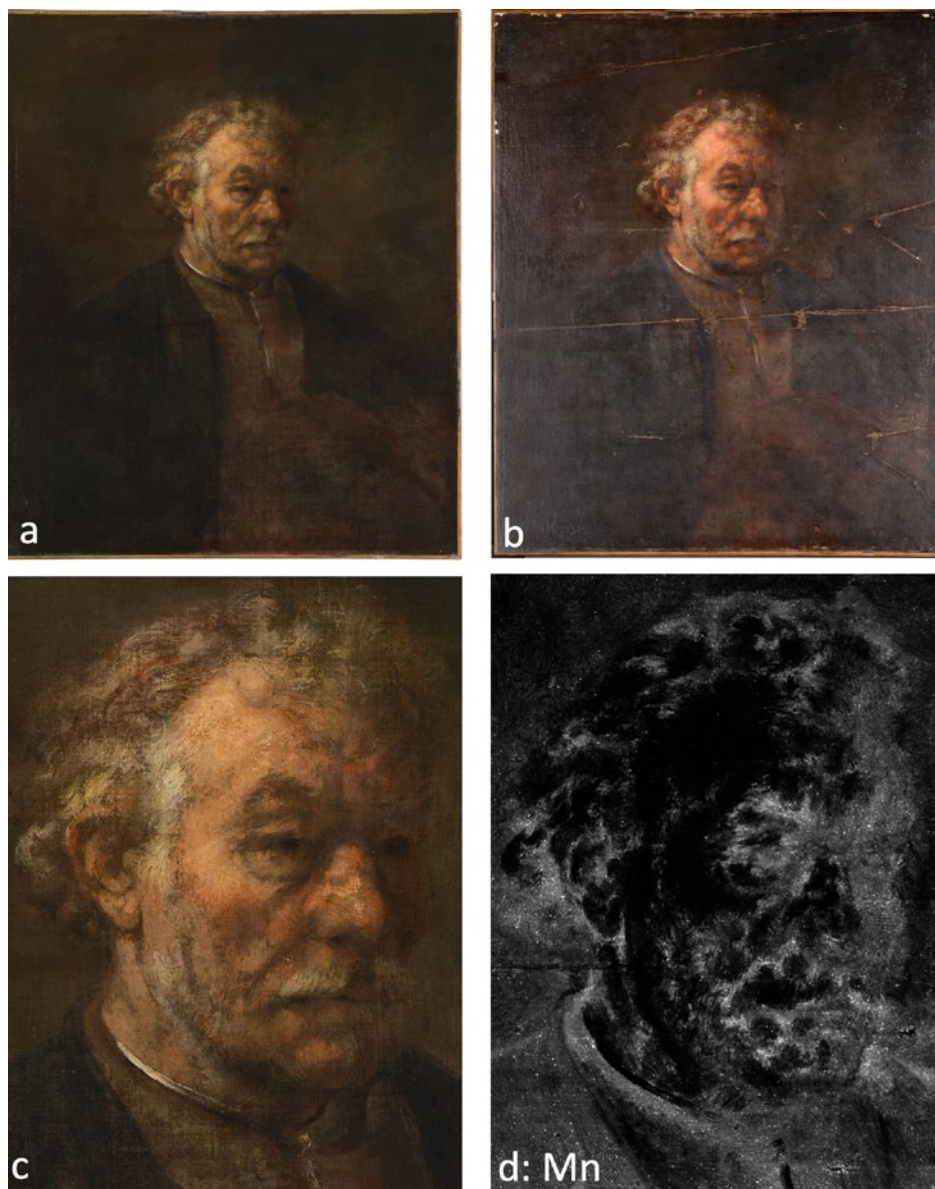


Figure 5 Rembrandt (?), *Study of an Old Man*, 1650, oil on canvas, 80.5 × 66.5 cm, Mauritshuis, The Hague, inv. no. 560: (a) recto, before treatment and (b) after varnish and overpaint removal following application of isolation varnish; (c) detail of the face before treatment; (d) MA-XRF map for manganese (Mn-K). © Mauritshuis, The Hague.

The reasons why the background was so broadly over-painted are still unclear. X-radiographs show insect damage to the upper right corner of the panel, and the right side of the panel has been cut down.³⁴ Alternatively, the original paint in the background (which contains earth pigments, charcoal black, lead white and chalk) is thinly painted, and might have been damaged by overcleaning.³⁵ The backgrounds in other paintings by Rembrandt and his studio made around 1630 were often painted with warm grey tones with a strong light from the left. Some show a vigorous paint application, with distinct brushstrokes and areas that are relatively thin.³⁶ Others, such as the *Head of an Old a Man with a Cap* (c.1630, Figure 6a, described below) have an opaque grey background with strong shadows.³⁷ Unfortunately, cleaning tests along the right edge established that it is not currently possible to remove the overpaint safely, so knowledge of the original background is reliant on imaging and analytical methods.

Study of an Old Man, signed and dated 'Rembrandt. f. 1650', was acquired by Bredius for the Mauritshuis in 1891 (Figure 5a).³⁸ He was convinced that it was a late work by the master that depicted Rembrandt's brother, Adrian. Bredius was aware of the poor condition of the painting and observed that the overpaint in the lower right did not match the original paint.

The painting was examined by a team of experts for the *Rembrandt in the Mauritshuis* project in the early 1970s. Using X-radiography, infrared and UV illumination, they concluded that the canvas had been rolled up in the past, and that the paint layers had suffered badly, which accounted for the large areas of paint loss, abrasion and overpaint.³⁹ They did not doubt the signature and date on the left side, which they thought were partially covered with retouching. They concluded that Rembrandt began painting – but never completed – *Study of an Old Man*.

Although the painting was examined twice by the RRP, it was never included in the *Corpus*. In 1973, Van Thiel and Levie concluded that while the painting technique was consistent with Rembrandt and his circle (mentioning his pupil Karel van der Pluym), *Study of an Old Man* was very damaged. Due to the amount of retouching, especially in the shadows of the face, it could not be evaluated. In 1988, the painting was re-examined by Van de Wetering for the RRP. Noting that the painting seemed unfinished, he suggested that assistants such as Carel Fabritius or Willem Drost may have contributed; however, due to its poor condition and the extensive overpaint obscuring the original materials, Van de Wetering also concluded that the painting could not be assessed adequately.⁴⁰

In a conservation treatment carried out within the current *Rembrandt?* project, old varnish layers and discoloured overpaint have now been removed (Figure 5b). Remarkably, the signature appears *not* to have been retouched. The unfinished character of the painting was confirmed by the absence of elaboration in the bottom right corner and supported by the study of cross-sections, which show only one thin application of paint apart from in some shadows in the face.

MA-XRF analysis provided new information about the technique and original appearance of the painting. The manganese (Mn) map indicates the presence of umber: a brown earth. This specific brown pigment was not used in any of the paint layers but is present in the upper ground layer.⁴¹ The high concentrations in the manganese map correlate to areas in the painting where the upper ground was left exposed at the surface (Figures 5c and d): for instance, to render the dark brown shadows in the face and neck. The overall presence of calcium (Ca) in the MA-XRF map derives from several materials used in the painting. It occurs in the form of chalk in the lower ground. More calcium is present in the cloak, in the form of bone (or ivory) black in the black brushstrokes (in combination with phosphorus (P)), and as a substrate for red and yellow lakes.⁴² In the background and face, calcium was also found, related to the presence of red lakes.⁴³ The cobalt (Co) map shows the distribution of smalt in the brown background.⁴⁴ It was used in combination with earth pigments, red lake, vermilion and black.

These observations are consistent with the materials and painting techniques known from the technical examination of other firmly attributed paintings by Rembrandt in the Mauritshuis. Leaving the ground layer deliberately visible to serve as a shadow tone is a technique that is especially prevalent in his later works. In the late *Self Portrait* (1669, Mauritshuis), Rembrandt used a similar approach to create the dark brown shadow areas in the face and neck, also visible in the MA-XRF map for manganese (Mn).⁴⁵ In the same painting, he also made abundant use of red and yellow lakes, which showed up in the maps of potassium (K) and calcium (Ca). In other paintings by Rembrandt, smalt was often mixed in with brown paint to adjust the colour, translucency, or drying properties and/or add body to the paint.⁴⁶

As MA-XRF mobile scanners were developed in the late 2000s and have only recently come into widespread use, this non-invasive technology was not available to the RRP.⁴⁷ It provides crucial information about Rembrandt's materials and their distribution, and those of other artists in his workshop, which could inform – or refute – results from other methods of analysis. Whereas the MA-XRF examinations of the *Portrait of Rembrandt with a Gorget* and *Study of an Old Man* focused primarily on original paint layers, for *Tronie of an Old Man*, MA-XRF was vital to differentiate original from later additions. MA-XRF scans of the other paintings in this study have allowed for comparison, material identification and identification of compositional changes.⁴⁸ Although different MA-XRF equipment was used in the three institutions (see Table 1), the characterisation and distribution of elements in the Ashmolean *Head of a Bearded Man* could still be compared to the Mauritshuis and Kingston paintings. For example, combinations of earth pigments – some containing both iron (Fe) and manganese (Mn) – lead white and vermilion were used to model the face. Vermilion (indicated by the presence of mercury, Hg) was used in mixtures throughout the face and hair but is concentrated around the left (proper right) eye, the bridge of the nose and the ear (see Figure 2c). This is similar to the localised application of red touches in the facial features of the Mauritshuis *Tronie of an Old Man*. Similarly, the mercury map in the Kingston *Head of an Old Man in a Cap* (described below) showed the highest concentration of vermilion in the nose and ears; mercury is also present in the cap. MA-XRF also indicates the use of smalt and the presence of copper in the underlayers of the latter painting, as well as compositional changes made at different stages of production.

High-resolution digital microscopy

Head of an Old Man in a Cap (c.1630) entered the collection of the Agnes Etherington Art Centre in Kingston (Canada) in 2003 (Figure 6a). It was a gift from Dr Alfred Bader, who had purchased the painting as a likeness of 'Rembrandt's father' in 1979, shortly after its attribution to the artist had become contested. It was considered an autograph work by Hofstede de Groot, Bredius and Gerson, but was rejected by the RRP leading up to their publication of *Corpus I*.⁴⁹ This reassessment was based predominantly on the rough paint handling, believed to have been incongruent with Rembrandt's early painting style. The decision presented the RRP team with its first public disagreement. Ernst van de Wetering published a dissenting opinion with the entry, noting that the coarse execution did not, in his view, preclude the work from being autograph.⁵⁰ He also cited the importance of a print by Jan Gillisz. Van Vliet (1600/10–68) after the painting, which includes an inscription that identifies Rembrandt as the composition's inventor. The close collaboration between Rembrandt and Van Vliet was demonstrated more conclusively by researchers in the final decade of the 20th century, which formed an



Figure 6 Rembrandt, *Head of an Old Man in a Cap*, c.1630, oil on panel, 24.3 × 20.3 cm, Agnes Etherington Art Centre, Queen's University, Kingston (Canada), inv. no. 46-031: (a) recto with boxes around details captured by the digital microscope; (b) background paint layers (350× magnification); (c) underpainting visible in cracks (35× magnification); (d) underpainting visible in cracks (140× magnification); (e) bristles from a paintbrush (140× magnification); (f) scratches in an eyebrow (35× magnification); (g) scratch marks in the beard (35× magnification). © Gift of Alfred and Isabel Bader, 2003 (images: Jocelyn Hillier).

important argument for the work's reattribution to the artist in *Corpus IV*.⁵¹ Growing insight into Rembrandt's early work increasingly showed his style and painting techniques during his Leiden period to be experimental, identifying the *Head of an Old Man in a Cap* as a valuable source towards a better understanding of this highly idiosyncratic phase in the artist's oeuvre.⁵²

Volume VI of the *Corpus*, published in 2015, revises a number of earlier attributions. In his introductory essay, Van de Wetering identifies the discussions around *Head of an Old Man in a Cap* as a major turning point in his thinking regarding the Rembrandt Research Project's methodology, which had insisted on a consistent stylistic development:

What we were confronted with was not so much a conflict of opinions, but more fundamentally the casual manner of overruling factual evidence ... that Rembrandt's early style was not so consistent as had been assumed by Bruyn and the other team members.⁵³

Close examination, combined with data obtained from X-radiography, played a significant role in the formation of the RRP's early hypotheses regarding Rembrandt's working methods and stylistic development, including the artist's inclination to work out his compositions from background to foreground.⁵⁴ The RRP team had access to microscopes with relatively low magnification (magnifying glasses and sometimes stereomicroscopes).⁵⁵ Current digital microscopy enables high-resolution images – with accurate rendering of colour and surface texture – to be viewed, saved

and easily compared, resulting in a more accurate assessment of an artist's working process. For the current study, *Head of an Old Man in a Cap* was examined between 35× and 1000× magnification using a 3D digital microscope.⁵⁶

The underpainting and ground were examined through the craquelure in the uppermost paint, revealing a layer structure designed to exploit the visual qualities of the materials. Throughout the background, Rembrandt applied dark brown paint over the ground, then covered it with a thin light grey paint (Figure 6b). This layering contributes to the cool tone of the background by taking advantage of the turbid medium effect (blue-hued scattering).

Examination showed that the white tufts of hair were painted over the wet black paint of the cap, whereas the flesh tones were rendered over a dry, warm brown underpainting (Figures 6c and d). Variations within the underpainting of the flesh, ranging from a deep dark brown to a light yellow-brown, shimmer through the painted surface.

Rembrandt rendered the eyes of the old man using vigorous brushstrokes of black, brown and pink (Figure 7a). The only distinct feature of the eye is the pupil – a single stroke of black paint – as opposed to the rest of the form, which is loosely implied through shadows. The paint was applied wet-in-wet, and different colours can be seen swirling together under high magnification. Rembrandt created thick impasto in the forehead, layering oil paint wet-in-wet, building up to the white highlight which indicates the direction of the light source (Figure 7b). While this furrowed brow superficially resembles that of the Ashmolean painting, the features are rendered differently. The brushstrokes in the latter painting are wide and flat; the illusion is more dependent on the interplay of light and shade,



Figure 7 Rembrandt, *Head of an Old Man in a Cap* (Figure 6): (a) detail; (b) microscopic image of the left eye and (c) the forehead wrinkle (images: Jocelyn Hillier).

rather than the physical volume of the paint. This difference provides additional support for its creator being within Rembrandt's studio, mimicking (without quite mastering) Rembrandt's style.

Fragments of bristles from Rembrandt's paintbrushes were found embedded throughout the upper layer of paint – especially in the background where a pale scumble was applied – hinting at the vigour and force exerted in applying the thin layer of paint (Figure 6e).

Rembrandt's intentional manipulation of paint, texture and colour to create a compelling image is best exemplified by examining the deliberate scratch marks in the eyebrows and beard (Figures 6f and g). Strands of hair were scratched through the wet paint, using a tool with a rounded tip like a brush handle to reveal the preparation layers. These types of incised marks were already present in Rembrandt's earliest works, and he continued to use this technique.⁵⁷ Scratch marks in the shadow of the beard reveal a much darker underpainting as compared to the eyebrows. The scratches in the brows are very consistent, rendered in quick short strokes, revealing a combination of a warm midtone brown and a cool dark brown in the underlying layers. Notably, the scratches strike through the darkest paint strokes, producing a high contrast with the bright preparation layers. The 3D digital microscope was used to determine the depth of the scratches, which averaged 21.5 µm in the brows and 13.8 µm in the beard.

Digital microscopy revealed the order in which the preparatory layers and paint layers were applied and allowed for a detailed examination of Rembrandt's brush handling and use of scratched paint. Since the authenticity of this painting is no longer doubted, technical investigation can serve as a comparative to (re)contextualise the analyses of other paintings in other institutions and provide additional insight into Rembrandt's confounding early oeuvre.⁵⁸

Conclusion

The collaborative *Rembrandt?* study has demonstrated that recent advances in non-invasive methods of technical examination can help us understand the materials and techniques used for painting *tronies* by Rembrandt and artists in his circle. It shows the possibilities and difficulties that specialised research can offer. The specific technologies considered here were complemented by the results from

other forms of scientific imaging and examination. Non-invasive imaging – for example, IRR, MA-XRF and digital microscopy – provides information about the distribution of certain materials, but it is not always possible to determine the *order* in which the materials and layers were applied. Therefore, analysis of microsamples is sometimes necessary to confirm the identity and distribution of these materials. Dendrochronology is an important tool to estimate the dating, probable geographic origins of panels, and connections between planks originating from the same tree. When used in isolation, each of these technologies provides limited information. The combination of complementary technologies and their comparison across different paintings are essential to gain a full picture. While it was hoped that this collaborative investigation would shed light on attribution, this remains difficult. Comparing *tronies* made around 1630 (and one from 1650) is especially challenging, as this group is very divergent – a difficulty recognised by the RRP from the outset in Volume 1 of the *Corpus*:

Rembrandt must initially have reacted in a number of different ways to the difficulties this subject-matter brought with it, especially in a large format. This is at least how it seems to the art historian, who finds it extremely difficult to find consistent criteria for his attributions among the, on the whole, meagre range of common features displayed by these paintings, both between themselves and in comparison to history paintings from the same period.⁵⁹

Despite this acknowledgement, the problem of assumptions regarding consistency of style in the project's early stages was highlighted by Ernst van de Wetering as a fundamental one in his reflections on method in 2015, referencing the attribution history of *Head of an Old Man in A Cap*.⁶⁰

The RRP's expertise has been respected and valued for the past 50 years, and their influence on shaping the field of Rembrandt connoisseurship is undeniable. Nevertheless, new technologies can complement and expand on their findings – and occasionally refute them – where there is sufficient evidence. For example, even if the faces of *Head of an Old Man in a Cap* and *Head of a Bearded Man* exhibit similar expressive qualities, the painting technique is very different. The easy sharing of digital images and information using comparative technologies was key for this study of paintings from collections far afield.

As Rembrandt *tronies* in other collections are (re-)examined with state-of-the-art technologies, comparison will continue. It is essential also to undertake complementary technical examinations of works by artists in his circle, such as Dou, Lievens, and Barent and Carel Fabritius. Therefore, although the paintings in this study form a diverse group, analysing and comparing them contributes knowledge on the painting technique of Rembrandt and artists connected to him. Only by understanding more about artists in Rembrandt's orbit can technical idiosyncrasies – such as panels that originated from the same tree yet have been painted on by different artists and varied uses of underdrawing – be recognised and accurately interpreted within a larger context. New technology has only just begun to clarify what lies under the surface, and future study will allow us to better understand the creative processes of Rembrandt and his expansive circle of followers.

Acknowledgements

We extend our thanks to: Marya Albrecht, Bader Philanthropies, Dr Morwenna Blewett, Dr Edwin Buijsen, Cultural Heritage Agency of the Netherlands (RCE), Justin Davies, Prof Dr Stephanie Dickey, Caroline van der Elst, Dr Tea Ghigo, Suzan de Groot, Kathryn Harada, The Jarislowsky Foundation, Prof em Dr Peter Klein, Dr Alison Murray, Rijksmuseum Conservation & Science, Charlotte Rulkens, Dimitri Salmon, Dr Andrea Seim, Karin Sprang, Margareta Svensson, Christopher Titmus, Sarah Turner, Ian Tyers, Prof em. Dr Jørgen Wadum, Dr Inez van der Werf, Scott Williams.

Notes

1. Gottwald 2009.
2. *Corpus I–VI* [1982–2015].
3. Non-invasive imaging and examination technologies do not require touching or removing material from an artwork. Dendrochronology can be *micro*-destructive; sometimes a small amount of wood must be shaved from an edge of the panel to clearly reveal the rings.
4. Although all three institutions have well-equipped conservation and technology departments, the methodology to examine each painting varied somewhat according to which methods were appropriate for each artwork, which technologies were available, and/or the specific type of instrument. When possible, we endeavoured to use similar settings and instruments to ensure that the results are as comparable as possible.
5. White 1999: 102–3, Salmon 2017. Bequeathed by the distinguished art dealer and collector Percy Moore Turner, its earliest provenance can be traced to 1777 when it appeared in the Paris sale of the late Hippolyte-Louis-Marie de Montblin's collections. The small panel painting most likely remained in France, where Turner bought it in February 1937 from the Paris dealer Paul Cailleux (listed in Turner's stock books under 'B1 596', bought from Cailleux, for 900 francs; Salmon 2017: 414).
6. *Corpus I* [1982]: 619–22, no. C31.
7. Domínguez-Delmás 2020.
8. Peter Klein, Dendrochronological report, Netherlands Institute for Art History (RKD): [https://rkd.nl/en/explore](https://rkd.nl/en/explore/technical/5010133)

9. [/technical/5010133](https://rkd.nl/en/explore/technical/5010133). This painting has traditionally been referred to as *Portrait of Rembrandt's Mother*. Like other paintings by Rembrandt and Lievens showing a similar elderly female model, the attribution and identification of the sitter has been questioned in the last few decades (Vogelaar and Korevaar 2005). Her recurrence in their oeuvre, however, possibly links the Dresden painting to their Leiden studio. While not much is known about the presence of pupils or assistants during this period, it is very likely that there would have been some (Van der Wetering and Schnackenburg 2001).
9. Brown et al. 2019: 20.
10. Peter Klein, Dendrochronological reports for *Minerva in her Study* (c.1631, Berlin, Gemäldegalerie) and *Simeon in the Temple* (1627, Hamburg, Hamburger Kunsthalle), RKD: <https://rkd.nl/en/explore/technical/5007644> and <https://rkd.nl/en/explore/technical/5004248>.
11. Agnes Etherington Art Centre, Curatorial Archive, object file 46-031: Peter Klein, Dendrochronological report dated 8 April 2014 for Gerrit Dou's *The Artist in the Studio* (New York, Leiden Collection).
12. These data will be made available on <https://dendro4art.org/> as well as RKDTechnical. They are presently dealing with technical difficulties, but these data will be openly available in the future.
13. Wadum 2022: 20.
14. Brown et al. 2019: 83; Van de Wetering 2009: 23–32.
15. Noble et al. 2018: 330–31; Wadum 2022.
16. The point measurements and smaller scans (approximately 9 × 9 cm) were carried out with the Elio MA-XRF spectrometer. The MA-XRF scan was carried out with the Bruker M6 JETSTREAM, loaned by the Rijksmuseum.
17. De Vries et al. 1978: 43–5.
18. *Corpus I* [1982]: 225–30, no. A21.
19. White and Buvelot 1999: 112–17.
20. Grimm 1991: 20–28; Wadum 2022: 22–3.
21. *Corpus IV* [2005]: 597; *Corpus VI* [2015]: 494.
22. Sluijter 2000.
23. Wadum 2000: 180; Brown et al. 2019: 260–67.
24. The aim of this project was to explore the strengths and limitations of replication in the humanities by carrying out a 'replication study' within the field of art history (Rulkens et al. 2022). The forthcoming article will be published by Charlotte Rulkens et al. in: *Humanities and Social Sciences Communications* (HSSC).
25. Some lead is visible in the map for Pb (Figure 3b), but this corresponds to the lead present in the upper ground layer. Samples mounted as cross-sections showed that the upper ground consists mainly of lead white with some chalk, earth pigments and black.
26. Noble et al. 2018: 317.
27. Manuth et al. 2019: 682–3, no. 276 list this painting under the title of *Old Man with a Black Cap* and explain how the painting became associated with Rembrandt's father since 1890.
28. *Corpus I* [1982]: 431–7, no. B7. Bruyn and Van de Wetering examined the *Tronie* using an artificial light and a UV lamp, as well as X-radiographs. They obtained scientific information from De Vries et al. 1978: 57–9, 214–15.
29. *Corpus VI* [2015]: 503–4, no. 46.
30. Red touches in and around facial features can be seen in a number of paintings by Rembrandt and his circle, including: *Raising of Lazarus* (c.1630–31, Los Angeles County Museum of Art), *Bust of a Man Wearing a Turban* (c.1628, Amsterdam, Kremer Collection), and *The Laughing Man* (c.1629–30, The Hague, Mauritshuis). The MA-XRF maps of the skin tones were also compared to the other *tronies* in this study.

31. Potassium can derive from potassium carbonate used in an alkali solution to extract the dyestuff and/or potash alum to precipitate the dye onto a substrate.
32. Samples from the left eye and the right side of the face (in shadow) were mounted as cross-sections. In UV, fluorescent red lake particles were visible, both in surface layers and in mixtures beneath the surface (in underlayers that established the shadows).
33. Blue verditer does not appear to have been commonly used by Rembrandt, but was identified in *A Bearded Man with a Cap* (c.1657, London, National Gallery); Bomford et al. 2006: 45–6, 157–8.
34. *Corpus I* (1982): 433. An X-radiograph of the *Simeon in the Temple* (1627, Hamburg, Hamburger Kunsthalle) shows woodworm holes in the lower left (*Corpus I* [1982]: 151). As dendrochronology proved that these panels were cut from the same tree, it is possible that these woodworm holes were present before painting began and/or that sapwood was present on both panels.
35. The pigments in the original background were determined through visual examination and scanning electron microscopy-electron dispersive X-radiography (SEM-EDX) analysis of cross-sections, which corroborated the elemental results from MA-XRF.
36. An example of a vigorously painted background with thinly applied areas is *Bust of an Old Man with a Fur Cap* (1630, Innsbruck, Tiroler Landesmuseum Ferdinandeum).
37. Two other *tronies* with a relatively opaque background and shadow are: Rembrandt, *Tronie of a Man in a Feather Cap* (c.1635–40, The Hague, Mauritshuis) and *Old Man in Military Costume* (c.1630–31, Los Angeles, J. Paul Getty Museum).
38. The first mention of the painting's provenance is a sale in 1809 in Paris, where it was sold as an authentic Rembrandt (De Vries et al. 1978: 136–7, 139 n. 2–5).
39. De Vries et al. 1978: 132–9.
40. *Study of an Old Man* was examined in 1973 by Pieter van Thiel and Simon Levie, and in 1988 by Ernst van de Wetering (using visual examination, UV and X-radiography). Information obtained from unpublished documents from the archives of the RRP, accessed in the RKD in November 2021.
41. The composition of the ground was determined by examining cross-sections using stereomicroscopy and elemental identification using SEM-EDX: the bottom ground layer contains red and yellow earth (Fe), chalk (Ca) and lead white (Pb). The upper ground layer contains yellow earth (Fe), lead white (Pb), umber (Mn) and charcoal black.
42. Noble and Van Loon 2005; Bomford et al. 2006: 177.
43. A sample taken in the shadow of the nose bridge between the man's eyes, mounted as a cross-section, confirmed the presence of red lake in the top paint layer.
44. Cross-section analysis showed that the smalt is only present in low quantities and remarkably, the smalt has retained its blue colour.
45. Noble et al. 2014: 3–5.
46. Van Loon et al. 2020.
47. Although MA-XRF was not available to the RRP, they obtained some elemental information from neutron activation autoradiography (NAAR); however, this technology was not used on any paintings in this study.
48. The Mauritshuis and Queen's University utilised the Bruker M6 JETSTREAM, while the Ashmolean used a Bruker Crono MA-XRF scanner, which has a lower spatial resolution (see Table 1).
49. De Witt 2008: 261, 264.
50. *Corpus I* [1982]: 16, 43–4, 576–80.
51. Schuckman et al. 1996; *Corpus IV* [2005]: 111–12, 628.
52. Ernst van de Wetering and Bernhard Schnackenburg further studied Rembrandt's varied early style with regard to its implications for ongoing connoisseurship of Rembrandt and his numerous pupils, and its entanglement with Flemish and Italian antecedents as well as contemporary studio practices. Respectively: Van de Wetering and Schnackenburg 2001: 58–81, 92–121. For *Head of an Old Man in a Cap*: 69, figs 17, 112, and 370–73, no. 80, as by Rembrandt.
53. *Corpus VI* [2015]: 41.
54. Van de Wetering recalled that the need for paint samples was gradually reduced as 'investigation with a surgical microscope, or even a strong magnifying glass, in combination with an X-radiograph was often sufficient to understand the early Rembrandt's working method as it gradually evolved' (*Corpus VI* [2015]: 27).
55. *Corpus I* [1982]: XI, XVIII
56. Queen's University used the Hirox RH-2000 3D digital microscope system with the trinocular lens with magnification range 35–5000×, lit with a 5700K LED. System specifications are detailed in Hirox RH-2000 datasheet, https://www.hirox.com/catalog/pdf/cat_RH-2000_en2_A.pdf.
57. Gifford 2022: 84–6; Brown et al. 2019: 84–5.
58. Manuth et al. 2019: 682, no. 275.
59. *Corpus I* [1982]: 8. *Tronies* painted within Rembrandt's workshop are also described in *Corpus VI* [2015]: 57–8.
60. *Corpus VI* [2015]: 41.

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