Fig. 1 Johannes Vermeer, *Young Woman Seated at a Virginal*
c. 1670, oil on canvas, 20 x 25 cm
Private Collection

The cloak of *Young Woman Seated at a Virginal*: Vermeer, or a later hand?

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Introduction
After many decades of disagreement amongst Vermeer scholars, this painting was the subject of a thorough technical investigation in the mid 1990s to find out if it was a fake, a nineteenth-century pastiche, a seventeenth-century imitation or a painting by Vermeer (fig. 1).[1] The techniques identified by this research, and, most importantly, the range of pigments and the distinctive way they had been used, provided convincing evidence to scholars that the painting was indeed the work of Vermeer, although the crude handling of the yellow cloak has remained a real source of concern.
The x-radiograph of the painting (fig. 2), revealed a surprising earlier version of clothing under the surface of the present yellow, which appears to depict a lighter-weight, finer textile being worn, with more intricate folds and tucks. What seems to be more sophisticated handling in this first painting of the costume aligns much more closely with the style which might be expected of Vermeer; and so it was the discovery of this underlying image which confirmed what most experts had assumed - that the cloak was an alteration or later addition. The painting was finally auctioned in July 2004 as a genuine Vermeer.[2] However, the question of who painted the shawl, and why it was painted so unskilfully has remained the subject of much debate.

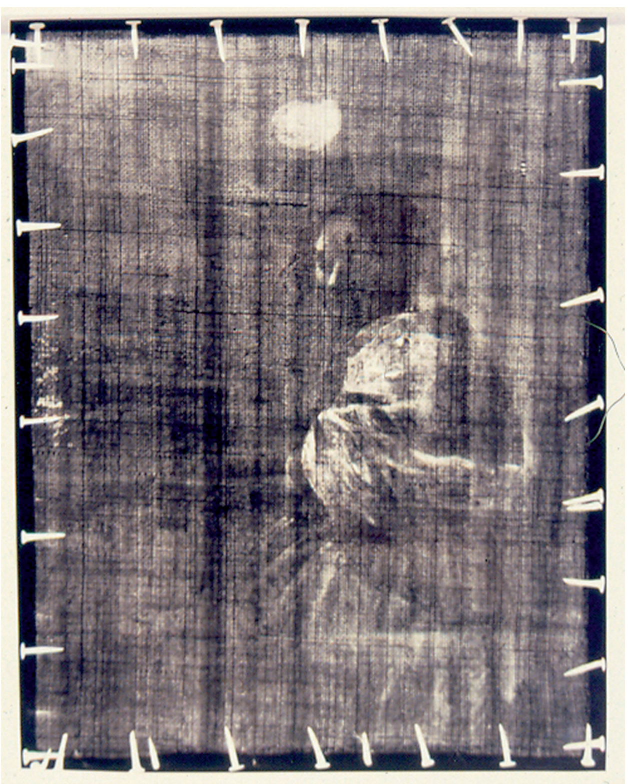

Fig. 2 X-radiograph of *Young Woman Seated at a Virginal*, showing underlying costume

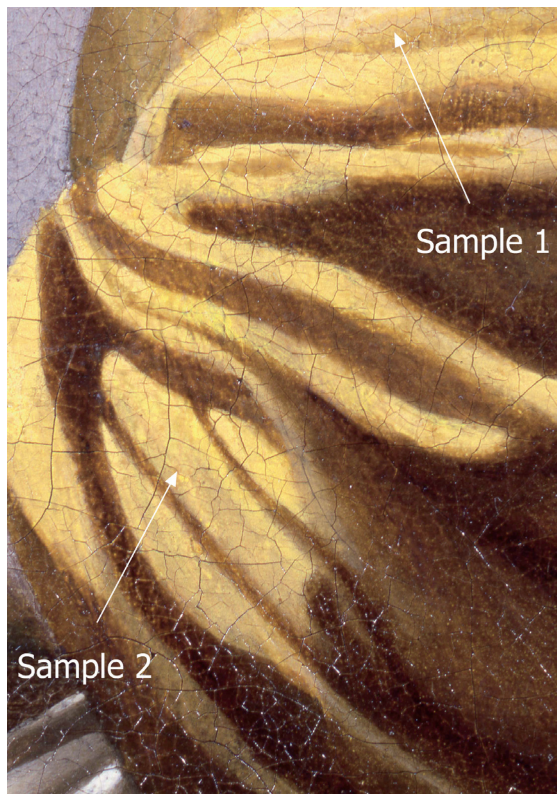

Fig. 3 Detail of the sampling site of the yellow cloak

The presence of lead-tin yellow in the cloak[3] indicated that it had been painted before this pigment's approximate terminal date of 1720; but neither the identification nor the handling of this yellow was peculiar to Vermeer, since it was still in common use after his death, so that the scientific examination did not support or refute the art historical argument that the yellow cloak was a later addition or modification. Nevertheless, because the x-ray had shown a different style of dress underneath, it was hoped that a closer study of the build-up of paint layers would reveal the answer to these questions.

To complicate matters further, preliminary investigations had shown that the layers of the lower image visible in the x-radiograph had been made with a paint which contained lead-tin yellow type I, as was the case in the upper layers. Were these yellows exactly the same, from the same palette or workshop? Critically, was there any separation layer between the two versions? Furthermore, had there been any deterioration in the upper layers? The answer to these questions lay in an in-depth analysis of the paint stratigraphy, notably the composition and structure of layers, interfaces and composing pigments.

The investigation procedure

Microscopic samples taken from different parts of the yellow cloak were embedded in resin and mechanically polished before being studied by optical microscopy: this allowed an approximate idea of structure, colours, layers and grain sizes of pigments within the layers to be gauged. However, the use of the Dual Beam Scanning Electron Microscope / Focussed Ion Beam (FIB) allowed more sophisticated examination of the cross-sections, their elemental constituents and individual particles within the stratigraphy.

The Focused Ion Beam was used for two purposes.[4] First, ion milling was performed to prepare smooth surfaces of the two layers in the cross-sections. Mechanical polishing of cross-sections can lead to misinterpretation of the structure and character of the paint layers since, during preparatory grinding action, pigment grains are sometimes removed and deposited elsewhere. The critical paint cross-sections from the *Young Woman Seated at a Virginal* were therefore processed further with the FIB, and selected areas in the layers of interest were ion-milled, the ion bombardment resulting in a clean and smooth layer surface with minimal preparation damage.

The second FIB application is the preparation of micrometer-scale thin sections for electron transmission microscopy (TEM), at the exact position of interest. Ion milling is used to prepare two micrometer-scale, parallel trenches, leaving a thin lamella intact. This lamella, of approximately 100nm in thickness, is then lifted-out and transferred to a Transmission Electron Microscope (TEM) sample grid. As TEM allows for electron diffraction analysis, the FIB gave us the unique opportunity to study the structure and elemental composition of individual micrometer-sized grains in the paint cross-sections. This analytical capability turned out to be of great interest in the study of the interface of the two layers of lead-tin yellow.

In depth investigations of critical cross-sections

To try to answer the question of who painted the cloak and whether it has changed futher with time, microscopic samples of the yellow cloak were taken from painstakingly selected sites. Careful superimposition of the x-ray image, showed precisely where to obtain cross-sections through both the first and second versions of the costume. Samples 1 and 2 (figs. 4a-b) from the yellow cloak were both from the lighter areas of the folds (fig. 3), while a third sample examined was from the grey background wall (not shown). Both samples from the cloak consist of a thick yellow top layer, corresponding with the upper yellow cloak. The substructure, however, is more complex. While in sample 1 only the pale brownish-grey ground lies directly below the yellow top layer, sample 2 showed the presence of a lower yellow layer, which can be associated with the earlier version of clothing underneath the cloak visible in the x-radiograph (the ground layer broke away during setting of the sample). Both samples, notably sample 2, showed a gradual decrease of colour saturation in the thick top layer: that is, the lower part of that upper paint of the cloak has a stronger yellow colour than the paler surface part. This was to prove a significant factor in the findings.

EDX analysis of the samples was to further elucidate the build-up and constituents of these paint layers. For example, the ground layer present in sample 1 consists largely of lead with trace amounts of silicates, and could be identified as such due to the identical colour and composition of that layer in the sample from the background. Elemental distribution images of the paint layers in both yellow samples showed the presence of lead and tin, but the homogenous spread of both these elements in the yellow is not consistent with the gradual fading of colour towards the surface. However, a significant difference in composition and structure of the upper and lower layers of this sample was readily visible in the smooth paint section prepared with the Focused Ion Beam. Figure 5 shows an electron image of a section through the paint of the top and the lower layer in sample 2, and we can see that, in addition to lead and tin, the top yellow layer is rich in calcium (see the black particles in the image), an element which is absent in the lower yellow layer. This calcium was identified as grains of chalk, which is a well-known substrate for organic yellow colorants. Indeed, the presence of organic yellows in these upper parts of the paint was then confirmed by examination of a microscopic dispersion, which showed traces of translucent, pale yellow isotropic particles, which are characteristic of a yellow lake pigment.

A different hand at work, and/or a deteriorated yellow?

The discovery of chalk mixed into the yellow of the upper layers gave rise to further avenues of discussion about the cloak's origins and original appearance. Firstly, the presence of the earlier version of clothing could be seen clearly in one of the cross-sections, and analysis showed that the lower layer consisted of a pure form of lead-tin yellow, while the top layer has been mixed with chalk-substrated organic yellows. This proves the use of different mixtures of paint for the lower and upper image, but it is still unclear when and by whom the upper layer was applied. Both versions of the costume employed lead-tin yellow, and the addition of a yellow lake to the upper layers could equally well have been made by Vermeer as by a later hand. Of course, the samples also lead to speculation about the state of the earlier version of the costume. The absence of the lower yellow layer in sample 1 might suggest that the first version was left unfinished. Or could the painting have been abraded locally before the top layer was applied? These questions remain unanswered for the present.

The finding of chalk in the upper layer, however, gained much more importance when assessing the original appearance of the second costume. It was, after all, the rough handling of the paint of the cloak, which has caused so much concern in attributing the painting to Vermeer. This examination indicated that the yellow cloak would have had a marked quantity of an organic yellow lake in the upper layers, and is therefore likely to have altered considerably in appearance through discolouration by fading of the yellow lake, leaving only the chalk and small traces of the original colour. The modelling of the cloak has suffered as a result of this fading, as some of the sharp and crude contrasts are now left unmodified, notably in the lighted area of the cloak. In addition, subtle variations in the halftones and shadows, where calcium has also been found, may too have disappeared. As a consequence, the spatial illusion of the cloak, the central element in the painting, is significantly reduced.

Alongside the distortion of colour resulting from the deterioration of the yellow lake, the degradation also may have affected the illusion of texture. With a more pronounced colour, some of the yellow highlights on the lighted parts of the cloak would have given an impression of a more glossy, less dull material for the cloak, perhaps suggesting the shininess of a certain fabric, more in line with the satin sheen of the woman's skirt. Whether or not this was so, it is clear that the yellow cloak has significantly altered in appearance. The invariable crudeness of the cloak, or lack of *houding* in seventeenth-century vocabulary[5], must partly be attributed to the discolouration of organic yellow colorants.

Findings at the interface between the two images of the costume

Even more detailed examination of these same cross-sections was carried out to try to further the question of who was responsible for the later version of the costume and when it might have been executed. Our attention focussed on the paint stratigraphy, and in particular the interface of the two layers of lead-tin yellow, representing the yellow cloak and the earlier version of clothing. Earlier examinations of the cross-sections on a stereo microscope had shown no sign of an interlayer such as traces of varnish, dirt or paint which is sometimes found between alterations to a painted feature and might imply a later hand at work. No readily visible separation had been observed.

In this examination with SEM/FIB, however, large particles consisting of potassium, aluminium and silica were found between the paint layers of the two versions in sample 2 (see fig. 4b). Their size is several factors higher than the average grain size in both layers and they occur only along the interface. We therefore decided to prepare a thin-section through one of these particles in order to establish a positive identification. We prepared a thin lamella through a single particle, which was then transferred to a TEM. In the TEM, EDX as well as electron diffraction identified the particle as monocrystalline orthoclase potassium feldspar ($KAlSiO4$). Feldspar is one of the most common rock-forming minerals and occurs abundantly in nature[6]. The mineral can be subdivided in more than 20 groups and some of them are known for their

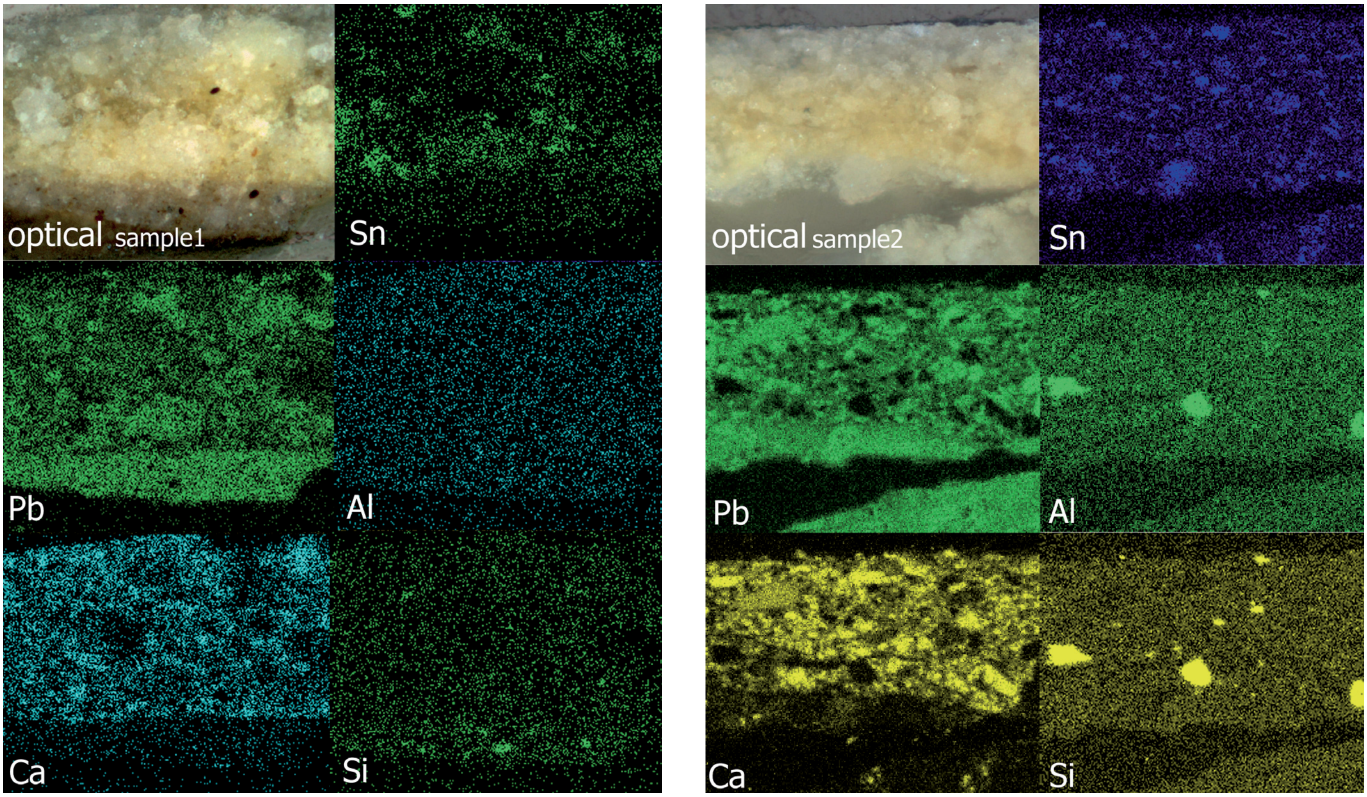

Fig. 4a-b Optical images and corresponding elemental distribution images of cross-sections from samples 1 and 2

colourful appearance, caused by trace-elemental presence of certain chromophores (Zr, Sb, Zn).

What, then, was the significance of these findings of potassium feldspar between the lower and upper layers of lead-tin yellow? As mentioned, feldspar is a common mineral. Its presence per se in historical paint is not surprising. Various earth pigments, such as ochres and the like, frequently occur with feldspars and other aluminium silicates as associated minerals. What did surprise us in our cross-section however, is the isolated appearance of large feldspar particles along the interface. The particles are clearly absent elsewhere in the paint stratigraphy. Were they intentionally deposited to obtain a deliberate optical effect? It should be mentioned that sprinkling of pigments was a painting method well known to seventeenth-century painters as is exemplified by Van Mander's description of the sprinkling of smalt particles.[7] As mentioned, certain feldspars are known for their shiny, colourful effect and, in addition, it is well known that Delft around 1650 was a centre of optical experiments in painting.[8] Based on these observations we carried out on a reconstructive experiment in order to assess a possible optical effect of feldspar on paint films. Feldspar particles of identical composition and comparable grain size were sprinkled on a freshly prepared layer of lead-tin yellow. However, no optical effect could be detected, other than a weak tempering of the surface shine (fig. 6).

However, it should be kept in mind that feldspar particles were used on an industrial scale in the production of Delftware.[9] Indeed, the potassium orthoclase type that was found in our painting was and still is used as clay additive lowering the silicate melting point.[10] Considering these circumstances, an intentional exploration of feldspar particles and their optical effect could have been feasible. However, the optical cross-section (sample 2 in fig. 4b) did not reveal a noticeable colour of the feldspar particles. Furthermore, a reconstruction experiment conducted in the laboratory did not show any special shine. This was mostly due to the particle size of 15 microns, which is still rather small for optical effects, the translucency of the particles and their refractive properties that are similar to an oil binder (R.I.=1.5). It must therefore be concluded that the feldspar particles served no deliberate painterly effect.

A more feasible explanation seems to be the incidental deposition of feldspar particles before the upper layer

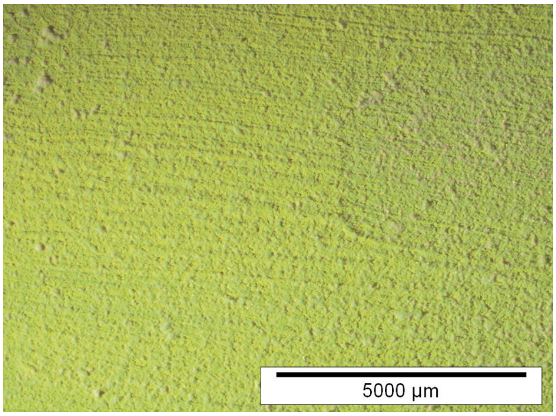

Fig. 6 Detail of a paint reconstruction showing feldspar particles sprinkled on a layer of lead-tin yellow. No significant optical effect could be observed.

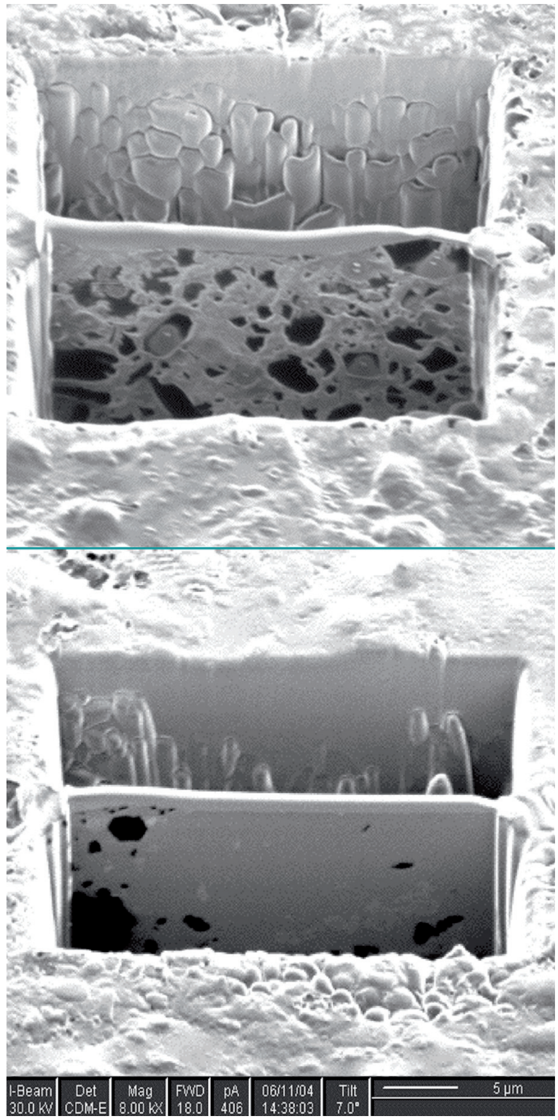

Fig. 5 Tilted view on freshly milled sections through the yellow top layer (above) and lower layer (below) in sample 2. Black particles are rich in calcium so that the difference in structure and composition is evident.

was applied. As mentioned, potassium feldspar is ubiquitous in nature and was certainly abundant in Delftware production in the near vicinity of Vermeer's workshop. Their deposition in the form of unintentional contaminants is the most likely explanation. This deposition, most probably as dust, is consistent with a break in the realisation of the cloak. However we cannot conclude anything about the duration of this break, which could have lasted from several days to the terminal date of lead- tin yellow in the 1720's. If our theory is correct then deposition of feldspar grains may have occurred on other Vermeer paintings, which could be checked by re-examination of existing cross-sections.

Conclusion

The analytical findings, notably the presence of interfacial feldspar particles, confirm the idea that there was a break in the making of the painting, but it does not provide evidence of the length of any gap of time. Furthermore, although this study has shown that there is a difference between the constituents of the lower layer of lead-tin yellow and the upper paint - the first version of the costume has been executed using a pure lead-tin yellow, whereas the upper paint contained chalk-substrated organic colours - it still does not indicate whether Vermeer or someone else finished the painting. More comparative studies of cross-sections from the paintings of Vermeer might show how common a technique was the addition of yellow lake, and whether it has been added in the same manner to lead-tin yellow, or to shadows. However, this study of the yellow layers has shown the probability that at least some of the yellows on the present costume have faded and led to an unmodified sharpness in the transition from light to dark. This aspect of the painting's condition, which has not been taken into account in the past, should be considered in any stylistic evaluation of the painting. Could one speculate that the yellow cloak, in its original, undiscoloured state may have matched the extraordinarily skilful modelling of drapery seen in the skirt, in the manner to be expected from Vermeer?

Acknowledgement
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Notes

1 L. Sheldon and N. Costaras, 'Investigation of *Young Woman Seated at a Virginal*: The Rolin Vermeer', *The Burlington Magazine*, CXLVIII (February, 2006), 89-97.

2 A summary of the findings of both the technical investigations and of a committee set up by the conservator Martin Bijl were written by Gregory Rubinstein in *Old Master Paintings*, Sotheby's catalogue for July 2004.

3 L.Burgio, R.J.H.Clark, L.Sheldon and G.D.Smith, 'Pigment identification by spectroscopic means: evidence consistent with the attribution of the painting *Young Woman seated at a Virginal* to Vermeer', *Analytical Chemistry*, 77 (2005), 1261-1267.

4 The analytical work was performed with a dual beam FEI SEM/FIB strata 235 DB equipped with an EDX system from EDAX. Elemental mapping of the embedded cross-sections was performed at a voltage of 15 kV and spot size 4, using the Field Emission Gun electron beam of the FIB/SEM microscope. In the dual beam microscope, the ion beam is extracted from a liquid gallium source and then accelerated with a voltage of 30 kV, with ion currents from 1 pA to 20 nA for milling, while the electron beam allows non damaging side view scanning of the freshly milled surfaces. TEM investigations of this work were made with a Philips CM30UT microscope with an acceleration voltage of 300 kV.
M.W.Phaneuf, 'Applications of focused ion beam microscopy to materials science specimens', *Micron*, 30 (1999), 277-288. For applications of FIB sample preparation in conservation science see also N. Groot, J. Dik, G. van der Kooij, P. F. A. Alkemade, V. G. M. Sivel, F. D. Tichelaar, 'Dark and Shiny: The Discovery of Chromite in Bronze Age Faience', *Archaeometry*, 48 (2006), 229-236.

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10 Oral information from *Porceleyne Fles*, Delft.