A peculiar emblematic still-life painting from Johannes Torrentius

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ART MATTERS

Introduction

One of the most enigmatic paintings of the seventeenth century is a still life in the collection of the Amsterdam Rijksmuseum. The painting is the only extant work of the infamous artist Johannes Torrentius (Jan Simonsz. van der Beek, Amsterdam, 1589-1644 Amsterdam). The painting is on a round oakwood panel with diameter of approximately 52 to 50.5 cm, and is signed and dated: *T.1614*.[1] On the circular panel we see closely placed together on a shelf, a flagon, a wine glass and a stone water jar, with above them a horse's bridle, and with two white clay pipes lying on either side of the wine glass. The glass stands on a piece of paper with musical notations and an inscription, which reads '*ER+ wat bu-ter maat be-staat, int on-maats qaat ver-ghaat*' (fig. 1).[2] The painting has been associated with an emblem in Roemer Visscher's *Sinnepoppen* of 1614 (fig. 2).[3] This emblem shows a similar flagon, glass, and a jar with the motto '*Elck wat wils*'. The emblem and the motto are meant to convey the virtues of *temperantia*. The wine from the flagon is diluted in the glass with the water from the jar, so that each person -'*elck*'- could mix it to his own measure or wish: '*wils*'.[4]

Fig. 1 Torrentius, *Emblematic Still life with Flagon, Glass Jug and Bridle*, round panel approx. 51 cm, signed and dated: T. 1614 Rijksmuseum Amsterdam (inv. no. SK-A-2813)

A similar message is conveyed in the inscription on the painting, which is written as if it were put to music: '*maat*'. Its meaning can be taken as: 'That which is outside *maat* - measure, or immoderate behaviour, behaviour which is literally out of time in the musical sense - will perish in *on-maats* - untimely, unmeasured - and so extreme *quaat*, evil', or 'That which exists beyond measure, will perish in evil beyond measure', indicating that immoderate behaviour will be immoderately punished. The objects on the painting support this message in that they present an allegory of temperance or moderation.

Torrentius

Johannes Torrentius (fig. 3) had a reputation as a '...seducer of the burghers, a deceiver of the people, a plague on the youth, a violator of women, a squanderer of his own and others' money...'[5] He had an eventful life; rose to great wealth, was interrogated, severely tortured, and tried.[6] His erotic pictures, some of which depicted masterful nudes in mythological settings and are now known only through literary sources, were publicly burnt (fig. 4).[7] At his trial a death sentence by burning at the stake was called for, but eventually Torrentius was sentenced to 20 years imprisonment for 'his atheism, abominable and awful blasphemy, together with his shocking and harmful heresy.' After two years he was released from

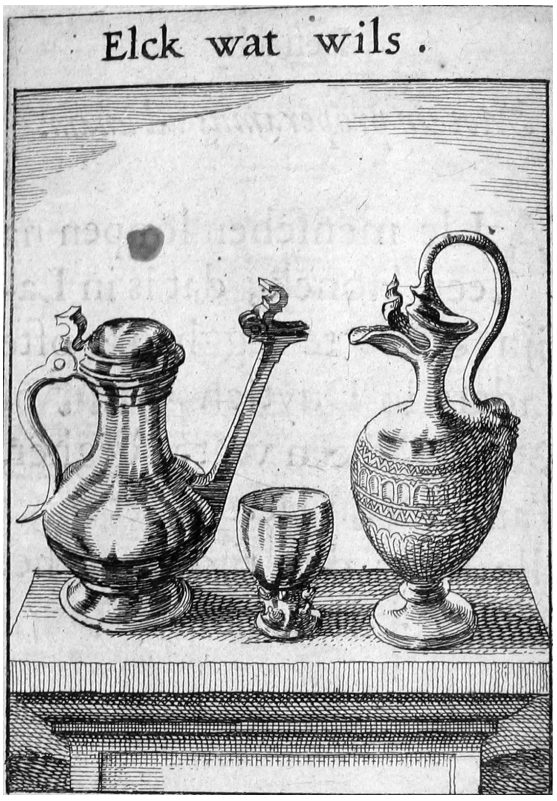


Fig. 2 Print: 'Elck wat wils', in Roemer Visscher: *Sinnepoppen*, (Amsterdam,1614) (RMA inv. 325 G 12)

prison through the intervention of King Charles of England and appointed court painter.[8] His stay in England may not have been entirely successful since: 'giving more scandal than satisfaction he returned to Amsterdam...'[9]

Torrentius was also as a painter very remarkable. The peculiarity of his working methods was repeatedly stressed, by himself as well as by his colleagues. Descriptions of Torrentius' technique by his contemporaries are marked by comments on the particular compelling rendering of physical objects and by observations about transparency. Suggestions have also been brought forward about Torrentius' possible use of the camera obscura. Constantijn Huygens was puzzled by Torrentius' methods and wrote that Torrentius: 'tires the inquisitive minds, as they are searching in vain, in what manner he used colours, oil - and if the Gods may wish - also brushes.'[10]
During his trial witnesses testified that Torrentius had a peculiar manner of painting. This was confirmed by Torrentius' own statement during the interrogations in which he declared: '...that he paints with other paints

Fig. 3 Johannes Torrentius (1589-1644), print by Jan van de Velde, Haarlem Municipal Archive

Fig. 4 *Couple making love*, etching on blue paper, 225 x 163 mm, signed: Torrentius f.., Printroom Rijksmuseum Amsterdam (inv. no. RP-P-OB-47.335), attributed to Johannes Torrentius

than all other painters, and therefore also works with these in a different manner than other painters.'[11]
As the peculiarity of Torrentius working methods are stressed over and over again in modern art historical literature, by Torrentius himself, as well as by his contemporary colleagues, the technical aspects deserve further investigation. The restoration of the painting provided a good opportunity for a technical examination.[12]

Technique

Camera obscura
In spite of the overwhelming attention expressed in a vast amount of literature on Torrentius, many questions about his working methods remain unresolved. Various suggestions have been brought forward about Torrentius' possible use of the camera obscura.[13] Some authors have even gone as far as calling Torrentius the first photographer, which has led to lively disputes, especially in periodicals such as *Het Vaderland*, *Lux*, and *Photographische Korrespondenz*.[14] It is remarkable that many of these discussions, solely based on historic documentary evidence, took place around 1910, i.e. before van Riemsdijk published in 1915, the only known painting by Torrentius still in existence. Others have been more reluctant [15], or even excluded the very possibility as wild speculation.[16]
To address this question beyond scholarly conjecture, it would be necessary first to tackle the question of technological developments in the optics and the accessibility of these technologies. Could Torrentius theoretically have known about the existence of such a device? If he had used the camera obscura, he would most likely be the very first painter to use this device after Johannes Kepler's description of it in his *Ad Vitellionem Paralipomena* of 1604. That would make the painting not only a puzzling, but also outstanding work of art, and at the same time a landmark in the history of science.

History
The camera obscura had found earlier description in Daniele Barbaro's *La Pratica della Perspettiva (molto profitterole a pittori scultori et architetti)*, published in 1569, in Venice. Barbaro described a camera obscura immobilis with the use of a bi-convex lens and a diaphragm.
Already in 1558 Giovanni Battista della Porta in Book 17, chapter X of his *Magia Naturalis sive Miraculis Rerum Naturalium*, claimed to have been the first to have used a concave lens in a camera obscura.[17] Della Porta's *Magia Naturalis* (1558 and 1589) consisted largely of recipes and experiments in medicine, the crafts, optics and 'other secrets of nature.' In this respect it was quite similar to that other famous craftsman's handbook, the *Secreti* (1555) of Alessio Piemontese. Much of the contents of the *Magia Naturalis* seems to originate from meetings of the 'Academia Segreta' that Girolamo Ruscelli helped to organise in the 1540s. This Accademia must have been an exciting and lively meeting point where no one was admitted: 'unless he had discovered some new secret of nature useful in medicine or the mechanical arts and beyond the level of ordinary comprehension.'[18] Della Porta was together with the Dutch physicist Joannes Eck (1577-1620) involved with the founding of the famous 'Accademia dei Lincei', where Galileo featured as inventor of the telescope. Della Porta wrote his book in Latin, hence not for a popular audience. Yet his *Magia Naturalis* appeared in more than twenty Latin editions. It was published in 1560 by Christopher Plantin in Antwerp, and saw more than fifty editions in the sixteenth and seventeenth century. As the *Magia Naturalis* was very popular, widely distributed and rapidly translated into Italian, French, German, English, and Dutch it seems quite possible that Torrentius could have had access to this development.[19]
Della Porta explicitly described the camera obscura as a tool for painters. It was of course the introduction by Della Porta of a bi-convex lens that would make the camera obscura actually applicable in the painter's workshop. The old conventional camera obscura with only a pinhole could give a reasonably crisp image but often the admitted amount of light was very low, resulting in a rather dark image. The sharpness of the image is dependent on the diameter of the pinhole. Increasing the amount of light by making the pinhole larger, resulted in less sharpness. The introduction of a lens made it for the first time possible to use higher light levels while at the same time maintaining a sharp image. A diaphragm made it possible to find the right balance between sharpness and brightness, and to reduce to some extent the effects of the flaws, such as spherical aberration or stray light, that the early lenses had.
Daniele Barbaro described with obvious pleasure the working of the new optical device:
'Having made a hole in the window of the room from where you wish to observe, as large as a glass of a spectacle, then take an old man's glass, that is one that is convex on both sides, not concave, like the glasses of youths that have short sight, and when the glass is fixed in the hole, shut all the windows & the doors of the room so that no light may enter, except the light that comes in through the lens. Now take a sheet of paper and place it

Fig 5 Reconstruction of the still life set-up in front of an old camera obscura

Fig. 6 The image of the still life reconstruction as projected by the seventeenth-century camera obscura

in front of the glass at such a distance that you see in great detail on the paper, everything that is outside the house. This takes place most distinctly at a determinate distance, found out by bringing the paper nearer to or farther from the glass till you have found the most convenient position. Here you will see the images on the paper as they are, and the gradations, colours, shadows, movements, clouds, the rippling of water, the flight of birds, and everything else that can be seen. For this experiment the sun must be clear and bright, because the sunlight has great power in bringing out the images. When it pleases you to make the experiment you should choose the glasses which do best, and should cover the glass so much that you leave a little of the circumference -192 // 193 - in the middle, which should be clear and open, and you will see an even more lively effect. Seeing therefore, on the paper the outline of things, you can draw with a pencil all the perspective that appears on it, and the shading and the colouring, according to nature, holding the paper in place till you have finished the drawing.'[20]

It is of course rather difficult to hold the panel in focus in an upright position while painting. It would be much easier if the panel would lie on the table and the image could be projected on it. Making use of a mirror, together with a careful adjustment of the position of the lens and the height of the table to make the level of the panel coincide with the focal plane, could make this perfectly possible. The mirror would also invert the projected 'reversed' image, so as to allow a 'normal' view of the subject while tracing or painting it.[21]

Torrentius, Huygens and the camera obscura

Constantijn Huygens excitedly reported the miracles of the camera obscura: '...the other instrument of Drebbel, which gives admirable painterly effects in a dark room, of which it is not possible for me to describe the beauty of it in words to you. All of painting is captured in it, as if it's life itself, or something of a higher order, as if it were only lacking words. That is because the contours and the movements of the figure are encountered in it in a most natural and greatly pleasing manner. The De Gheyn's enjoyed it tremendously.'[22] At the time (April 13, 1622) when Huygens wrote this letter, Torrentius already may have been fully aware of the possibilities of the camera obscura. This may explain the rather sour remark of Huygens that Torrentius faked interest in his camera.

Torrentius approached Huygens in a friendly manner with the request if he could see the camera obscura that Huygens had obtained in London from the Dutch inventor Cornelis Drebbel on his return from England to the Netherlands.[23] Huygens explicitly stated that this instrument was demonstrated to great pleasure of the painters: 'cum oblectatione pictorum utebar.' On that occasion Torrentius feigned ignorance about a development that at that time in some circles apparently was common knowledge: 'in re nulli non hodie manifesta.' Huygens called it 'purposeful deceit especially with regard to this invention, as he had given every effort to pretend that he did not know anything about it.' Because of this attitude both Huygens and his friends, the painters De Gheyn, presumed that the quality of Torrentius' paintings was to a very large extent dependent on the use of the camera obscura, and that the purported ignorance was in fact an attempt to conceal the tricks of his trade. If Torrentius did indeed use such an instrument in our still-life painting, this would indicate that the application was well developed prior to 1614, and therefore long before Huygens may have seen Drebbel's instrument in London in 1622.

Whatever the precise date of introduction of the camera obscura, the flexibility of the instrument must have been limited.[24] The focal length of the lens was rather short and maximum depth of field was impossible to achieve. If the lens was stopped down with a diaphragm to increase the depth of field, much light was kept out and the image became too dark to discern, and even less to work from. A limited depth of field therefore also put severe limitations on the subjects that could be recorded with it, and still life settings with narrow focal planes could be the subjects of choice.
The painter Joachim von Sandrart gave in his *Teutsche Academie* a detailed account of Torrentius' special ability in the depiction of such settings: '...he made many beautiful pieces, and has chosen a peculiar way of life, also specialised mainly on still life pieces, open and closed books piled up on each other, hour-glasses, pens, ink jars and all sort of things on tables...' Objects that went beyond these limitation may have been much harder to record, as Sandrart states about Torrentius' pornographic paintings that: '...apart from these still life paintings I have not seen anything special from him, but quite a lot of pictures of naked women, quite brutal and indecent,

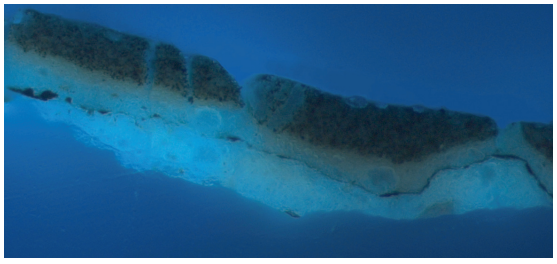
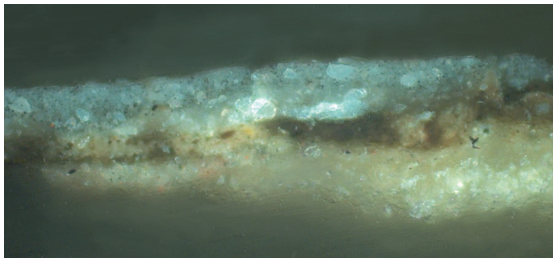


Fig. 7 Paint cross-section (5/4) of sample from the writing on the cartellino shows a very simple build-up of paint layers. UV fluorescence, magnification 1000 x



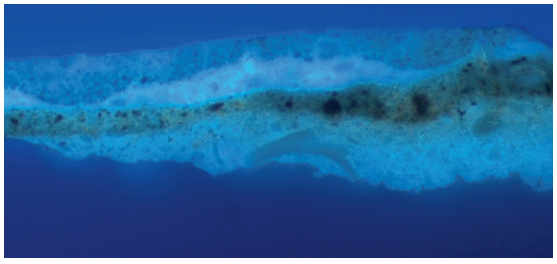


Fig. 8 Paint cross-section (5/1) of the paint for the pewter flagon
a. Direct incident light, bright field illumination, magnification 500x
b. UV fluorescence

and therefore not deserving any praise.'[25] From this judgement it is unclear whether these paintings were in a morally or in a painterly manner of bad quality.
The use of the camera obscura may also give another explanation for the reported fact that Torrentius (according to Huygens' and Sandrart's descriptions) was very good at painting still lifes, but that his painting of figures was considerably less convincing. A projection of a life person would have to be recorded in one single session. After a break in that first session it would be impossible to recreate exactly the same situation. A still life set-up, by its very nature remains the same and could be worked on in several sessions. With the limited depth of field it seems significant that all objects in Torrentius' still life are placed in a row on the same focal plane. No recession in space is visible. Torrentius' images also have a certain assuredness, and a strong similarity between the darker shades and shadows on the objects represented in his painting and the shadows on the object itself. Huygens was convinced that this similarity could only have been produced through the use of this device: 'This suspicion is until now confirmed by the close similarity of Torrentius' painting with these shadows, as well as by the "undisprovable, the certitude", which is attributed to him, of his art compared with the real shape of the object, about which all spectators agree in every respect.'[26]
The image that is projected by the camera obscura is circular, and thus a circular - like Torrentius' still life -or square format would make the best use of the amount of image rendered by the camera.[27]
In spite of all the shortcomings that the early seventeenth-century camera obscura had, it seemed to have been an instrument that could be of great use in the painter's studio. Instead of asking ourselves if Torrentius may have used it, we may rather wonder with Huygens, why the other painters at that time did not: 'And I cannot be more astonished, through what negligence painters until now have disregarded or are ignorant about a device that can be pleasant as well as useful to them.'[28]

A reconstruction

We know that in Torrentius' time knowledge on the camera obscura was accessible through the literature, and that Torrentius knew from the instrument through Huygens' demonstration, and probably even before that occasion. To find out whether it was indeed possible to make a painting with the lenses available in the seventeenth century we built a reconstruction of the still life setting with a flagon, a glass and a jug. With a small portable camera obscura, most likely dating from the seventeenth century (collection Groningen University Museum), some preliminary observations were made. These findings were basically confirmed by later observations performed with a camera obscura that probably dates from the eighteenth century (fig. 5).[29] The image produced showed remarkable similarities with features on Torrentius' painting.
The way in which we see objects in the camera obscura is rather different from the way we see them naturally. The glass lens placed between objects and their representation on the screen or panel, intercepts the rays of the reflected light, which results in relatively dark shadows.

Seventeenth-century lenses had various shortcomings. Straight lines projected with these lenses become slightly curved at the edges of the image.[30] Examination of the painting with infrared reflectography revealed the presence under the paint layers of lines drawn along a straightedge. These lines obviously served to make up for this optical deficiency.
Another serious problem was caused by flare: light coming from the side and hitting the curvature of the lens at an angle causing light fogging which resulted in the spreading of the light across the visual image and thus a reduction in contrast and definition. This effect is further enhanced by the spherical aberration of the simple bi-convex lenses of the time, causing a lack of sharpness and an overall softening, even in the principal plane of focus. The presence of air bubbles, which are always present in seventeenth-century glass, will have exacerbated this problem. This effect is most prominent in lighter coloured areas or in highlights on darker objects. The most essential features of Torrentius' painting, the highlights on the ewer and the jug, are remarkably soft and blend smoothly with the darker tones. Also the highlights of the glass have a 'soft-focus' appearance (fig. 6).
The reconstructed camera obscura image and Torrentius' still-life painting share similar features: an intensified rendering of light and dark with brilliant highlights and rich shadows. Together with this increased tonal contrast we observed a softening of contours and a decrease in colour contrast.

Materials

The painting is in execution and style quite different from other still life paintings that were produced at the time. A comparison with still life paintings by Torrentius' contemporaries Floris Claesz. van Dijck, Ambrosius Boschaert, Balthasar van der Ast, or Jacques de Gheyn, immediately shows a significant stylistic differ-

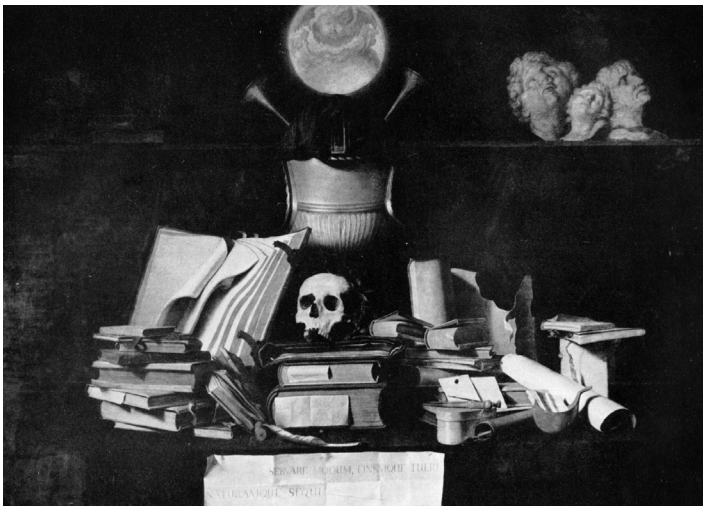


Fig. 9 *Vanitas Still Life*, oil on panel. 117.5 x 165.4 cm, signed and dated IDGheijn An. 1621, (Yale University Art Gallery, inv. no. 1957.36), made by Jacques de Gheyn in competition with Torrentius

ence. Meijer assumed that Torrentius achieved his results by applying glazes - layer upon layer of thin, transparent films of paint, giving delicate nuances.[31] In reality the number of layers appears to be rather limited. Examination of paint cross-sections, in the area of the writing on the cartellino showed a conventional calcium carbonate ground, a double application of lead white, and a layer of lamp black (fig. 7). The paint for the greyish metal of the flagon is build up of lead white mixed with lamp black to a cool grey over a lighter mixture and some bone black, applied over a tan calcium carbonate ground (fig. 8). The painting technique seems to be in direct relation to the 'photographic' way the image was recorded.

Contemporary comments

Descriptions of Torrentius' technique by his contemporaries are marked by remarks on its transparency. Huygens used the expression '*bijna doorschijnend*': almost translucent. Similarly Michel le Blon stressed this aspect in Torrentius' paintings. He writes that:' at the work neither beginning nor end could be seen, so that it seems to be washed or painted like a mist.' From his description it is not clear whether he discusses a still life or another genre. This particular 'transparent' kind of painting was not exclusively used in still-life paintings. During the interrogations of witnesses for the trial, doctor Jacob Hoogenheym recorded having seen a painting by Torrentius of Adam and Eve: '...in the shapes they have had, so in stature, length and resemblance of their being. And this translucent like glass so that all the limbs could be seen and recognised from the inside as well as from the outside, and this was transparent in all things and appearing as if of a substance that cannot decay or be burnt.'[32] Huygens was of the opinion that Torrentius painted in a miraculous way and that: '...not easily would a man stand up who would represent glasses, earthenware and tin or iron things, almost translucent, through the power of the brush.' It is almost as if Huygens is actually describing the still life in the Rijksmuseum.

Torrentius must have applied his paints in such a way that brush strokes were no longer visible. Forms became shapes with imperceptible transitions. Highlights blended into darker areas without any demarcations. This was a manner of painting that could not easily be imitated. However, this praise for Torrentius led to much irritation with his contemporaries. So much so that this exaggerated fame aroused the jealousy of the established artist Jacques de Gheyn, who challenged Torrentius for a contest in painting skills. At the end of his life De Gheyn offered a painting for comparison; a work, which is generally identified with, the large *Vanitas Still Life* with books surrounding a skull crowned with a laurel (Yale University Art Gallery, inv. no.1957.36), (fig. 9).[33] The Latin inscription on the cartellino SERVARE MODUM FINEMQUE TUERI NATURAMQUE SEQUI, 'Observe due measure, look to the end, and follow nature', appears to be a direct comment on Torrentius' inscription in the vernacular on moderation as 'maat'.[34] De Gheyn's friend Huygens, diplomatic even when addressing himself, refrained from giving a final judgement, saying that he did not see the two paintings together. In de Gheyn's paintings there was, according to Huygens' comment, nothing of which the manner and method could not be recognised by connoisseurs. There was nothing supernatural in De Gheyn's art. Torrentius on the other hand, 'tires the doubtful minds, as they are searching in vain, in what manner he used colours, oil - and if the Gods may wish - also brushes.' Similar comments can be found in Sandrarts description of Torrentius' depictions of still life objects like curtains '...and other things, painted so industriously, cleanly and smoothly and strong, that his art almost had its origin in nature itself, and that next to his paintings no others could stand up in the comparison, and that therefore they were considered miracle things that fetched high prices.'[35] Le Blon argued in 1635 that Torrentius painting was: 'by some of the most prominent painters, not unjustly considered a work of magic, for which there is no comparison in the world.'[36]

According to a popular pamphlet published in 1628 on the occasion of the trial, this miraculous aspect of his

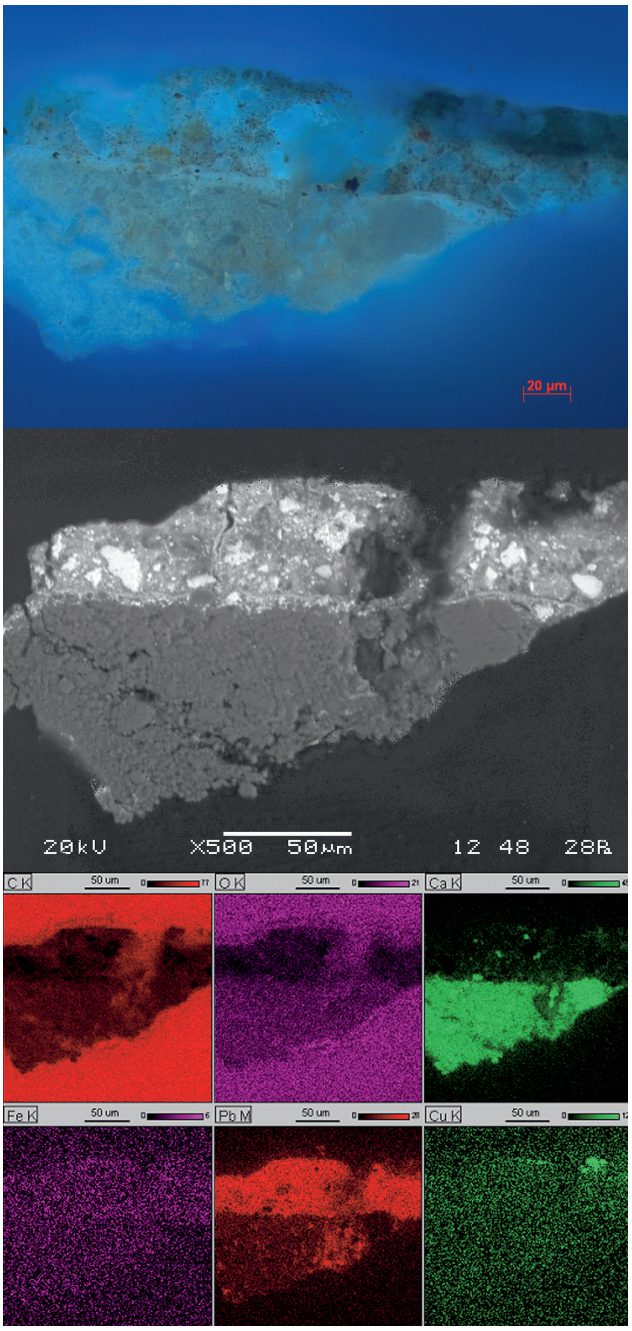


Fig. 10 a. Paint cross-section (5/2) from the green wine glass in Torrentius' *Emblematic Still Life*. magnification 500x, UV fluorescence
b. Scanning electron micrograph of the same sample, magnification 500x
c. Spectral images showing the elemental distribution for C, O, Ca, Fe, Pb, and Cu in the same paint cross-section

technique added to the suspicion and may eventually even have contributed to his conviction: 'Finally he is charged with what seems to me a sort of magic. That he could paint without an easel or brushes, in a new manner, yes that he would lay his panels on the floor. And then, from out of his prepared paints, there comes a sweet sound, right above the panel. As if a swarm of sweet bees were humming and singing, or similar melodies.'[37]

This refers to the statement made in the context of the trial by a witness, Doctor Jacob Hogenheym, with whom Torrentius had corresponded. Hogenheym testified that Torrentius had a manner of painting that involved laying his panels flat on the floor and arranging his paints to blend in such a way that it produced a sizzling, buzzing or hissing sound similar to that of humming bees. This statement was confirmed by Torrentius during the interrogations: on the question whether he had refused to buy ordinary paints on one occasion on the grounds that he had a different way of making paintings, Torrentius declared: '...that he paints with other paints than other painters, and therefore also works with these in a different manner than other painters. That he sometimes had to lay the panels flat on the floor so that the paint would blend flat on the panel, from this mixing or combining of the paint often arises a sound or a buzz, that finally ends when the paint has taken. But if he uses paints like other painters, he would also use easel and brushes.'[38]

Apparently Torrentius practiced, besides his special method, also the ordinary methods of painting whenever there was a specific need or request. This may explain the rather obscure line in his letter of 17 February 1620 to Doctor Jacob Hogenheim: '...as I would not dare to risk Judgement on the fundamentals of my Art, since Your Honour does not appreciate it, in this case I will make do with the means that are commonly used...'[39] Torrentius' methods must have been rather dangerous. In fact, so dangerous that he did not need to lock the doors of his studio. The noxious fumes in his workshop would be sufficient to keep any intruders out: '...declares having said that if he prepares and contrives certain paints, there is such a deleterious vapour in the room that a person could not stand to remain there, staying healthy. Therefore the room would not need to have a lock on those occasions because the bad fumes would be sufficient to keep people out...and if he then quickly had to go into the room, he would plug his ears and nose to escape from the noxious vapours.'[40] The fumes he sometimes produced were not only toxic but also flammable or explosive. One night, Torrentius had to interrupt a ses-

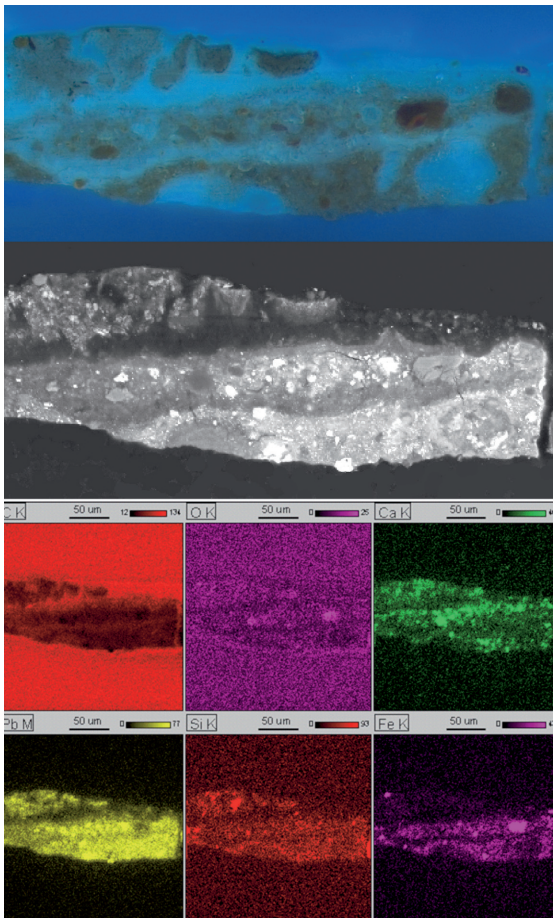


Fig. 11 a. Paint cross-section (5/6) from the foot of the earthenware jug in Torrentius' *Emblematic Still Life*. magnification 500x, UV fluorescence
b. Scanning electron micrograph of the same sample, magnification 500x
c. Spectral images showing the elemental distribution for C, O, Ca, Pb, Si and Fe in the same paint cross-section

sion with his friends: 'I have to be at home in time because if I would not pay attention to it, my attic and roof would catch fire as if a small barrel of gunpowder would ignite.'[41]

Technical investigation

Prior to conservation the painting was examined with the stereomicroscope, infrared reflectography and x-ray. Also a number of small paint samples were taken. Identification of the pigments with polarised light microscopy (PLM) indicated the presence of fairly common pigments: the samples contained calcite, lead white, verdigris, yellow and red ochres.[42] Some of these identifications were confirmed with x-ray diffraction (XRD) analyses.[43] Examinations of the paint cross-sections under the light microscope showed that these pigments were applied in very thin paint layers with a simple stratigraphy.[44] On top of the ground only a few layers and occasionally just one single layer of paint was found in each cross-section. These layers were further examined with the scanning electron microscope (SEM-EDX).[45] The elements analysed in the individual paint layers were in line with the previous identifications. The analyses of the cross-sections indicated fairly large amounts of lead in all paint layers.

However, these inorganic analyses did not resolve the question of Torrentius' unusual technique as the pigments that Torrentius used were clearly not different from those used by any other Dutch seventeenth-century painter (figs. 10-11). Therefore, the significant difference between Torrentius' methods and those of his contemporaries should be sought in the binding medium. For the identification of the binding medium, direct temperature resolved mass spectrometry (DTMS) was used.[46]

In recent years DTMS, most often applied in the study of biologic materials, has found use in the study of carbohydrate and oleaginous binding media as well as tri- and diterpenoid resins and their mechanisms of decay in painted works of art.[47] [48] [49] Chemical ionisation/MS techniques have also been applied in the study of flavonoid colorants.[50]

This analytical technique was chosen because it is the most sensitive method for media identification presently available. For some compounds like polysaccharides or fatty acids its detection limits are well below that of Fourier transform infrared spectroscopy (FTIR) or gas chromatography (GC). DTMS allows rapid analyses of both volatile and polymeric components of a paint sample in one analytical run.[51] With this method the presence of a drying oil such as linseed oil, walnut oil or poppy seed oil would be indicated by peaks for the most

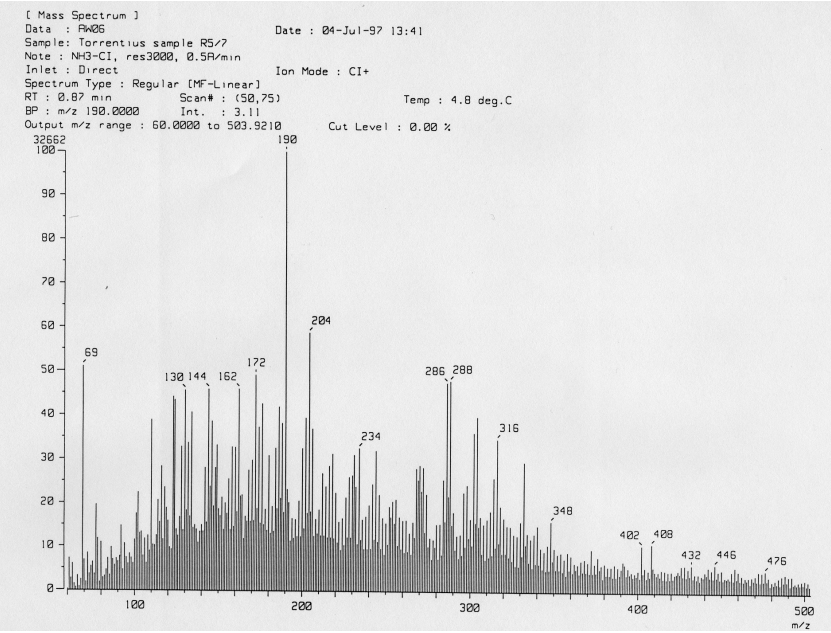


Fig. 12 Chemical ionisation- direct temperature resolved mass spectrum of paint sample (5/7), mass spectrum obtained under NH_3/CI conditions shows sample components often as $[M+NH_4]^+$ ions and $[M+H-H_2O]^+$ ions

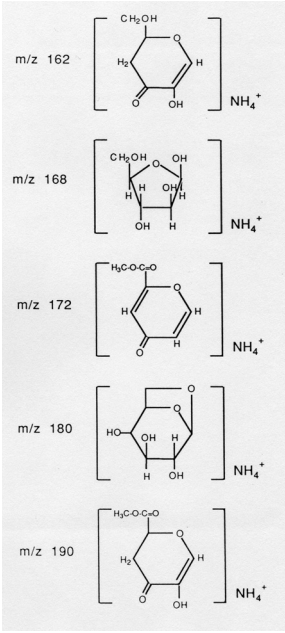


Fig. 13 Structures of pectic components as found in the paint sample

important fatty acids such as palmitic acid (C16:0, m/z 256) and stearic acid (C18:0, m/z 284). No indications for the use of any oil medium or for the use of a proteinaceous tempera (such as parchment glue, glair, gelatine or egg) could be found.[52] Not any of the common seventeenth-century paint media appeared to be present.

It was decided to use the mass spectrometer in a different mode. This time we made use of the selectivity and gentler ionisation that the ammonia chemical ionisation method can offer.[53]

To our surprise, mass spectrometry now indicated the presence of pectin substances, carbohydrate molecules linked through homogalacturonan chains.[54] We found the presence of sugars like rhamnose (m/z 146), linked through chains of galacturonic acid (m/z 132) and galacturonic acid methyl esters (m/z 172, 190, 226) (fig. 12). Through these links the pectin molecules form aggregates and gels, the most important components of which are: D-galactose, L-arabinose, D-galacturonic acid, D-glucuronic acid. The hexose sugars D-glucose, and D-galactose are commonly found in higher plants. These sugars may oxidise to other components. The oxidation product of glucose at carbon 6, for instance, is D-glucuronic acid, a common constituent of gums. D-galacturonic acid, which arises from the oxidation of galactose at carbon atom 6, is a component of pectin and of gums and as such a widespread plant product.[55] The derivatives of polygalacturonic acids are pectic substances, the gelatinous principle of plants (fig. 13). Pectins are neutral, water-soluble substances obtained from plant or fruit extracts. These sugars may eventually also dry up to an insoluble substance. This property has troubled painters in the past, as becomes evident from a sixteenth century recipe: 'This Gumm Hederae is the same that Gum Ivye is...put it into a little glass stopping it close, and so keep it from drying, for if it be once dry it is nought...'[56]

The reasons for the presence of these pectic substances in the paint are not yet clear. If they were used to provide a stable insoluble binding medium, then there seems to be only one possible pathway to accomplish this. Pectins may be hydrolised or de-esterified quite rapidly in a mildly alkaline solution and then precipitated as the calcium salt. Because of its great number of free acid groups, pectic acid is readily precipitated by calcium and other polyvalent cations, which act to stabilise the intimate association of the individual chains. Addition of Ca ions to a solution of pectic acid results in the immediate formation of a rigid Ca pectate gel.[57] The action of Ca^{2+} is not specific, but replaceable by Ba^{2+}, Sr^{2+}, and other polyvalent cations. These sugars may also precipitate with lead salts.

In such a construct Torrentius would initially have used paints that consisted of common pigments suspended in a pectic binder. This would give him a smooth paint with good working properties.[58] The next step would then have been the conversion to pectic acid and its pre-

cipitation into an insoluble complex with Ca or Pb ions. The crucial step in the transformation of the hexose sugars may have been the esterification with an acid. The action of this acid, which in dissolving some of the Ca ions out of the chalk ground, would then have produced an effervescence that could be interpreted as: 'a sweet sound, of sweet bees humming and singing, right above the panel'. Once this sound had stopped, the paint would have 'caught', i.e. the pectic acid medium would have hardened into an insoluble rigid complex: a fixed paint layer.

Conclusion

We seem to have learned a bit more about Torrentius' peculiar technique. The flurry of circumstantial, anecdotal evidence around Torrentius and his working methods appears to carry a lot of weight. Analytical and reconstructive work has shown that legal testimony; hearsay, gossip and documentary evidence, may yield valuable insights into peculiar technical aspects of historical reality. Many aspects on the identity, working properties and use of binding media in seventeenth-century painting are still poorly understood. Convincing reconstructions with seventeenth-century camera obscura's have led to a better understanding of Torrentius' working methods. His still life may well be the first seventeenth-century painting that was ever made with this instrument. However, a fair amount of, mainly reconstructive, experimental and analytical work still needs to be done before all the questions will be fully resolved.[59]

One nagging question remains. Is the painting really made with a carbohydrate-based medium, or are the sugars we identified just remnants from the time that the painting served in a grocery shop in Hengelo, supposedly as the lid of a raisin-barrel?[60]

Notes

1 P. van Thiel et al., *All the Paintings of the Rijksmuseum in Amsterdam*, A completely illustrated catalogue, (Amsterdam, 1976), 543, inv. no. SK-A 2813.

2 *Stilleben in Europa*, [exhib. cat. Westfälisches Landesmuseum für Kunst und Kulturgeschichte Münster, and Staatliche Kunsthalle Baden-Baden], U. Bernsmeier, C. Klemm, J. Lammers, G. Langemeyer and G. Luther eds., (Münster, 1979), 172, 178-179, 205-206, and 575. (The attribution on pp. 205-206 in this publication of a still-life painting from a private collection to Torrentius seems rather improbable.) The meaning of the two capitals and the cross at the beginning of the inscription: 'ER+', has puzzled many scholars. Some assume that it alludes to a possible association of Torrentius with the Rosicrucian movement: ER+ = Eques Rosae Crucis. See J.L.A.A.M. van Rijckevorsel, 'Johannes Torrentius, Rozenkruiser en Schilder', *Historisch Tijdschrift*, XIV (1935), 323-330.

3 Roemer Visscher, *Sinnepoppen*, (Amsterdam, 1614) (4° obl.), with 52 prints by Cl. J. Visscher, (RMA inv. no. 325 G 12).

4 E. de Jongh, *Zinne- en minnebeelden in de schilderkunst van de zeventiende eeuw*, Nederlandse Stichting Openbaar Kunstbezit en Openbaar Kunstbezit Vlaanderen, (Amsterdam, 1967), 56-59.

5 T. Schrevelius, *Beschriving der Stad Harlem*, (Haarlem, 1645), 445.

6 S. Ampzing, *Beschryvinge ende lof der stad Haarlem in Holland… Mitsgaders Petri Scriverii Laure-kranz voor Laurens Koster*, Adriaen Rooman, (Haarlem, 1628), (RMA inv. no. 328 M 2). To bring him to a confession Torrrentius was severely tortured. His shinbones were first clamped in irons. Then his hands were tied behind his back and he was hung on his arms with several weights pulling at his feet. Next the executioner and his assistant pulled his legs with all their might. This not being enough, two other men were called in to assist in pulling till his limbs would separate, '…dat hy ten tijde als hy den voorsz. Torrentium soude pynigen, hem eerst het wafelijser op zijn scheen gestelt, ende tselve wel vast toegeschroeft hadde, dat hy hem alsoo voorts de gewichten aen syn beenen hangen ende de handen achterom gebonden met hulpe van Pieter Soenen een van des Heers Officiers dienaers, hadde opgetrokken, soo sterck en veel zy met heur beyden konden…; datte voorsz. Heer Officier daerop buyten camer was gegaen ende noch twee andere zynder dienaers binnen geroepen hadde, dat zy alsdoen met hun vyeren den voorsz. Torrentium hadden opgetrokken sooveel als sy konden, ende hem alsoo een tijt langh laeten hangen…Doch dat met sulcke fortse ende geweldich trecken als den voorsz. Torrentium aengedaen was, de leden nootsaeckelycken vuyt malcander mosten', citation from legal records in A. Bredius, *Johannes Torrentius schilder, 1589-1644*, Martinus Nijhoff, ('s-Gravenhage, 1909), 46.

7 A reference in the State Papers of Charles I, vol. 155, no. 75, in the Public Record Office mentions his 'other bawdye pictures' on show in the Haarlem city hall. They are rather prudently described as: '…an Adam and Eve, his fleshe very ruddy, theye show there syde faces; The other is a woman pissing in a man eare; The best of these 3 is a young woman sitting somwhat odly with her hand under her legg'. Cited in Bredius 1909, 9.

8 The eventful life of Torrentius is amply described by Bredius 1909. Also see: C. Brown, 'The Strange Case of Jan Torrentius: Art, Sex, and Heresy in Seventeenth-Century Haarlem', in *Rembrandt, Rubens and the Art of their Time: Recent Perspectives*, R.E. Fleischer and S.C. Scott eds., vol. XI of *Papers in Art History from The Pennsylvania State University*, (Pennsylvania, 1997), 224-233, and A.G. van der Stuer, 'Johannes Torrentius', *Spiegel Historiael*, 2 (1967), 217-224, especially 256.

9 H. Walpole, *Anecdotes of Painting in England*, 5 vols. 1826-1828, vol. 2 (1826), 241-242., cited in Brown, 229.

10 J. A. Worp, 'Constantijn Huygens en de schilders van zijn tijd', *Oud Holland*, 9 (1891), 106-136, 132.

11 See note 10, also Constantijn Huygens, *Mijn Jeugd*, translation and introduction C.L. Heesakkers, (Amsterdam, 1987), 91.

12 The restoration was done by M. Zeldenrust, head of the department of paintings conservation, Rijksmuseum Amsterdam from 1993 through 1994. To assist in the decision making for the treatment, in November 1993, a number of paint samples were taken and cross-sections were investigated by K. Groen, conservation scientist at the Netherlands Institute for Cultural Heritage, (ICN) in Amsterdam.

13 B.W.F. van Riemsdijk, 'Een Schilderij van Johannes Torrentius', *Feestbundel Dr. Abraham Bredius aangeboden den achttienden April 1915*, (Amsterdam, 1915), 243-249, 97; A. Bredius, 'Joh. Symonsz. Torrentius (een nalezing)', *Oud Holland*, XXXV (1917), 219-223. W. Bernt, *Die Niederländischen Maler des 17. Jahrhunderts*, vol. III, (Munich, 1948), no. 839.

14 This suggestion was first put

forward -solely on the basis of documentary evidence- by A.P.H. Trivelli, 'Johannes Torrentius, 1589-1644', *Lux*, XXI (1910), 1-16. The argument was repeated in A.P.H. Trivelli, 'Johannes Torrentius, 1589-1644', *Photographische Korrespondenz*, XLVII (1910), 1-18. Also W.H. Idzerda, 'Ist der Holländische Maler Johannes Torrentius der Erfinder der Photographie?', *Photographische Korrespondenz*, XLVII (1910), 117-123, and 269-271. Even after the 1915 discovery of the only extant painting by Torrentius the debate continued: G.A.Evers, 'Johannes Torrentius, 1589-1644, Kunstschilder of fotograaf', *Lux*, XXXI (1920), 5-6, and 277-278.

15 H. Schwarz, 'Vermeer and the Camera Obscura', *Pantheon*, XXIV (1966), 170-180, especially 177.

16 F.G. Meijer, 'Johannes Torrentius, *Emblematic Still Life with Flagon, Glass, Jug and Bridle, 1614*', in *Dawn of the Golden Age, Northern Netherlandish Art 1580-1620*, G. Luijten et al. eds., [exh. cat. Rijksmuseum, Amsterdam] (Amsterdam, 1993), 605-606. A.M. de Wild, *De Schildertechniek van Johannes Torrentius*, (s.l., 1934), 4: 'If one would simply repeat such an experiment, it would show that such an assumption is nothing but fantastic' (translation AW).

17 P.F. Liesegang, 'Die Camera obscura bei Porta', *Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften*, XVIII, no. 80/81, 1/2, (1919), 1-6.

18 W. Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture*, (Princeton NJ, 1994), 200.

19 Eamon 1994, 206.

20 Daniele Barbaro, *La Pratica della Perspettiva di monsignor Daniel Barbaro, eletto Patriarca d'Aquileia*, Opera molto utile a Pittori, a Scultori & Architetti, con privilegio in Venetia, Appresso Camillo, & Rutilio Borgominieri fratelli, al Segno di S. Giorgio, (MDLXVIIII), 192-193.

21 P. Steadman, *Vermeer's Camera: Uncovering the Truth Behind the Masterpieces*, (Oxford, 2001), 12.

22 Constantijn Huyghens as cited by Schwarz 1966, 177 (translation AW).

23 Huyghens wrote in his diary: '..studiosè me adiret (...) visendae quasi machinae speculatoriae gratia, qua rerum foris objectarum species in occluso loco candidae tabellae inducuntur' cited in Worp 1891, 131-136. The Dutch scientist Cornelis Drebbel, who gave Huygens the camera, spent the latter half of his life in England. He had studied with the painter Hendrik Goltzius, whose 'beautiful, but disreputable sister' he married. He appears to have been partly an engineer, part alchemist and wholly a magician. He constructed a submarine propelled by oarsmen, which made the journey from Westminster to Greenwich. He used the camera obscura to entertain his friends. See G. Tierie, *Cornelis Drebbel (1572-1633)*, diss. H.J. Paris, (Amsterdam, 1932); A.G.H. Bachrach, 'The role of the Huyghens family in seventeenth-century Dutch culture', *Studies on Christian Huyghens*, H.J.M. Bos, M.J.S. Rudwick, H.A.M. Snelders and R.P.W. Visser eds., (Lisse, 1980), 27-52.

24 A.A. Mills, 'Vermeer and the camera obscura: some practical considerations', *Leonardo*, 31/3 (1998), 213-218.

25 J. von Sandrart, *Teutsche Academie der Bau-, Bildhauer- und Maler-Kunst...*, Johan Andreas Endterische Handlung, (Nürnberg,1768-1775), II Hauptheil Bd. 6-8, vol. II, 306 (translation AW).

26 The note in Huyghens diary reads: 'Suspicionem hactenùs firmat hinc picturae Torrentij, cum his umbris proxima similitudo, tùm artis eius ad objecti veritatem το ανελεγτον, το, ut asserunt, ανελλιπεσ, de quo secum omni modo spectatores volunt', cited in Worp 1891, 136.

27 Steadman 2001, 21.

28 Huygens,: '...nec satis miror qua socordia tot pictores nostri jucundae sibi rei perindè atque utilis auxilium neglexerint hactenùs, vel ignorarint', cited in Worp 1891, 136.

29 We could not use the original lenses from the 1650s, ground by Constantijn and Christiaan Huygens, as these were specifically made for astronomical observations. Their focal lengths were too long to be of practical use in a camera obscura. A.C. van Helden and R.H. van Gent, *De Huygenscollectie*, Museum Boerhave, (Leiden, 1995). A.A. Mills and M.L. Jones, 'Three lenses by Constantin Huygens in the possession of the Royal Society of London', *Annals of Science*, 46 (1989), 173-182. The optical instruments were obtained through courtesy of Dr. Jan Deyman of the Utrecht University Museum. The camera obscura image was photographed by Peter Mookhoek, head of the photography department at the Rijksmuseum, Amsterdam.

30 Steadman 2001, 143.

31 Meijer 1993, 605-606.

32 A.J. Rehorst, *Torrentius*, W.L. & J. Brusse N.V., (Rotterdam, 1939), 155. For Le Blon see note 36.

33 Yale University Art Gallery, New Haven, Connecticut. *Vanity Still Life*. inv. no. 1957.36, oil on panel, 117.5 x 165.4 cm. This painting, formerly signed and dated IDGheijn An. 1621, is discussed by W. Valentiner, 'A Still-Life by Jacques de Gheyn', *Art Quarterly*, XVIII (1955), 159-162, and by D.O. Merrill, 'The 'Vanitas'of Jacques de Gheyn', *The Yale University Art Bulletin*, vol. 25, 3 (1960), 4-29.

34 The Latin modus, modulus can be translated in Dutch as 'maat', a word that may carry the meaning of 'measure', as well as of 'moderation'. In the cartellino on Torrentius' painting the musical notations also refer to the Dutch word 'maat'. The Dutch expression: 'de maat slaan', can be translated as 'beating time' in music. Unfortunately, the pun and the complexities of these connotations go lost in any translation. Also see Z. Herbert, *Still Life with a Bridle, Essays and Apocryphas*, (New York, 1991). P. Fischer, *Music in Paintings of the Low Countries in the 16th and 17th Centuries*, (Amsterdam, 1975), 56-63, noted that the misspelt word 'qaat', is placed beneath a B, which should be a B-flat if the music were to be playable. The witty pun of this *diabolus in musica* adds to the verbal play on words. In line with the musicological explanation, Fischer thinks that the letters ER+ on the cartellino should be interpreted as Extra Ratione.

35 Sandrart vol. II, 306 as cited in Rehorst 1939, 222.

36 Letter by Le Blon to the resident of Sweden, Petter Spiering Silvercron: '..also UE sin en vermaeck heeft in ongemeene, nette en uytgevoerde dinge, so en weet ick ter werelt niets dat hiery vergeleken mach worden, en niet t' onrechte bij eenige van de voornaemste schilders voor toverye geoordeelt. Want behalve de wonderlycke speculatien dieder bevonden worden daerinne geobserveert en uytgebeelt te sijn, so en siet men nerged eenige veheventheyt van verwen, begintsel noch eynde aent heele werck en schijnt mer gewassen off als eenen waessem daerop geschildert. Eyndelycken so en weet ick nu niemant, die wat van hem heeft, als den Coninc van England en UE', published by W. Martin, *Het Leven en de Werken van Gerrit Dou*, [thesis University Leiden, S.C. van Doesburgh], (Leiden, 1901), 43.

37 'Eyndelyck houd' den eisch noch in
Een specy van Toovery: naer dat ick bevin:
Als dat hy kan schilderen, sonder esel of Pinceelen
Op een nieuwe manier: jae dat hy syn Panneelen
Plat neer leyt op de vloer, en dat dan uyt
Syn gheprepareerde Verwen komt een soet geluyt
Recht boven 't Paneel; als offer een deel soete Byen
Hommelden en songhen, of diergelijcke melodyen.'

Fragment from a popular pamphlet: *Veers-Schuyts-praetgen tusschen een Coopman ende Leyenaar: over d'examinatie van Johannes Torrentius*, Printed for Willem Jansz. Wijngaert, 1628, 4, published by W.P.C. Knuttel, *Catalogus van de Pamfletten-verzameling berustende in de Koninklijke Bibliotheek, I.2: 1621-1648*, ('s-Gravenhage, 1889), no. 3828.

38 '...dat hy met andere verwe schildert als andere schilders ende dyenvolgende oock op een andere manier daermede toegaet als andere schilders, oock bytijde syn schilderijen opte plattevloer neer moet leggen op datte verwe hem soude voegen vlack opt paneel, deur welcke verwsmenginge ofte tesamensettinge dickmaels wel een geluijt ofte suysinge wt ontstaet twelck eyntelyck over gaet als de verwe gevat heeft; maer als hy met verwen schildert als andere schilders alsdan mede gebruijckt een esel en Penceelen.' See Bredius 1909, 7.

39 Rehorst 1939, 12: '...als dat ick nyet durvende de Sententie uwer Saecken laeten aencoomen op de gront mijner Konst, overmits U.I. selffs van deselve disconfideert, mijn selven behelp in desen met de middelen by de meeste int gebruyck...'

40 Bredius 1909, 43: '...verclaert wel geseyt te hebben dat als hy sommige verwen prepareert en toemaect sulcken feneynigen damp op te camer es dat een mensch deselve nyet wel en soude connen verdragen, gesont blijvende, dat derhalve de camer op die tijdt weynich slot van doen heeft dewijle de quade dampen souffisant syn de menschen daeruyt te houden....en als hy opte camer alsdan metter haest eens moet wesen, syn ooren en neus stopt omme de quade dampen te ontcommen'.
41 Rehorst 1939, 29: 'Ick moet precys thuys syn, want soo ick daer nyet op en paste soo vlooch mijn solder ande dack wel om veer offer een Tonneken bospoeyer aengingh'.
42 Polarized light microscopy (PLM) of pigment dispersions in transmitted light was done with the Leitz Orthoplan microscope. The mounting mediums for the microscope slides were Cargille melt mount (nD = 1.662), and Permount (nD = 1.539). The white pigment of the first ground layer showed as extremely birefringent rhombohedra with parallel extinction. The refractive indices were slightly lower than that of our standard mounting medium (Cargille meltmount $N = 1.662$). It was not possible to give an exact figure for variations in $N\omega$. The microscopy gave a perfect match with our laboratory standard for calcite.
43 Debye-Scherrer powder diffraction patterns were obtained with 57.3 mm cameras with Gandolfi mounts, with the sample in cedar oil on the tip of a glass spindle. Exposures varied from 4-7 hours. CuKα radiation ($\lambda = 1.542$Å) was used at 40kV, with tube current of 30mA. All intensities were estimated visually.
44 Observations of microscopic cross-sections were done with a Leitz Orthoplan polarizing microscope. Objective magnifications ranged from 100x; 200x; to 500x.
45 Scanning electron microscope (SEM) examinations with energy dispersive spectrometry of x-rays (EDX) were performed on a JEOL JXA-840A electron probe micro analyzer, usually at 10nA., 25kV, with a 39mm working distance. Samples were coated with a thin carbon coating to improve the conductivity of the sample and so prevent the accumulation of charge. EDX analyses were performed at various points throughout the cross-section by measuring the emitted X-rays with a Noran Vantage EDS-system with Pioneer Norvar detector.
46 DTMS measurements were done with a JEOL SX102A double focusing mass spectrometer with a B/E geometry. Samples were homogenised in ethanol and placed on a Pt/Rh (9:1) wire, which was resistively heated (05A/min). The temperature was increased in 2 minutes from room temperature to approximately 800 C. Desorbed material was ionised by 16eV electron impact ionisation, with the mass spectrometer scanning each second over a m/z 20-1000 range. Total acquisition time for each measurement was 2 minutes.
47 R.E. Aries, C.S. Gutteridge, W.A. Laurie, J.J. Boon, and G.B. Eijkel, 'A pyrolysis mass spectrometry investigation of pectin methylation', *Analytical Chemistry*, 60 (1988), 1498-1502.
48 J.J. Boon, 'Analytical pyrolysis mass spectrometry: new vistas opened by temperature resolved in-source PYMS', *International Journal of Mass-Spectrometry and Ion Processes*, 118/119 (1992), 755-787.
49 J.J. Boon and G. van der Doelen, 'Advances in the current understanding of aged dammar and mastic triterpenoid varnishes on the molecular level', *Firnis*, postprints of the conference in Braunschweig, 15-17 June 1998.
50 J. Yinon, D. Issachar, and H.G. Boettger, 'Studies in chemical ionization mass spectrometry of some flavonoids', *Organic Mass Spectrometry*, 13/3 (1978), 167-171.
51 The application of DTMS for identification of paint media is amply described in J.J. Boon, S.L. Peulvé, O.F. van den Brink, M.C. Duursma, D. Rainford, 'Molecular aspects of mobile and stationary phases in ageing tempera and oil paint films', *Early Italian Paintings: Techniques and Analysis*, Symposium, Maastricht, 9-10 October 1996, T. Bakkenist, R. Hoppenbrouwers, H. Dubois eds., (London, 1997), 35-56.
52 The DTMS method is less sensitive for the detection of proteins.
53 The same instrument was used as for the experiments with electron ionization. The evaporated products that came off from the Pt/Rh filament were ionized under NH_3/CI conditions at a standard pressure in the ion source of 20 Pa (7×10^{-4} Pa above the diffusion pump) accelerated to 3kV and analysed over the same mass range as with EI. The sample components are often characterised as $[M+NH_4]^+$ ions and $[M+H-H_2O]^+$ ions. The application of CI methods has proven to be particularly useful in the examination of biological substances. E.R.E. van der Hage, T.L. Weeding, J.J. Boon, 'Ammonia Chemical Ionization Mass Spectrometry of Substituted Phenylpropanoids and Phenyl-Alkyl Phenyl Ethers', *Pyrolysis mass spectrometry of lignin polymers*, E. van der Hage, diss. (Amsterdam, 1995), 19-34.
54 The identification of pectic substances was confirmed by a positive reaction (red colour) to a staining test with ruthenium red. See J. Bonner, *Plant Biochemistry*, (New York, 1950), 131.
55 Bonner 1950, 41.
56 British Library, Ms Harley 6376, fol. 20r.
57 This process is known in the cider making as 'cuvage': Fermentation of minced apple pulp in the vessel causes the juice to separate out into different layers – a floating layer of pectin gel on top; clear juice in the middle; and crud on the bottom. The traditional way of helping this to happen is to add a mixture of chalk ($CaCO_3$) and salt (NaCl). Often calcium chloride ($CaCl_2$) is used for the same purpose. This reacts with the pectin in the juice to form calcium pectate, which is insoluble, floats to the top, and can easily be skimmed off.
58 J.A.L. da Silva, M.A. Rao, 'Rheology of structure development in high-methoxyl pectin/sugar systems', *Food Technology*, 10 (October) (1994), 70.
59 A more detailed study of historical sources and reconstructions of various paint stratigraphies in different media is forthcoming. In this study samples from reconstructions and from the painting will be examined with conventional staining tests under the light microscope, gold labelled antibodies in the scanning electron microscope (SEM), gas chromatography / mass spectrometry (GCMS); Fourier transform infrared microspectrometry (FTIR); and surface enhanced Raman spectrometry (SERS).
60 Riemsdijk 1915, 249.