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Series editor **Ashok Roy**

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Sebastiano del Piombo, *The Raising of Lazarus*, detail

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PLATE 1 Sassetta, *Saint Francis meets a Knight Poorer than Himself and Saint Francis's Vision of the Founding of the Franciscan Order* (NG 4757), 1437–44. Poplar, 87 × 52.5 cm.

‘Some Panels from Sassetta’s Sansepolcro Altarpiece’ revisited

RACHEL BILLINGE

The first article in the first *National Gallery Technical Bulletin* (in September 1977), concerned seven panels from the altarpiece painted by Sassetta for the church of San Francesco at Sansepolcro (PLATES 1–8).¹ These paintings had recently been restored offering the opportunity for extensive technical analysis, resulting in a two-part article: the first part, by Martin Wyld, describing the recent restorations; the second part, by Joyce Plesters, giving a detailed description of the artist’s methods and materials as far as she could determine with the techniques available in the 1970s. Thirty years later the seven panels were again the subject of a major programme of technical examination as part of a multi-national project initiated and directed by Dutch art historian Machtelt Israëls investigating every aspect of the altarpiece, including an examination of all the extant parts with a view to determining how it was originally assembled and reconstructing how the altarpiece might once have looked.²

This new scientific research in London was limited to non-destructive techniques but improvements in technology have allowed full X-radiographs to be assembled digitally and image-processed, making them much easier to read; new digital infrared reflectography has provided clear, undistorted images of the underdrawing and pentimenti for the first time; and a better, more powerful stereobinocular microscope has revealed a great deal about how the pigments and materials identified by Joyce Plesters were used by the artist.

The vast altarpiece, elaborately carved, gilded and painted on both sides, was commissioned from Sassetta by the friars of Borgo San Sepolcro in September 1437 and was installed on the main altar of the church in June 1444. Between 1578 and 1583 the altarpiece was dismantled and later the separate pieces were dispersed following the Napoleonic Suppressions in 1808–10.

The front of the altarpiece showed *The Virgin and Child* (Paris, Louvre) with, on the left, *Blessed Raniero Rasini* and *Saint John the Baptist* (both Settignano, Berenson Collection), on the right, *Saint Anthony of*

Padua and *Saint John the Evangelist* (both Paris, Louvre). The back showed *Saint Francis in Glory* (Settignano, Berenson Collection) flanked by eight compartments showing scenes from the life of Saint Francis: the seven National Gallery panels plus the *Mystic Marriage of Saint Francis with Poverty, Chastity and Obedience* (Chantilly, Musée Condé). Above the main panels were pinnacles: in the centre *Saint Francis before the Crucifix* (Cleveland Museum of Art) with on its reverse *The Annunciation* (New York, Metropolitan Museum, Lehman Collection), flanked by head and shoulder depictions of saints of which only one is now known, *Saint Augustine* (private collection). The main panels stood on a box-shaped predella. On the front were scenes from the Passion of Christ of which three are known: *The Agony in the Garden*, *The Betrayal of Christ* and *The Ascent to Calvary* (all Detroit Institute of Arts). On the back of the predella were scenes from the life of Blessed Raniero Rasini. Again three panels survive: *Raniero Rasini shows Friars the Miser of Citerna's Soul carried by Demons to Hell* (Paris, Louvre), *The Apparition of Blessed Raniero Rasini to a Cardinal* (Berlin, Gemäldegalerie, Staatliche Museen) and *The Liberation of the Prisoners of Florence* (Paris, Louvre). Flanking the central panels were huge supporting piers painted on three sides with full-length standing saints and blessed, with half-length figures at the predella level (26 figures in all), of which four are known: *Saint Lawrence* and *Saint Stephen* (both Moscow, Pushkin State Museum), *Saint Christopher* (Assisi, Museo-Tesoro della Basilica di San Francesco, Mason Perkins Collection) and *Saint Matthew* (Venice, Cini Collection).³

When the altarpiece was dismembered, the huge panels of the main tier were split down the middle to separate the Virgin and standing saints on the fronts from the *Saint Francis in Glory* and smaller narrative scenes on the backs. The narrative scenes were then cut into eight panels and over time knowledge of the original arrangement of the scenes was lost.



PLATE 2 Sassetta, *Saint Francis meets a Knight Poorer than Himself and Saint Francis's Vision of the Founding of the Franciscan Order* (NG 4757), 1437–44. Poplar, 87 × 52.5 cm.



PLATE 3 Sassetta, *Saint Francis renounces his Earthly Father* (NG 4758), 1437–44. Poplar, 87.5 × 52.4 cm.



PLATE 4 Sassetta, *Saint Francis before the Pope: The Granting of the Indulgence of the Portiuncula* (NG 4759), 1437–44. Poplar, 88.4 × 52 cm.



PLATE 5 Sassetta, *The Stigmatisation of Saint Francis* (NG 4760), 1437–44. Poplar, 87.8 × 52.5 cm.



PLATE 6 Sassetta, *The Wolf of Gubbio* (NG 4762), 1437–44.
Poplar, 87 × 52.4 cm.



PLATE 7 Sassetta, *Saint Francis before the Sultan* (NG 4761), 1437–44.
Poplar, 86.4 × 53.2 cm.



PLATE 8 Sassetta, *The Funeral of Saint Francis and Verification of the Stigmata* (NG 4763), 1437–44. Poplar, 88.4 × 53.5 cm.



PLATE 9 Detail from *Saint Francis renounces his Earthly Father* (PLATE 3).

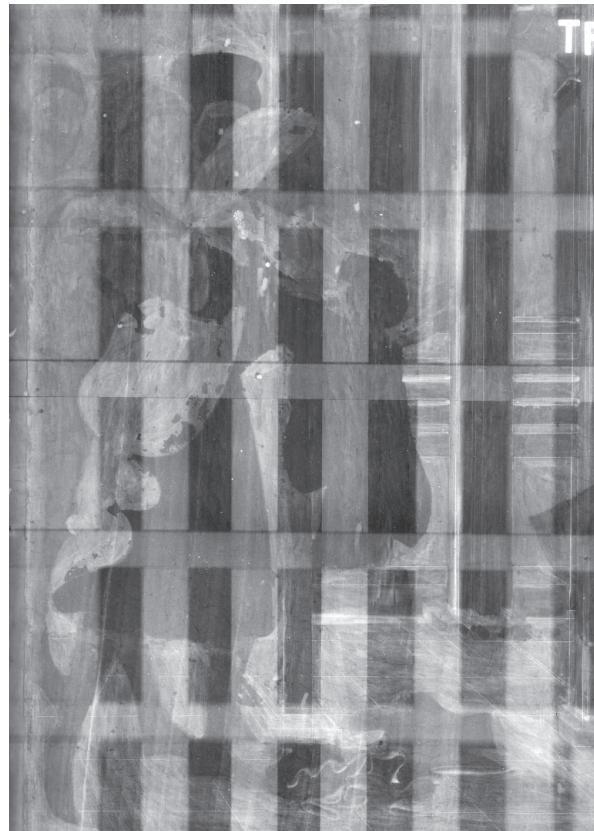


FIG. 1 Detail from *Saint Francis renounces his Earthly Father* (PLATE 3). X-radiograph taken in 1974 of Saint Francis's father, showing problems of legibility caused by the presence of the mahogany cradle.

X-radiography

In the 1970s only a few X-radiographs had been taken since the results were dominated by the heavy mahogany cradles on the backs of the panels, which effectively hid details such as the wood grain (FIG. 1). The new X-radiographs were digitised and mosaics assembled on a computer. It was then possible to reduce the effect of the cradles by digital image processing, allowing a much clearer picture of the original wood to be seen (FIG. 2).⁴ All the panels have vertical grain but vary considerably in the number of knots, which by causing deviations in the otherwise straight grain make it possible to follow patterns of wood grain between pairs of panels that had originally been placed one above another, showing that they had been part of single continuous planks.

X-radiographs were also taken of the spandrels, which had been separated from the main panels and set into modern frames in the early twentieth century. The

clarity of the new X-ray mosaics showed patterns in the grain of the main panels which could be followed into the spandrels, making it possible to prove which spandrels had originally been part of which panel. Image processing allowed composite X-ray mosaics to be assembled digitally, attaching the spandrels to the correct panels (see FIG. 2). The panel displayed in any particular frame has been changed a number of times over the years but it was found that, in the current arrangement (as illustrated by Gordon⁵), most of the panels are framed with their original spandrels (two have been swapped: NG 4761 and 4762). Also apparent from the new X-rays is the careful preparation undertaken by the artist before painting. Beneath the gesso ground wherever there was a knot or fault in the wood that might later cause a problem a fragment of fine canvas, frayed at the edges, was adhered.



FIG. 2 *Saint Francis renounces his Earthly Father* (PLATE 3), X-ray mosaic, digitally image processed and with spandrels attached.

Infrared reflectography

Infrared reflectography (IRR) was carried out using the National Gallery's new digital infrared camera SIRIS.⁶ Full reflectograms of all seven panels were recorded. The underdrawing revealed consists of simple outlines executed in a liquid material with a brush (FIG. 4). For the most part it is carefully followed in the paint layers so that it is often not possible to be sure whether the line seen in IRR is genuinely part of the black underdrawing or an outline in the surface paint.

Occasionally small changes were revealed between the underdrawing and the final paint, for example the figure of Saint Francis being held by the Bishop in *Saint Francis renounces his Earthly Father* (NG 4758) was first drawn with his right shoulder wider and his elbow lower. The final position of the arm was also underdrawn and hatching has been used to indicate shadows on his left arm, in his neck and below his ribs.

One change, however, is more significant iconographically and worth describing in greater detail here.⁷ In *The Stigmatisation of Saint Francis* (NG 4760) the saint is painted casting a dark shadow on the ground behind him, and close examination of the paint around the shadow reveals various strange ridges that appear to bear no relation to the layout of the ground as painted there (PLATE 10). Infrared reflectography reveals

that Sassetta has worked hard at the shadow, changing its shape and size several times (FIG. 3). It is difficult to identify underdrawing for the shadow though some of the narrow dark lines visible in the infrared reflectogram may be drawing. The first shadow painted by the artist filled up almost all the space between the saint and the rocks behind, the head touching the edge of the panel and the left hand being partly obscured by the right elbow of the saint. The rocks also cast a shadow which almost touched that of the saint's head. The artist then painted some of the pinkish-brown background paint around the shadow, but reduced the size of the head and the width of the left arm. It was probably also at this stage that the shadow of the rocks was suppressed. The curved lines visible in the infrared in the middle of the first shadow coincide with ridges in the surface paint which suggests that Sassetta experimented with several different smaller sizes for the shadow and then painted over the ones which he decided not to use. With thinner paint he seems later to have painted out the shadow completely. What is seen as shadow now is a greenish paint on the surface (the same colour as is used for the shadows of the rocks in the foreground) over a layer of pinkish-brown background colour, except on the bridge where the shadow is just a darker version of the colour the bridge is painted in. Finally Sassetta put



PLATE 10 *The Stigmatisation of Saint Francis* (PLATE 5), detail showing same area as infrared (FIG. 3).



FIG. 3 *The Stigmatisation of Saint Francis* (PLATE 5), detail from digital infrared reflectogram showing Saint Francis and changes to his shadow.



FIG. 4 *Saint Francis renounces his Earthly Father* (PLATE 3), digital infrared reflectogram.

all the little plants in: the patterns they make helping to disguise the different colours and thicknesses of paint.

IRR also shows clearly the extent to which the artist made use of incisions both for the architecture, where straight lines have been ruled with the aid of a straight edge and arcs drawn with compasses, and to give more general guidance for construction of perspective. At its simplest these perspective lines consist of a vertical centre line, identifiable on almost all of the panels, and simple orthogonals, but sometimes very clear patterns can be seen, such as a fan of incised lines meeting at a vanishing point on the horizon in *Saint Francis before the Sultan* (NG 4761, FIG. 5). The incisions for the architecture are not particularly carefully made: many are longer than necessary or are slightly misplaced, requiring a second attempt resulting in a double line. As mentioned by Plesters, there are pentimenti in the architectural incisions too, including an extra arch in the balcony in *Saint Francis's Vision* (NG 4757) and a redesign of the vaulted ceiling in *The Funeral of Saint Francis* (NG 4763).⁸ One major area of incisions, the purpose of which remains a mystery, is in the lower part of *The Wolf of Gubbio* (NG 4762). Here there is a network of ruled lines making a grid like a tiled floor beneath the figures in the foreground (FIG. 6). It is not clear whether these lines were actually intended to be an architectural feature or are part of a more general perspective construction but whatever the case they were not used in the final scene as painted and would make more sense in relation to an indoor scene, which suggests some confusion in the early stages of work on this episode.



FIG. 5 *Saint Francis before the Sultan* (PLATE 7), detail of central window from digital infrared reflectogram showing incisions meeting at a point.



FIG. 6 *The Wolf of Gubbio* (PLATE 6), detail from digital infrared reflectogram showing grid incised at bottom of painting.

Stereobinocular microscopy

For works of this date the seven panels are remarkable in the extent to which not only gold but also silver leaf has been used, tooled and painted to produce a rich variety of brilliant textiles. In 1977 Plesters dedicated a major part of her text to describing how these effects were achieved.⁹ The recent study of the surface using a Wild M650 stereobinocular operating microscope at magnifications between $\times 6$ and $\times 40$ has made it possible to examine more closely some of the effects she described and to elaborate on some of the techniques.

As noted by Plesters, most of the gold and silver has been applied using water-gilding onto red bole which she described as 'unusually red, almost vermillion in hue'. In fact there is nothing unusual about the bole which is, as Plesters says, 'the usual type of red clay'.¹⁰ The higher magnification enables us to see that the strong red colour is due to the presence of vermillion used by restorers over the years to disguise areas where the gold and bole have become abraded exposing the white ground.

The various luxurious textiles are created using many different combinations of opaque and translucent paints over plain or tooled gold or silver. The simplest of these rich draperies consist of silver leaf covered with a glaze, for example the blue sleeve of the onlooker at the right edge of *Saint Francis before the Sultan* (PLATE 11), where a glaze of pure natural ultramarine lies over the silver (exactly the same layer structure as illustrated by Plesters.¹¹

The gold cloth hanging from the throne of the Bishop in *Saint Francis renounces his Earthly Father* has a pattern of short hatched lines incised into the gold to create the effect of gold threads. It is otherwise undecorated but the folds are created by painting them on with a brownish glaze (PLATE 12). This pattern of incisions to indicate threads is also used in several coloured draperies, for example the red cloak worn by Francis in *Saint Francis meets a Knight Poorer than Himself* and *Saint Francis's Vision* which is silver leaf, incised and then covered with a red lake glaze (PLATE 13); and the bed cover, which is gold leaf, incised then covered with a green glaze (now discoloured).

Generally where the paint over metal leaf is opaque then the incised pattern is made into the paint as *sgraffito*, while if the paint is a transparent glaze the incisions are directly applied to the metal leaf as just described. In purple draperies created by painting an opaque blue underlayer with a red glaze on top the pattern is made as *sgraffito* into the blue layer and then the red glaze is applied over the whole, blue and exposed metal leaf alike (PLATE 14).

The more elaborate patterns such as the cloths of honour behind the Bishop, Pope and Sultan, cushions,

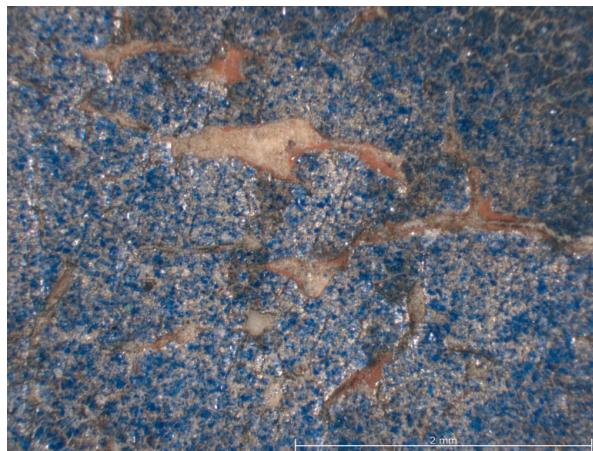


PLATE 11 *Saint Francis before the Sultan* (PLATE 7), photomicrograph of blue sleeve of man at right edge, showing blue pigment over silver leaf.



PLATE 12 *Saint Francis renounces his Earthly Father* (PLATE 3), photomicrograph of gold cloth hanging from throne, showing brown glaze modelling over incised gold leaf.

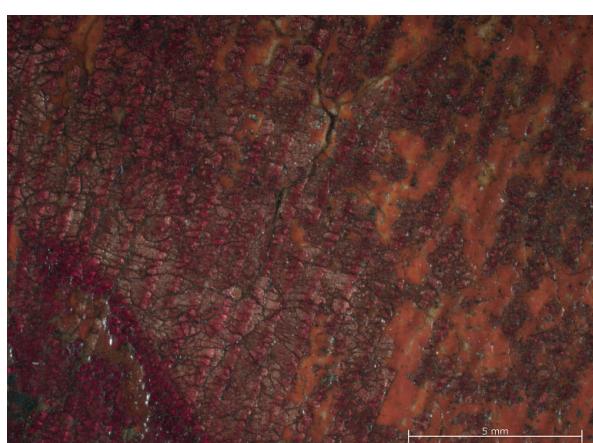


PLATE 13 *Saint Francis meets a Knight Poorer than Himself* (PLATE 1), photomicrograph of Saint Francis's red robe, showing red lake glaze over incised silver leaf.



PLATE 14 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of purple lining to robe worn by acolyte holding crucifix, showing red lake applied over incised blue paint.



PLATE 15 *Saint Francis before the Pope* (PLATE 4), photomicrograph of sgraffito key pattern in the Pope's cloth of honour.

slippers, and the star pattern over Francis's bed, are all created using a traditional *sgraffito* technique, though even here there are subtleties in how the paint was applied. The complicated patterns on Francis's pillow (*Saint Francis's Vision*), the carpet at the Pope's feet and the papal keys pattern on his cloth of honour (*Saint Francis before the Pope*) are all scraped out of white paint, the exposed gold then incised with short parallel hatching (PLATE 15). At higher magnification it is possible to see that each star in the canopy over Saint Francis's bed (*Saint Francis's Vision*) has been created from four strokes scratched into the blue paint from left to right, often leaving little piles of displaced paint at the ends of strokes, which are striped showing that the blue was applied in two layers, a lower opaque layer of white (or pale blue) with a pure ultramarine glaze over the top (PLATE 16).

A particularly interesting use of *sgraffito* is seen in the altarpiece depicted in *The Funeral of Saint Francis*. The whole area where the altarpiece was to go was gilded and the predella and arches around the main panels decorated with *sgraffito* patterns in green paint (PLATE 17). The blue background was painted over the gold up to the edges of the main panels. The ornate crockets and finials were created by scraping away the paint and then shadows were added using a red lake glaze (PLATE 18).

The flames and smoke from the fire in *Saint Francis before the Sultan* were created by painting various different colours – yellow, orange, red, pink, grey and white – sometimes separately and sometimes in overlapping layers over gold leaf. Sparks were depicted by the use of a simple dot punch and swirls of smoke with freehand *sgraffito*. Mostly these swirling incisions expose the gold but some are more subtle, scraping through an upper layer of opaque paint to reveal a different colour beneath (PLATE 19).

In *Saint Francis before the Pope* the windows were created using silver leaf onto which the roundels of glass, leading and coloured details were painted (PLATE 20). Interestingly in *Saint Francis renounces his Earthly Father* there are two types of window: the two above the man reading are executed using silver on bole onto which the details are painted (PLATE 21) as in *Saint Francis before the Pope*, but for the two in the white wall to the left the silver leaf has been applied over a pale grey mordant, and then painted as before (PLATE 22). Possibly the reason for this variation in technique was that the water-gilded silver could have been burnished, while that on a mordant could not and so there would have been a subtle difference in the reflective qualities of the two sets of windows. Also in this panel, along the top of the white wall, and across the top of the pink building,

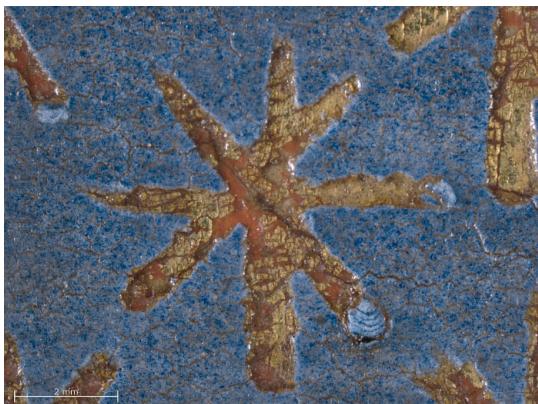


PLATE 16 *Saint Francis's Vision* (PLATE 1), photomicrograph of sgraffito star in bed canopy.



PLATE 19 *Saint Francis before the Sultan* (PLATE 7), photomicrograph of smoke showing sgraffito patterns and sparks made with punches.



PLATE 17 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of green sgraffito decoration on altarpiece.



PLATE 20 *Saint Francis before the Pope* (PLATE 4), photomicrograph of central window, showing paint over silver leaf to depict glass roundels.

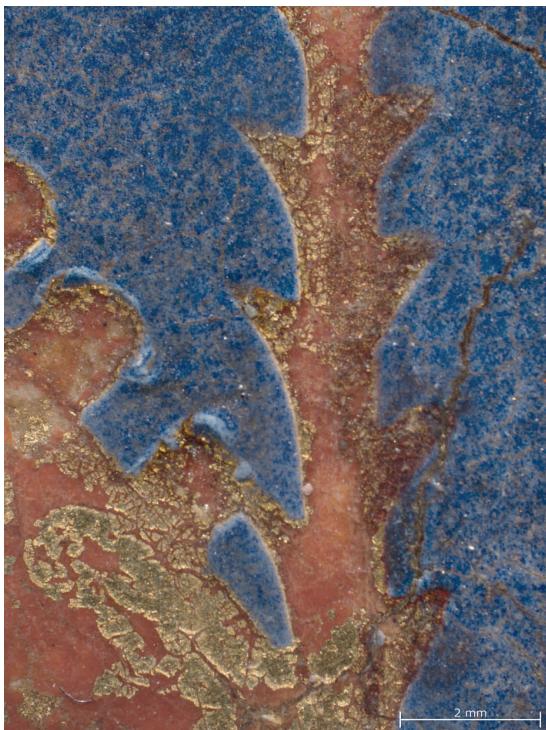


PLATE 18 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of crockets and finials at top of altarpiece created using sgraffito.



PLATE 21 *Saint Francis renounces his Earthly Father* (PLATE 3), photomicrograph of edge of window above central man with book, showing traces of paint over silver leaf and bole.

are strips of exposed gesso. At high magnification fragmentary traces of paint and silver leaf, again over a light-coloured mordant, reveal that these roof areas were once silver, decorated with grey and blue paint to create the effect of a slate roof (PLATE 23).

In her section 'Embellishment of the gold and silver leaf (a) tooling' Plesters mentions the use of two ring punches for the haloes and goes on to describe how the frame of Saint Francis's bed in *Saint Francis's Vision* is "seeded" or punched all over with little dots to give it texture.¹² It has now been possible to identify, in addition to the ring punches and simple round dots already mentioned, several more tools. The seeding of Francis's bed was done using a tool with a square profile (PLATE 24); this tool was also used for similar effects in the Bishop's and Sultan's thrones. In the colonettes of the altarpiece in *The Funeral of Saint Francis* a tool consisting of four rectangular prongs arranged in a straight line has been used (PLATE 25). Oval jewels in the Pope's morsæ were made using a punch of concentric ovals (PLATE 26). For smaller ovoid decorations an unusual punch consisting of an ovoid shape with a nipped-in waist, like a peanut shell, has been used (PLATE 27). This punch seems to have been a favourite of the Sassetta workshop and has been identified elsewhere on the altarpiece.¹³

Gold leaf applied using a pale-coloured, whitish mordant is used sparingly, mostly for decorative effect, as in the case of the clasps of the book read by Brother Leo in *The Stigmatisation*, which were mordant gilded (PLATE 28). In the same scene the rays of the stigmata descending from Christ were originally mordant gilded but now appear white due to the loss of the gold, leaving the pale mordant exposed (PLATE 29). The choice of mordant gilding for the rays is eminently practical, especially as this panel has less water-gilding than most of the others.

Another purely practical use of mordant gilding can be seen in *The Funeral of Saint Francis*. Here most of the candle flames are created by scraping away background paint in the shape of a flame, to reveal gold which had been laid under the paint, and then adding vermillion and red lake to intensify the flame (PLATE 31), but the candle held by the small boy on the left is nowhere near any other gold and so has a flame created using mordant gilding, with vermillion and red lake (PLATE 32).

Silver applied with a mordant is used for the windows and roofs in *Saint Francis renounces his Earthly Father* as described above, and for small details such as the spurs worn by Francis in *Saint Francis Meets a Knight Poorer than Himself*. Here the mordant is a translucent brownish colour, different from the opaque mordant used for both gold and silver elsewhere (PLATE 30).



PLATE 22 *Saint Francis renounces his Earthly Father* (PLATE 4), photomicrograph of window in white wall showing paint over silver leaf applied with a grey mordant.



PLATE 23 *Saint Francis renounces his Earthly Father* (PLATE 3), photomicrograph of strip of roof at top of building, showing fragments of silver leaf applied with a mordant.



PLATE 24 *Saint Francis's Vision* (PLATE 1), photomicrograph (in raking light) of side of bed, showing square shape of punch.

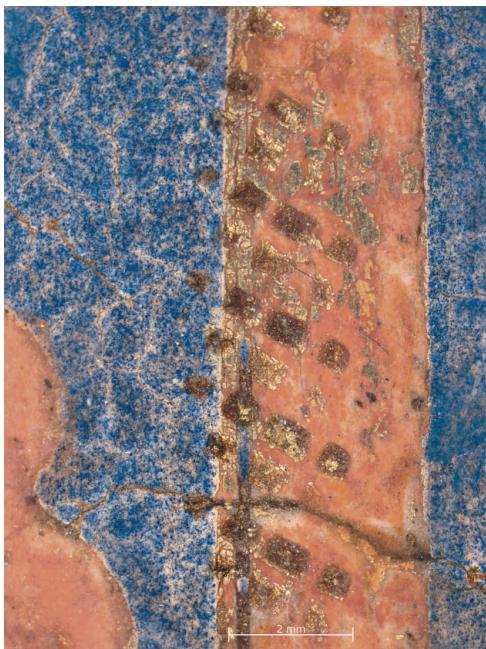


PLATE 25 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of colonette on altarpiece, showing four-prong punch.



PLATE 26 *Saint Francis before the Pope* (PLATE 4), photomicrograph of the Pope's morsæ, showing oval punch used for jewels.



PLATE 27 *Saint Francis's Vision* (PLATE 1), photomicrograph of angel's belt, showing punch shaped like a peanut shell.

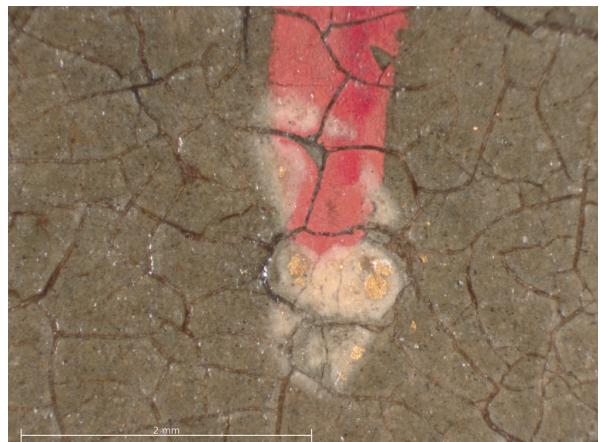


PLATE 28 *The Stigmatisation of Saint Francis* (PLATE 5), photomicrograph of fastening for book held by Brother Leo, showing mordant gilding.



PLATE 29 *The Stigmatisation of Saint Francis* (PLATE 5), photomicrograph of wound in Saint Francis's left hand, showing mordant gilding for ray.



PLATE 30 *Saint Francis meets a Knight Poorer than Himself* (PLATE 1), photomicrograph of Saint Francis's right spur, showing silver leaf applied with a translucent mordant.

Analysis of paint samples¹⁴

Plestros carefully examined the pigments found on the seven panels.¹⁵ In addition to the usual lead white, yellow, brown and red earths and carbon blacks she identified natural ultramarine, vermillion, red lake (deriving from an insect not a plant dyestuff), malachite, verdigris and lead-tin yellow type I as well as the presence of a translucent yellow that she suspected was yellow lake, although she was unable to identify it precisely.

In this early study, identification of the malachite had posed some problems, mainly due to its unusual appearance and particle shape. On the paint surface the particles appear large, often protruding above the surface of the layer (PLATE 33). In cross-section most are rounded which led to the identification of the pigment as 'synthetic malachite'. A re-examination of cross-sections from the green chest in *Saint Francis's Vision* shows that there are particles of various different shades of green, mostly rounded but some tabular, together with impurities (PLATE 34). Recently more research has been done into spherulitic green copper-containing pigments and an alternative source for malachite with similar large particle size, strong colour and rounded appearance has been identified as natural precipitation from waste water where copper mines are located.¹⁶ The presence of other green copper minerals, including posnjakite (copper sulphate), and other impurities such as silica, silicates and dolomite are common features of the green copper mineral pigment from this source. EDX analysis of the green pigment in Sassetta's painting showed that while the rounded particles are malachite, the tabular particles are a copper sulphate, and in addition some silicates are present, suggesting it is of the same type and has a natural origin. The term 'naturally precipitated spherulitic malachite' has been adopted for this pigment, although the name 'mountain green', found in historic documentary sources, is a more accurate term than malachite since the pigment also includes other minerals.¹⁷

An area in which technology has advanced significantly since the 1970s is the analysis and identification of the dyestuffs used in lake pigments. Re-examination of a sample of the red lake used on the Sassetta panels has confirmed that the dyestuff used is basically kermes, but with a trace of cochineal.¹⁸

One striking feature of all seven Sassetta panels is the use of a strongly coloured semi-translucent yellow. It can be seen, used over a pale lead-tin yellow base, for the marbled yellow architecture in *The Funeral of Saint Francis* (PLATE 36) and in the carpets in *Saint Francis renounces his Earthly Father*, *Saint Francis before the Pope* (PLATE 37) and *Saint Francis before the Sultan*, but it is also used for smaller details such as leaves and rocks and



PLATE 31 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of candle flame just behind crucifix, showing gold exposed by scraping away yellow paint.



PLATE 32 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of flame of candle held by boy in foreground, showing gold applied on a mordant.

even the eye of the wolf in *The Wolf of Gubbio* (PLATE 35). Despite her best efforts Plesters was not able to identify the pigment or dyestuff providing the strong colour so this was deemed to be an area worth revisiting during the most recent study, with the benefit of new analytical techniques.¹⁹

The yellow marbled areas of the architectural arch at the top of *The Funeral of Saint Francis* were painted with an opaque pale yellow base layer containing lead white and lead-tin yellow. The marbling was formed with brushstrokes of a warm yellow paint consisting of a silica-rich yellow earth.²⁰ In places a more translucent yellow glaze-like layer was visible, which could be simply the same yellow earth paint applied more thinly or a yellow lake glaze as Joyce Plesters suggested. A sample was analysed by high performance liquid chromatography (HPLC) in an attempt to ascertain if a yellow dyestuff was present. This was unsuccessful, but does not necessarily indicate the absence of a yellow lake pigment, as certain dyestuffs would not be detected with this method, or it may be that the sample was too small.

A cross-section was taken from the yellow marbling at the left edge of the painting and shows three layers: the pale yellow underlayer, a layer of yellow earth and finally a translucent yellow layer (PLATE 38). SEM-EDX analysis detected a small amount of calcium, magnesium and dispersed lead in this final layer and Fourier transform infrared microscopy (FTIR) identified calcium carbonate and suggested the presence of a small amount of calcium magnesium carbonate. This could be interpreted as evidence of the presence of a yellow lake substrate. However, the FTIR spectra also contain strong absorption bands which can be assigned to fatty acids, most probably from a drying oil. There was little indication of protein and the composition was clearly very different from the underlying egg tempera paint layers.²¹ In addition this layer was found to fluoresce strongly under ultraviolet light and could therefore be an old resin varnish which remained in the particular area sampled, and not the translucent paint seen elsewhere in the marbling. This highlights the difficulty of correlating what was observed on the surface of the painting under the stereomicroscope with the cross-section and with the FTIR results from scrapings of paint. Further work is needed to confirm the composition of this material, particularly through comparison with FTIR analyses of similar yellow glazes on other paintings of the period. Despite the advances in analytical techniques, confirmation of the presence of a yellow lake pigment still constitutes a challenge, particularly for early Italian paintings, as very little is known about what dyestuffs are likely to be present.

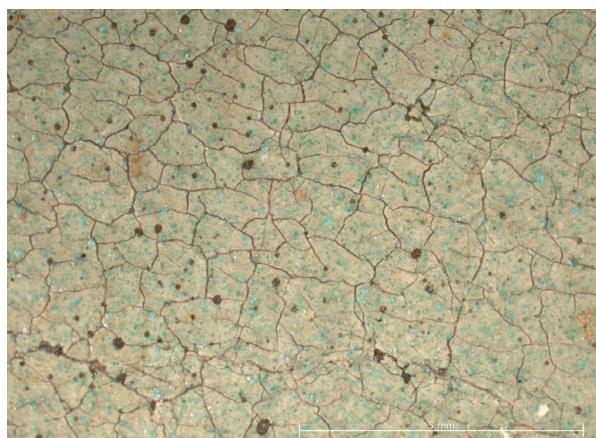


PLATE 33 *Saint Francis before the Pope* (PLATE 4), photomicrograph of green paint of walls, showing protruding malachite particles.

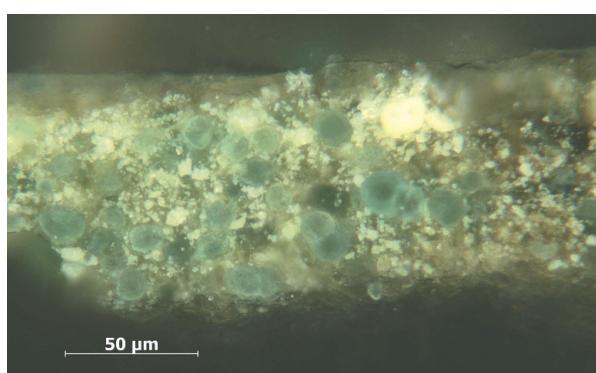


PLATE 34 *Saint Francis's Vision* (PLATE 1), cross-section of green paint from the step in front of Saint Francis's bed, containing a green copper mineral pigment composed mainly of malachite of spherical particle form mixed with lead-tin yellow.



PLATE 35 *The Wolf of Gubbio* (PLATE 6), photomicrograph showing the wolf's eye.



PLATE 36 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of yellow marble in architecture.

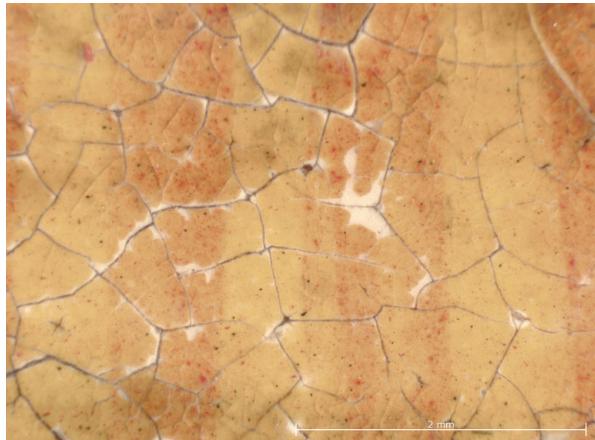


PLATE 37 *Saint Francis before the Pope* (PLATE 4), photomicrograph of fringe of yellow carpet hanging over wall, showing red lake and brightly coloured yellow over pale opaque yellow paint.

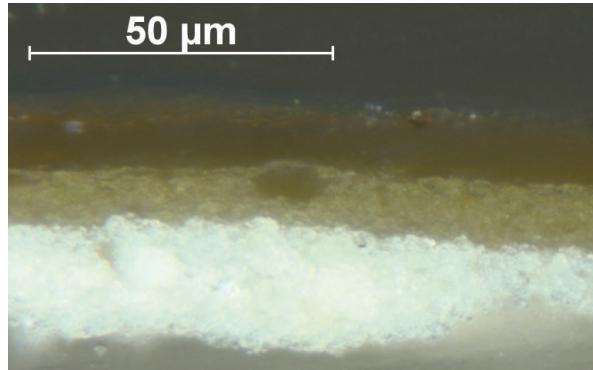


PLATE 38 *The Funeral of Saint Francis* (PLATE 8), cross-section of a paint sample from the yellow marbled vault. The sample does not include the gesso ground. The lowest layer is the pale yellow base colour of lead white and lead-tin yellow, with translucent areas which have been identified as lead soaps. Over this is a warm yellow paint composed of a silicate-rich yellow earth. The translucent yellow layer at the top of the cross-section, which is fluorescent under ultraviolet light, is either a yellow glaze or the remains of an early varnish.



PLATE 39 *The Funeral of Saint Francis* (PLATE 8), photomicrograph of yellow marbling in architecture, showing lead soap pustules.

Close examination of the surface of this area with the stereomicroscope also led to another interesting discovery; the presence of small translucent lumps in the yellow passages of paint (PLATE 39). These appear to originate from the lower paint layer but have protruded through the upper yellow layers to the surface. In places they appear as slightly raised, pale yellow lumps, but in some cases the protrusions have become completely exposed and translucent pustules are visible. FTIR microscopy gave a clear identification of lead soaps, which have presumably been formed by the reaction of the lead-tin yellow pigment with fatty acids in the egg tempera binding medium.²² Lead soaps are commonly identified in paintings with an oil medium but they have only been found in egg tempera paintings in a few instances, notably in the lead-tin yellow containing curtain in the *Portrait of a Man*, attributed to Raffaellino del Garbo (NG 3101).²³ Test samples of red lead and lead-tin yellow in egg tempera that had been artificially aged at high humidity have also been found to contain lead soaps.²⁴ Earlier ideas that lead soaps only form where lead pigments are in an oil medium should therefore be reconsidered.

Conclusion

The 1977 article set a standard of extensive, thorough scholarship which may still be used as a model to strive towards today and made the National Gallery's seven Sassetta panels the most studied and best understood works of the period. Their re-examination thirty years later has been able to confirm the results published then and, thanks to new technology, expand on them, following up questions identified in the first article as needing further research, such as the status of the spandrels in the frames, and the possible presence of a yellow lake pigment. It cannot be doubted that Joyce Plesters would have been fascinated and delighted with what can now be achieved, but we do not have all the answers and as new technologies continue to be developed these paintings will undoubtedly have more secrets to give up to future studies.

Notes

- 1 M. Wyld and J. Plesters, 'Some Panels from Sassetta's Sansepolcro Altarpiece' in *National Gallery Technical Bulletin*, September 1977, pp. 3–17.
- 2 *Sassetta: The Borgo San Sepolcro Altarpiece*, ed. Machtelt Israëls, to be published by Villa I Tatti, Florence, and Primavera Press, Leiden, with art-historical and technical essays, a reconstruction of the altarpiece and a full account of how this was determined, documentary sources and bibliography and the results of all the technical examinations, is scheduled for publication in Autumn 2009.
- 3 For illustrations see, for example, D. Gordon, *The Fifteenth Century Italian Paintings*, Vol. 1, London, 2003 pp. 325–63. For a full account of the construction of the whole altarpiece see Israëls 2009 (cited in note 2).
- 4 I would like to thank David Wood of the National Gallery Photographic Department for the skill and care with which he carried out the image processing of the seven X-ray mosaics. Image processing was conducted using Vips-ip and Adobe Photoshop.
- 5 Gordon 2003 (cited in note 3), pp. 325–5.
- 6 SIRIS uses an indium gallium arsenide (InGaAs) array sensor. For further details about the camera see David Saunders, Rachel Billinge, John Cupitt, Nick Atkinson and Haida Liang, 'A New Camera for High-Resolution Infrared Imaging of Works of Art' in *Studies in Conservation*, 51, No. 4, 2006, pp. 277–90.
- 7 For a full discussion of the iconographic significance see the essay by Koichi Toyama in Israëls 2009 (cited in note 2).
- 8 Wyld and Plesters 1977 (cited in note 1), p. 10.
- 9 Wyld and Plesters 1977 (cited in note 1), pp. 11 and 12.
- 10 Wyld and Plesters 1977 (cited in note 1), p. 11.
- 11 Wyld and Plesters 1977 (cited in note 1), pp. 14 and 15 and plate 2b.
- 12 Wyld and Plesters 1977 (cited in note 1), p. 11.
- 13 For an illustrated catalogue of all the punches used in the Sansepolcro Altarpiece see Israëls 2009 (cited in note 2).
- 14 The unmounted samples and cross-sections surviving from the 1970s were re-examined, and some new samples were taken from the yellow marbling. New research was carried out by Marika Spring, Rachel Morrison and Jo Kirby.
- 15 Wyld and Plesters 1977 (cited in note 1), pp. 13–15.
- 16 See, for example, G. Heydenreich, M. Spring, M. Stillhammerova and C.M. Pina, 'Malachite pigment of spherical form' in *ICOM Committee for Conservation, 14th Triennial Meeting, The Hague, Preprints*, Vol. II, 2005, pp. 480–8.
- 17 For a discussion of the nomenclature of green copper-containing mineral pigments in historic documentary sources see A. Burmester and L. Resenberg, 'Von Berggrün, Schiefergrün und Steingrün aus Ungarn: Apothekentaxen verhelfen zu neuen Einsichten', *Restauro*, 109, no. 3, 2003, pp. 180–7.
- 18 Analysis with HPLC. It is possible that the sample was contaminated with modern retouching, but if not then the cochineal must be an old world variety such as Polish cochineal: J. Kirby report dated 6 October 2004 in Scientific Department files. For information about red lakes and how they are analysed see J. Kirby, M. Spring, C. Higgitt, 'The Technology of Red Lake Pigment Manufacture: Study of the Dyestuff Substrate', *National Gallery Technical Bulletin*, 26, 2005, pp. 71–87.
- 19 Wyld and Plesters 1977 (cited in note 1), p. 13.
- 20 The pigments were identified by energy dispersive X-ray analysis (EDX) in the scanning electron microscope (SEM).
- 21 FTIR microscopy was carried out in transmission mode on scrapings of this layer in a micro-compression diamond cell. The upper layer in the cross-section was also analysed using ATR-FTIR imaging at Imperial College, London. The advantage of this technique is that it is possible to be more certain about the location of the material analysed within the layer structure than when analysing scrapings. Unfortunately, there was insufficient sample for GC-MS analysis. We are grateful to Professor Sergei Kazarian, Katrina Jacks and Sarah de Zoysa for the ATR-FTIR imaging. See M. Spring, C. Ricci, D.A. Peggie and S.G. Kazarian, 'ATR-FTIR imaging for the analysis of organic materials in paint cross sections: case studies on paint samples from the National Gallery, London', *Analytical and Bioanalytical Chemistry*, 392, 2008, pp. 37–45, for a description of the method.
- 22 FTIR microscopy of the more translucent parts of the pale yellow under paint gave unusually well-resolved spectra for lead soaps. As well as the major carboxylate doublet at ~ 1522 and 1540 cm^{-1} , the spectra are characterised by a regular series of small peaks in the 1350 – 1180 cm^{-1} region, which correspond to the vibrations associated with the long hydrocarbon chain of the fatty acids. These peaks match well with spectra of standard samples of lead palmitate and lead stearate. ATR-FTIR imaging was carried out directly on the cross-section with the aim of identifying the binding medium of the pale yellow paint from which the lead soaps originate more securely than was possible by analysis of scrapings. The results showed clearly that it had a proteinaceous binding medium, most probably egg tempera, since strong absorptions were seen at around 1645 cm^{-1} and 1540 cm^{-1} . It was also possible to locate the lead soaps within this layer using this technique, and to show that the binder of the yellow earth layer was also proteinaceous.
- 23 For information about lead soaps in oil paint see, for example, C. Higgitt, M. Spring and D. Saunders, 'Pigment-medium Interactions in Oil Paint films containing Red Lead or Lead-tin Yellow', *National Gallery Technical Bulletin*, 24, 2003, pp. 75–95. Identification of lead soaps in the painting by Raffaellino del Garbo was carried out by FTIR microscopy by Catherine Higgitt.
- 24 Analysis of the test samples was carried out by FTIR microscopy by Catherine Higgitt. Copper soaps have also been found in a malachite-containing egg-tempera paint. See Spring, Ricci, Peggie and Kazarian 2008 (cited in note 21).