CONSERVATION OF WALL PAINTING DEPARTMENT
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Peterborough Cathedral, nave ceiling: Scientific examination of the original decoration

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1 Summary

As part of a major project aiming to ensure the long-term preservation of the ceiling, a preliminary investigation of the original and added materials of the painted surfaces was undertaken. The objective of the investigation was to determine the nature and extent of any original paint layers still remaining, to characterise the various phases of later repainting, and to assess the implications these results may have for the conservation of the ceiling. In addition, a number of queries resulting from the emergency conservation treatment were addressed. The examination and sampling was undertaken in April 1997 in conjunction with a phase of emergency treatment by the Perry Lithgow Partnership which focused on the figures of *St. Paul*, *St. Peter* and the *Psaltery Player,* and on surrounding areas accessible from the two bridge scaffolds.

Results indicate that original paint layers exist in a number of areas, usually beneath layers of rather crude overpaint, as in the flesh tones of St. Peter. It also appears that some original layers remain exposed—though juxtaposed with cursorily applied overpaint—as in the Psaltery Player, where parts of the instrument appear to be of 13th-century date. The original palette includes natural azurite, lead white, verdigris and vermilion, and the binding medium of layers containing lead white and verdigris has been identified as a drying oil.

Of particular interest is the use of green underpainting for some of the flesh tones, in azurite combined with lead white and yellow iron oxide. It is significant that azurite was also used to indicate shadows in the flesh tones in the ceiling fragments from the Painted Chamber of Westminster Palace, dating from *c.*1263-6. These panels, which survive in remarkably good condition, provide perhaps the closest surviving English parallel in terms of original function and date to the original scheme at Peterborough.

The results of the investigation have clear implications for the conservation of the painted ceiling. The presence of calcium sulphate at the wood/paint interface, and also at varying concentrations throughout the paint layers, makes the painting profoundly sensitive to moisture. In addition, some 19th-century paint layers were also found to contain high concentrations of both calcium sulphate and clay-rich minerals, which accounts for their extreme moisture sensitivity. This was dramatically demonstrated by the severe blooming which followed even brief contact with water during the recent emergency conservation testing and treatment.

There is also evidence of pigment alterations in both the original and later phases of painting. These include the transformation of natural azurite to copper oxalate, which indicates deterioration of the original painting, and which may be partly due to an episode of high humidity at some time in the past.

2 *Introduction*

The nave ceiling at Peterborough is the only 13th-century painted wooden ceiling surviving *in situ* in England.[1] Two fragments of the wooden ceiling of *c.*1263-6 from the Painted Chamber at Westminster Palace have recently been discovered and examined in detail, and the resulting information, together with analytical evidence from some of the few other early medieval English panel paintings, provides important comparative technical information for Peterborough.

Parallels have also been drawn between the Peterborough ceiling and painted examples on the Continent, such as those at Zillis, Switzerland (*c.*1150); St. Michael, Hildesheim (*c.*1200); and Dädesjö, Sweden (*c.*1275). However, technical, structural and other comparisons with these ceilings will only be possible as a result of the present overall study of the Peterborough ceiling, of which this report forms a part.

3 *Selected history of the nave ceiling*

***c.* 1140**	building of the nave commenced after 1140 under Martin de Bec, and was continued by William de Waterville (1155-75), and completed, up to but not including the W. front, by Benedict (1177-93).[2]
***c.* 1220**	painting of the nave ceiling.[3]
early 14th c.	east end was re-fenestrated.
15th c.	all clerestory windows west of the apse, and those in the lower levels of the east and west transepts, were replaced.
1740s	repair, washing and repainting of the ceiling.
1834/5	roof repaired by Ruddle and ceiling again repainted (Charles Layton received £30.00 for the repainting).[4]
1880s	central tower rebuilt by Pearson. This intervention caused some disruption to the east end of the nave ceiling.
1890	limewash removed from the walls of the nave. This work is recorded in inscriptions on the frieze below (26 & 27 I).

1 Other early medieval wooden ceilings are known to have existed, such as that at Canterbury Cathedral which was destroyed in the fire of 1174.

2 It has been suggested that a stone vault for the nave was intended but later abandoned.

3 Opinion on the dating of the wooden ceiling varies considerably: c. 1177-93, Gunton 1686 (see Highham 1995); *c.* 1220 (Cave & Borenius 1937:304-309); and 1236-7 (Nordström 1955). I am grateful to David Park for discussing the stylistic evidence for the dating with me.

4 Cave & Borenius 1937:304-9.

1926	new roof over nave. The roof and also the ceiling were treated with '*Silvertown*,' an insecticide containing sulphur chloride and carbon bisulphide. Structural repairs were necessitated by infestation of death watch beetle.[5] The upper surface of the boards was covered with hessian and glue at this time.
1994	Pollution tests by Dr. B. Knight of English Heritage indicate much soluble acid present in the wood. Tests for chlorides and sulphates also gave weakly positive results.
1995	Hirst Conservation undertakes cleaning and conservation testing and pigment analysis.
1996	G. Lewis and J. Limentani inspect the ceiling from a hoist. G. Lewis samples the ceiling painting at this time.
1997	Phase of emergency conservation treatment and documentation of present condition by the Perry Lithgow Partnership in the zones around *St. Peter, St. Paul* and the *Psaltery Player.*

4 *Methodology of the present investigation*

The area examined in detail and sampled was limited to that accessible from two bridge scaffolds spanning the nave from bays 25-27 and 29-31, and focused particularly on the *Psaltery Player* (*ref.: 25/26 I/II*), *St. Peter* (ref.: 30/31 II/III) and *St. Paul* (ref.: 26/27 II/III). Following a detailed inspection of this part of the ceiling in normal, raking, IR, and UV light, and at magnification with the aid of a video microscope, a small number of samples was taken to identify the original and added materials. This examination and sampling was undertaken in April 1997.

The paint samples were mounted as polished cross-sections (in polyester embedding resin), and as dispersions (in *Meltmount,* which has a refractive index of 1.662), and were examined with an optical microscope at 170-2500x magnification in incident, transmitted and UV light; photomicrographs were taken at between 500 and 2500x. Microchemical tests were undertaken to identify some metallic ions (Pb^{2+}) and functional groups (SO_4^{2-}), and histochemical tests were carried out to indicate the presence of oils and proteins.[6] A scanning electron microscope (SEM), used with energy-dispersive X-ray (EDX) analysis which provides elemental analysis, was employed to confirm the identifications made with polarised light microscopy (PLM). Identification of organic materials and additional confirmation of

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5 A report on the condition of the roof at this time is provided by the architect, see Moore 1925.

6 The microchemical tests included: hydrochloric acid and potassium iodide, which produce a yellow stain for lead; lead nitrate and sodium rhodizonate, which produce a purple colour in the presence of sulphate ions; and hydrochloric acid, which results in the evolution of carbon dioxide, in order to identify carbonates. Preliminary staining for oil was undertaken using Sudan Black B which produces a blue colour when indicating a positive result. In UV light, proteins give a yellow fluorescence when stained with fluorescein isothiocyanate (FITC). Acid fuchsin was also used for the identification of protein.

inorganic components were undertaken using Fourier Transform Infra-red (FTIR) microspectroscopy.[7]

5 The documentary evidence

We are fortunate that anecdotal evidence provides us with considerable detail about the intervention undertaken during the 1740s. Pownall (1789:149) records a conversation in 1773 between the Bishop of Peterborough and a man who had been employed to repair the ceiling some thirty years earlier. He told the bishop that 'the whole had been repainted in oil'. Moreover, he indicated that several of the figures were then entirely encrusted with dirt, but that 'upon applying a sponge they became clear bright, whence he concluded that the last coat was in oil'. The man also indicated that 'the body of the painting (under what he supposed to be in oil) was in distemper—parts came off from the wainscot. He assured the bishop that he had only retraced the figures , except in one instance (the third or fourth compartment from the W. door where the entire figure had peeled off, and so here he followed his fancy, though imitating the style of the rest'.[8]

One entire figure was added by Charles Layton in the 19th century (an archbishop, on whose hem is painted Rd. Layton, 1834 Sexton), since the original figure had peeled away. Although examination of the surface and technical evidence suggest that Layton undertook repainting across many areas of the ceiling, it seems likely—since he was paid a relatively small sum (£30) for this work—that his intervention was less extensive than that undertaken in the 18th century.

5.1 Previous analytical investigations

Hirst Conservation undertook some pigment analysis which indicated the presence of red iron oxide, vermilion, lead white, and verdigris. It was also suggested that no white ground layer was present in the earlier decoration, though a chalk and size ground was identified in Samples 3 & 15.[9]

Further paint samples were taken by G. Lewis in 1996, and were examined and photographed at English Heritage. Some of the samples were also subjected to analysis by SEM/EDX which confirmed the presence of: a copper green with some sign of alteration to a

7 All FTIR microspectroscopy was carried out by the author at Imperial College, London.

8 Pownell 1789:149.

9 See Hirst Conservation 1995: Appendix B, and additional notes.

copper chloride; yellow iron oxide; red iron oxide; red lead; and some calcium sulphate at the wood/paint interface.[10]

6 Results: The original decorative scheme (Tables 1-IV)

6.1 Support

The original support appears to be oak and although a number of woods have been suggested in connection with replacement boards, further investigation of the ceiling structure would need to be undertaken to determine their identity.[11]

6.2 Preparatory techniques

Porous materials such as wood and stone were commonly sealed to reduce the absorption of binding media from the ground and paint layers. For panels, this sealant was commonly animal glue, and a glue sealant has in fact recently been identified on an early 14th-century screen from Kingston Lacy.[12]

Calcium sulphate combined with a proteinaceous material—probably animal glue—was identified by FTIR analysis at the wood/ paint interface in Sample 7/2099. However, given the invasive conservation treatments sustained by the Peterborough ceiling—including the application of animal glue and hessian to the reverse of the boards—and the difficulty in identifying sealants which have often been almost completely absorbed by the porous support, it is not certain whether this represents an original or added material. Traces of calcium sulphate and a clay-rich material were also identified at the wood/paint interface in a number of other samples (7/2099, 8/2100, 24/2116 & 23/2115), and it is possible that these materials may have been employed to bulk out any sealant which was applied to the support.[13]

In samples where original paint layers are almost certainly present—for example, in Samples 16 & 23, where natural azurite is combined with yellow iron oxide—traces of a lead white ground are visible. This ground would have provided a compact and highly reflective

10 SEM/EDX analysis was undertaken by H. Howard and G. Satterthwaite (English Heritage) at the Ancient Monuments Laboratory.

11 Oak, mahogany and softwood replacement boards were suggested by Hirst Conservation 1995:9-10.

12 For the use of sealants on panels generally, see (Bomford *et al.* 1990:17), and for the Kingston Lacy panel, see Tracy (1997:28).

13 The calcium sulphate here may have been employed as a material in its own right, or may represent an alteration product of calcium carbonate.

surface to interact optically with the paint layers applied subsequently. In some samples (1/2093/ 2/2094,16/2108) calcium sulphate was combined with the lead white in this preparatory layer, while in Sample 7/2099 a little carbon black was also incorporated to provide a slightly grey tone.

Given the dearth of technical evidence concerning original preparatory layers on early medieval English panels, it is unfortunate that the degree of sulphation which occurs throughout the paint layers at Peterborough makes certainty impossible as to whether calcium sulphate or calcium carbonate was originally applied to bulk out the sealant. Indeed, further sampling and analysis may help to clarify whether the bulked-out sealant may actually be regarded as an initial ground layer. In the Thornham Parva Retable of *c.* 1335, for example, the chalk ground is so thin in some places that it barely fills the wood grain, and over this chalk layer, a lead white imprimatura has been applied.[14]

In northern European panel painting generally chalk grounds are most commonly employed, and indeed a chalk ground applied in three layers has recently been identified on the ceiling panels of *c.* 1263-6 from Westminster Palace.[15] Calcium sulphate grounds have been identified in two instances—on the early 13th-century Adisham reredos, and on the most important surviving English medieval panel painting, the Westminster Retable (*c.* 1270), while a lead white ground was employed for the early 14th-century screen at Kingston Lacy.[16]

There is little evidence for the original setting out of the complex series of geometric elements and figurative details; for example, no incised or compass lines are apparent. However, close examination *in situ* did reveal a dark brown line suggesting the top of the Psaltery Player's head, and since this appears to have been executed almost directly on the surface of the wood, it seems likely that it represents part of a preparatory drawing. A paint sample taken from this area (9/2101) indicated that a combination of carbon black combined with a few brown and yellow iron oxide particles was employed.[17] In addition, in a small number of other paint samples (2, 24 & 27), traces of an underdrawing in carbon black are evident which suggests that a drawing may have been employed for locating the complex series of forms within the framework of lozenges.

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14 Analysis of the technique of the Thornham Parva Retable is currently being undertaken by Dr. S. Bucklow of the Hamilton Kerr Institute, and I am grateful to him for discussing the results of his unpublished research with me.

15 For the Westminster paterae, see the analysis by J. Lynn in Liversidge and Binski 1995:499.

16 For the Adisham reredos, see Howard 1993; for the Westminster Retable, see Binski and Freestone (1995); and for the Kingston Lacy screen, see Tracy 1997:28.

17 A single yellow particle identified by PLM and SEM/EDX as massicot (PbO) was also present.

6.3 *The original scheme of decoration: pigment and their application*

The pigments present in paint layers which appear to be original are as follows: natural azurite ($2CuCO_3.Cu[OH]_2$); vermilion (HgS); red lead (Pb_3O_4); basic verdigris ($Cu(C_2H_3O_2)_2.2Cu(OH)_2$, carbon black ($C$); lead white ($2PbCO_3 \cdot Pb[OH]_2$); red iron oxide ($Fe_2O_3$); and yellow iron oxide ($Fe_2O_3 \cdot H_2O$).

These pigments are consistent with those identified in other early English panel paintings. For example, a similar palette was employed in the mid 13th-century ceiling paterae from Westminster Palace (with the addition of ultramarine and red lake), and in the early 14th-century screen from Kingston Lacy (with the addition of red lake). Although only slight traces of paint survive on the early 13th-century Adisham reredos, vermilion, red lead, basic verdigris and lead white have been identified in its original polychromy.

Although few paint layers which are almost certainly original remain in those areas sampled, of particular interest is the unusual use of an underpaint of natural azurite combined with a little yellow iron oxide and lead white to produce the effects of modelling in the flesh tones. Despite the extensive and crude repainting which now disfigures the surface, traces of this green underpaint for the flesh are visible *in situ* with the aid of the videomicroscope. Similarly, azurite—though combined with black and white pigments—was employed to outline the figures on the Westminster Palace paterae, producing a bluish undertone in areas such as the chin of the prophet.[18]

The flesh tones themselves were produced from varying combinations of vermilion and lead white (Samples 20/2112, 21/2113, 23/2115 from St. Peter), and with the addition of a little yellow iron oxide and carbon black for the Psaltery Player (Sample 7/2099). The comprehensive later repainting of the flesh, undertaken in lead white combined with red lead or carbon black—and with harsh outlines in black reinforcing linear details—effectively conceals any subtle effects of modelling which may have been intended by the medieval artist.

Natural azurite, combined with a few particles of yellow iron oxide, also appears to have been employed for the inner zone of St. Paul's cusped mandorla (Sample 16/2108). Although this appears to have been repainted in varying shades of green, a blue colour is more likely to have been intended iconographically.

[18] A more complete pale blue underpaint is evident beneath the flesh tone of the prophet's hand; Liversidge & Binski 1995:499.

6.4 Original binding media

Although analysis of the original binding medium has been severely compromised by the later phases of repainting and invasive conservation treatment, FTIR analysis of the original flesh tone in Sample 20/2112—taken from just above St. Peter's left eye—confirmed the presence of lead white in oil.

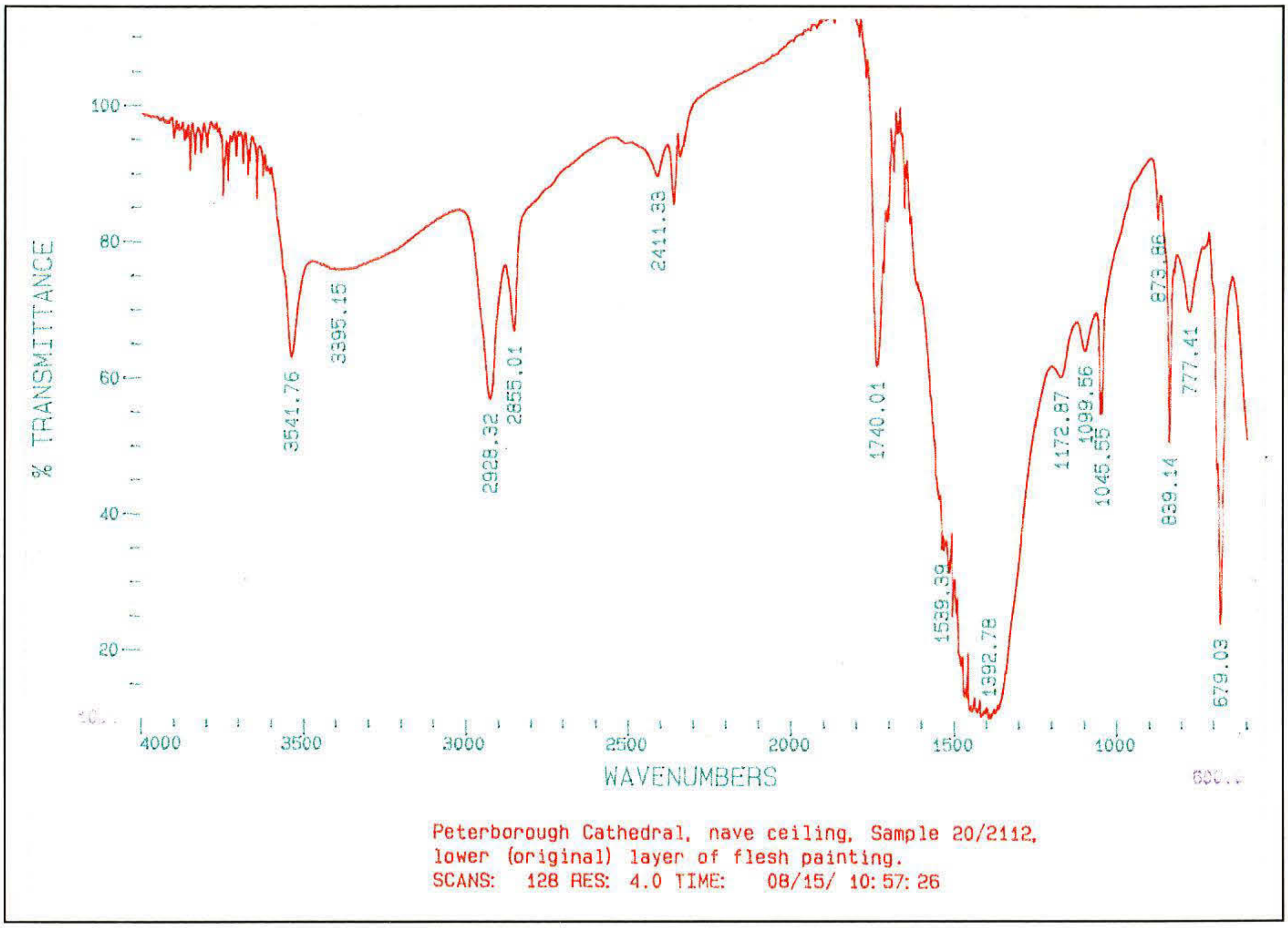

Figure 1: *The presence of lead white is indicated by the broad band around 1400* cm^{-1} *(CO_3) and peaks at 3541* cm^{-1}*, 839* cm^{-1} *& 679* cm^{-1}*, oil is suggested by the carbonyl band at 1740* cm^{-1} *and* CH_3 *stretches at 2928* cm^{-1} *and 2855* cm^{-1}*. The effect of lead white on the drying of oil results in the characteristic features around 1539* cm^{-1} *and 1622* cm^{-1}.

Linseed oil has been identified as the original binding medium of other early medieval English panels as for example the Westminster paterae of *c.* 1263-6 and the Westminster Retable of *c.*1270-90 .[19]

[19] Liversidge & Binski 1995:499; Binski & Freestone 1995:60.

6.5 Pigment alterations

FTIR analysis of samples indicated the presence of copper oxalate, which is likely to be a transformation product of the original natural azurite particles. This transformation is particularly evident in Sample 16/2108 where constituents of a pale-coloured layer beneath the blue pigment were identified as lead white, calcium sulphate and copper oxalate. In addition, copper oxalate was found in association with natural azurite in Sample 23/2115.

The presence of oxalates on stone and painted surface has been confirmed in relation to a number of factors, including the application of proteinaceous treatments.[20] Since glue—presumably from the 1920s intervention—has been found in a large number of the samples, including those showing this pigment alteration, it seems likely that the copper oxalate represents an alteration of azurite in associated with this proteinaceous material and an episode of high humidity.

Calcium sulphate has been identified at the wood/paint interface, and also at varying concentrations throughout the paint layers. This may be due to its incorporation as an original material, or to an alteration of calcium carbonate in the presence of atmospheric sulphur dioxide from the combustion of fossil fuels, or to both reasons. In addition, the application of silver chloride and carbon bisulphide—constituents of the *Silvertown* treatment —to the structure of the ceiling in the 1920s would profoundly effect the concentrations of sulphides and chlorides throughout the wooden support, ground and paint layers.[21] The presence of calcium sulphate throughout the stratigraphy makes the painting very water-sensitive.

Analysis has also confirmed the alteration of verdigris to form a copper chloride, identified by FTIR as atacamite (Samples 3/2095, 4/2096 & 8/2100). It seems likely that *Silvertown* treatment may also be implicated in this alteration, since it would have provided a ready source of chlorides.

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20 The presence of oxalates on marble and other stone and painted surfaces has been confirmed in relation to the action of cyanobacteria and lichens (del Monte and Sabbioni 1986); protective treatments—such as calcium caseinate applied to the surface (Franzini *et al* 1984); and atmospheric oxalic acid (Saiz-Jimenez 1989).

21 *Silvertown* treatment was adapted from its original function as part of a process for waterproofing fabrics—and involved treatment with a combination of silver chloride and carbon bisulphide. Details of this process are outlined in *Spons Workshop Receipts*, 4th Series, 1885:6.

7 Results: Later phases of decoration

7.1 Preparatory techniques

It appears that no fresh ground layer was generally applied to the surface in preparation for the 18th- and 19th-century interventions, but that layers of repainting were applied directly over existing paint. For example, in Sample 3/2095, Prussian blue combined with lead white has been applied directly over verdigris and yellow iron oxide, while in Sample 20/2112 repainting of the flesh tones has been executed directly on to the original layers.

However, in some cases a later lead white ground is evident, for example to prepare replacement pine boards inserted in the 19th century (Sample 18/2110). Secondary lead white grounds are also evident in Samples 13/2105 and 19/2111 where the geometric border patterns have undergone wholesale repainting, and in Sample 15/2107 for the extensive reworking of St. Paul's hair.

7.2 Pigments and their application

Pigments identified over the original paint layers are as follows: Prussian blue ($Fe_4[Fe(CN)_6]_3$); vermilion (HgS); red lead (Pb_3O_4); basic verdigris ($Cu(C_2H_3O_2)_2.2Cu(OH)_2$; carbon black ($C$); lead white ($2PbCO_3 \cdot Pb[OH]_2$); red iron oxide ($Fe_2O_3$); brown and yellow iron oxides ($Fe_2O_3 \cdot H_2O$); and barytes ($BaSO_4$).

Some of these pigments are identical to those employed in the original paint layers, making interpretation of the results particularly difficult. Certainly, it is not always possible to assign a date to each example of later painting, though in some cases the presence of a particular material does provide a clear *terminus ante quem.* Thus, although Prussian blue was well known throughout Europe by 1750 and may have been applied in the 18th- or 19th-century interventions, the presence of barytes—employed as a painting material only since the beginning of the 19th century—combined with the blue pigment in Sample 24/2116 firmly suggests the later of the two dates.

In areas of flesh painting the upper surface of the original scheme is clearly defined by a distinct dirt layer (Samples 20 & 21). However, in many other areas—presumably where the 18th-century surface washing was undertaken more vigorously—there is no clear interface between the original and various later painting phases. For example, in Sample 16/2108 a layer of verdigris and yellow iron oxide is closely associated with the underlying layer of natural azurite. In this instance the lack of distinction between the layers may also be due to the pigment alterations which appear to be ongoing in both paint layers, resulting in the transport of particles towards the upper surface.

It is particularly difficult to be clear about the relationship between this green layer—consisting of verdigris combined with yellow iron oxide, and which is evident in a number of the samples—and other layers within the overall stratigraphy. Since Prussian blue is found on top of this pigment mixture in sample 3/2095, the green layer clearly pre-dates the 19th-century intervention. The same combination of verdigris and yellow is found over the original azurite background of St. Paul's mandorla (Sample 16/2108), and it is unlikely that it is original. However, it is possible that this sample was taken from a detail in green applied over the original blue background, so further sampling and analysis of other areas of the ceiling will be necessary to interpret this green layer fully.

Close examination of the surface in raking light indicated the presence of a trefoil design which extends beneath the chevron pattern in some places. Sample 27/2119, taken from this area, indicated that a combination of vermilion with lead white was employed to create the trefoil pattern. The thick lead white preparation, over which the pink paint layer appears to have been painted almost wet-on-wet, suggests that this design represents a later addition. A similar pink layer was detected in Sample 26/2118—taken from an area further along the board, but where no trace of an underlying design is visible even in raking light—indicating that the trefoil pattern may be more extensive than was initially thought.

8 Discussion

In this preliminary phase of examination and analysis it has been possible to establish the presence of original paint layers (dating to *c.*1220) on the ceiling, and moreover, to confirm that oil was employed as a binding medium in these layers. It is possible that a proteinaceous component would also have been employed, particularly in combination with the copper-based pigment natural azurite. However, the wholesale application of glue to the reverse of the ceiling in the 1920s makes it impossible to be certain about the origin of any proteinaceous material detected in the ground and paint layers.

Despite the extensive repainting to which the ceiling has been subjected, it has also been possible to elucidate some aspects of the application of the original materials—such as the use of azurite combined with lead white and yellow iron oxide to form a green underpaint for the flesh tones of St. Peter. It is significant that the closest parallel for this is found in the ceiling fragments from the Painted Chamber at Westminster Palace, of *c.*1263-6.

Concern was expressed by the conservators on site about the degree and speed of blanching exhibited by some paint layers in contact with water. This phenomenon was particularly serious in the repainted grey linear details on the red drapery of St. Paul and St. Peter (Samples 10/2102 & 22//2114), and on St. Paul's turquoise-blue drapery (Sample 14/2106). The high proportion of clay-rich minerals and calcium sulphate in these paint layers has clear implications for its water sensitivity, since clay-based materials swell readily in the presence of moisture. Overall, the presence of calcium sulphate at the wood/paint interface and throughout the structure makes the painting profoundly water sensitive.

An episode of high humidity at some time in the past—perhaps when the hessian and glue were applied to the reverse of the ceiling panels—is implicated in the pigment transformations which have been detected, such as that of azurite to copper oxalate. The treatment of the ceiling structure in 1926 with *Silvertown*, a product containing silver chloride and carbon bisulphide, is likely to have further facilitated the transformation of calcium carbonate to form calcium sulphate and verdigris to a copper chloride.

9 Acknowledgements

I am particularly grateful for the active collaboration of Adrian Heritage (English Heritage), who was fully involved with the *in situ* investigations, including undertaking the examination of the painted surface with a video microscope. Julian Limentani and Gillian Lewis have facilitated the investigations throughout, and thanks are also due to Mark Perry and Richard Lithgow for valuable practical help of numerous kinds. I am indebted to the Photogrammetric Unit of the Professional Services Survey of English Heritage for providing drawings based on its photogrammetric survey of the ceiling, which have been used here in the graphic documentation. I am also especially grateful to David Park and Sharon Cather for assistance with the preparation of this report.

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• Table I - Psaltery Player

Sample No. Accession No.	Location & Description	Original & Later Polychromy	Additional materials & Comments
1/2093	Nave ceiling, Psaltery Player, instrument: *pink/brown colour on wooden support.*	• *yellow earth pigment with siliceous inclusions in a lead white matrix 250µm* • *red iron oxide in lead white matrix 25 µm* • *lead white preparation with some calcium sulphate 15 µm* • *trace wood support*	• coating and accretion of dirt on surface 10 µm
2/2094	Nave ceiling, Psaltery Player, cusped mandorla: *green paint layer.*	• verdigris combined with a brilliant yellow earth pigment 90µm • *carbon black (drawing?)* • *lead white preparation with some calcium sulphate 5-80µm* • *trace wood support*	• coating and accretion of dirt on surface 5 µm • analysis by SEM/EDX indicated that the verdigris has a high chlorine content. This analysis also indicated a high Al and Si content in the yellow iron earth pigment, together with traces of Ti and K.
3/2095	Nave ceiling, Psaltery Player, cusped mandorla: *blue/green over green.*	• Prussian blue in lead white matrix 90 µm • large particles of verdigris (400 x 200 µm) combined with brilliant yellow earth pigment in an oil medium 850 µm • *wood support*	• presence of verdigris in oil confirmed by FTIR analysis. This analysis also indicated a partial alteration of verdigris to form a copper chloride (atacamite).
4/2096	Nave ceiling, Psaltery Player, edge of instrument: *purple with white line applied in impasto.*	• *lead white 85 µm* • *particle of verdigris (180 x 160 µm)* • *black and orange/red iron oxide particles in a lead white matrix 100 µm* • *wood support*	• coating and accretion of dirt on surface • analysis by SEM/EDX indicated that the copper green particle in this sample has partially altered to form a copper chloride. The upper portion of the particle has a high Si content with a little Al. SEM/EDX analysis also indicated a low Al and Si content in the yellow iron earth pigment, together with traces of K. The black pigment particles contain some S, Si, Al & Ca.
5/2097	Nave ceiling, Psaltery Player, cusped mandorla: *glue over intense red detail.*	• pure vermilion 350 µm • medium rich white preparation 50 µm	• crust on surface 20 µm • thick dark coating of animal glue on surface (confirmed by FTIR) 330 µm • accretion of dirt 10 µm
6/2098	Nave ceiling, Psaltery Player, cusped mandorla, red decorative motif: *bright lower red.*	• *dispersion sample only. Analysis by PLM indicated the presence of vermilion*	
7/2099	Nave ceiling, Psaltery Player, left proper cheek: *pale flesh tone.*	• *few tiny particles of vermilion in a lead white matrix with a single large particle of carbon black 65 µm* • *vermilion with a few particles of yellow iron oxide and carbon black in a translucent lead white matrix 20 µm* • *carbon black in a matrix of calcium sulphate, lead white and* animal glue *35 µm*	• analysis of animal glue in lowest layer was confirmed by FTIR

8/2100	Nave ceiling, Psaltery Player, hair: *metallic bloom on surface of brown hair.*	• carbon black combined with yellow iron oxide and lead white 35 µm • large particles of verdigris combined with a brilliant yellow earth pigment 80µm • *wood support (calcium sulphate is present at the interface of the wood and paint layers)*	• dense black layer on surface which has a metallic sheen 15 µm • SEM/EDX analysis indicated a high Al and Si content in the yellow iron earth pigment, together with traces of Ti and K. This analysis also indicated that the verdigris has partially altered to form a copper chloride.
9/2101	Nave ceiling, Psaltery Player, top of head: *dark line which appears to be beneath 'early green' (S2).*	• *carbon black with brown and yellow iron oxide particles and a single particle of a lead-based yellow, likely to be massicot 120 µm*	• dense black layer which has a metallic sheen 5 µm • SEM/EDX analysis indicated a low Al and Si content in the yellow iron earth pigment, together with traces of K.

• Table II - St. Paul

Sample No. Accession No.	Location & Description	Original & Later Polychromy	Additional materials & Comments
10/2102	Nave ceiling, St. Paul: *highlight of red drapery which blooms readily on contact with water.*	• carbon black with yellow iron oxide, white and some vermilion from underlying layer 45 µm • *vermilion 20 µm* • *red lead combined with calcium carbonate 35 µm* • *red lead combined with carbon black 45 µm* • *wood support*	• some positive staining for sulphate in the upper-most layer—specific translucent particles give a positive result. In addition, analysis by SEM/EDX indicated that clay-rich particles are present in this layer. This analytical technique was also used to confirm the presence of vermilion (HgS).
11/2103	Nave ceiling, St. Paul: *drip of glue from near to bible.*	• yellow iron oxide 180 µm • lead white 80 µm	• thick layer of animal glue on surface (confirmed by FTIR) 130 µm
12/2104	Nave ceiling, St. Paul, left proper sleeve, yellow brown drapery: *intense yellow agglomerate in yellow/brown paint layer.*	• intense yellow iron oxide 250 µm • black pigment 60 µm • red iron oxide with lead white 15 µm • yellow iron oxide combined with some calcium carbonate and lead white 90 µm • *wood support*	• accretion of dirt on surface • SEM/EDX analysis indicated that the yellow earth pigment in both layers is rich in Al and Si with a trace of K & S. This method of analysis also indicated that the black layer is rich in Al, Si with traces of S, Ca and Fe.
13/2105	Nave ceiling, St. Paul, 1st order of border pattern around figure: *white with black key pattern.*	• lead white 25 µm • large particles of carbon black combined with yellow iron oxide and lead white 125 µm • lead white 260 µm • wood support	
14/2106	Nave ceiling, St. Paul, cusped mandorla: *turquoise blue which blooms readily in contact with water.*	• Prussian blue combined with lead white 15 µm • Prussian blue combined with lead white 60 µm • lead white preparation 25 µm • wood support	
15/2107	Nave ceiling, St. Paul, hair, left proper side: *yellow highlight over purple/brown.*	• yellow iron oxide combined with carbon black and lead white 100 µm • lead white 75 µm • *large particles of carbon black combined with red and yellow iron oxides and lead white 300 µm*	• SEM/EDX analysis suggested the presence of a trace of S in black particles in the upper layer containing black pigment, while traces of Al, Si and S were present in the black pigment in the lowest layer.
16/2108	Nave ceiling, St. Paul, cusped mandorla, inner area: *bright yellow/green with darker green on surface.*	• vermilion in yellow and white matrix 25 µm • dark green combined with brilliant yellow 50 µm • *azurite combined with yellow earth in an organic matrix 175 µm* • *white layer consisting of lead white, calcium sulphate and copper oxalate 20 µm* • *wood support*	• FTIR analysis indicated the presence of copper oxalate, which is likely to be a transformation product of the original azurite particles.

17/2109	Nave ceiling, St. Paul, stepped 'battlement' border around figure: *brown/black.*	• brown and yellow iron oxide particles combined with brilliant yellow and black 150 µm • large carbon black particles combined with yellow iron oxide and lead white 80 µm • lead white 45 µm	• pale layer of coating or consolidant on surface 5 µm • a few particles in the uppermost paint layer stain positive for lead, as does the white ground. SEM/EDX analysis suggested the presence of a trace of S in black pigment particles in the upper paint layer, and indicated that calcium sulphate is also present in this layer.
18/2110	Nave ceiling, St. Paul, 19th-century replacement board with stepped 'battlement' border pattern: *metallic grey over cream.*	• brown and yellow iron oxide particles combined with brilliant yellow, barytes and black 45 µm • lead white 75 µm • pine support (replacement board)	• coating, as yet unidentified, and accretion of dirt on surface 5 µm • SEM/EDX analysis indicated the presence of barytes (barium sulphate) in the paint layer.
19/2111	Nave ceiling, St. Paul, chevron border: *opaque rich black.*	• shiny black pigment particles 15 µm • lead white 7 µm • dense black combined with lead white 65 µm • lead white 45 µm • wood support	• SEM/EDX analysis suggested the presence of a trace of S, Cl and Ti in black pigment particles from the uppermost layer.

• Table III - St. Peter

Sample No. Accession No.	Location & Description	Original & Later Polychromy	Additional materials & Comments
20/2112	Nave ceiling, St. Peter, above left proper eye: *flesh tone.*	• red lead combined with lead white and some carbon black 50 µm • dirt • *tiny particles of vermilion combined with lead white in an oil medium 85 µm* • *tinted preparation (lead white combined with a little black and red) 45 µm* • *trace wood support*	• accretion of dirt on surface
21/2113	Nave ceiling, St. Peter, above right proper eye: *flesh tone consolidated by the Perry Lithgow Partnership, 4.97.*	• lead white combined with a little carbon black 20 µm • dirt • *tiny particles of vermilion in a lead white matrix 50 µm* • *azurite combined with yellow earth in a lead white matrix 60 µm* • *wood support 25 µm*	
22/2114	Nave ceiling, St. Peter, left proper knee: *highlight of brilliant red drapery which blooms readily in contact with water.*	• red lead combined with lead white and some calcium sulphate 65 µm • *vermilion 100 µm* • *red lead combined with lead white and carbon black (there is a sulphate-rich zone at the top of this layer) 80 µm* • *red lead combined with carbon black 10 µm*	• a few translucent particles within uppermost red lead and lead white layer give a positive sulphate test. There is also a sulphate-rich zone immediately beneath the vermilion.
23/2115	Nave ceiling, St. Peter, left proper temple: *flesh tone with what appears to be an earlier consolidant on the surface.*	• *vermilion in a lead white matrix 110 µm* • *azurite combined with a little yellow earth in a lead white matrix 65 µm* • *wood support with some clay-rich material and lead white at the interface of the wood and paint layer.*	• FTIR analysis indicated that the azurite has partially altered to form copper oxalate. • FTIR analysis also confirmed the presence of a proteinaceous material, likely to be animal glue, combined with calcium sulphate on the surface of the sample. • lead test positive in matrix of vermilion and in matrix of blue/green layer. The blue particles are decolourised by the acid. • SEM/EDX analysis confirmed the presence of vermilion (HgS) in the uppermost paint layer and confirmed Cu in the azurite particles.
24/2116	Nave ceiling, St. Peter, right proper sleeve: *dark-blue lining of sleeve.*	• dark blue layer containing Prussian blue with barytes (barium sulphate) and a little lead white 25 µm • pale blue layer containing Prussian blue in a lead white matrix 100 µm • *trace carbon black (? drawing)* • *wood with calcium sulphate at the wood/paint interface*	• SEM/EDX analysis suggested the presence of a trace of S in the upper layer containing black pigment

25/2117	Nave ceiling, St. Peter, border with key pattern: *shiny black paint with white bloom on surface.*	• dense dark layer with black, brown and yellow inclusions 750 µm • carbon black, yellow and brown particles 55 µm • lead white 15 µm	• pale white layer on the surface 10 µm (? consolidant as yet unidentified). Inner portion of this layer stains positive for lead, as does ground.
26/2118	Nave ceiling, St. Peter, border with chevron pattern: *brown stain at edge of border.*	• lead white 50 µm • pale pink layer of vermilion combined with lead white 35 µm • lead white 100 µm • wood support	• consolidant and accretion of surface dirt • pink and white layers appear to have been applied wet on wet
27/2119	Nave ceiling, St. Peter, border with extended chevron pattern: *ghost of trefoil pattern beneath chevron design.*	• lead white 80 µm • pale pink layer of vermilion combined with lead white 25 µm • lead white 125 µm • *carbon black (?drawing)* • *wood support*	• consolidant and accretion of surface dirt • pink and white layers appear to have been applied wet on wet • white layers and matrix of pink stains positive for lead
28/2120	Nave ceiling, St. Peter, chevron border: *impasto decoration beneath grey paint.*	• grey layer of carbon black combined with lead white and some red, yellow and brown iron oxide particles 430 µm • lead white combined with a little carbon black 800 µm	• accretion of surface dirt and consolidant which has penetrated into the upper portion of the paint layer. FTIR analysis indicated that this material is likely to be shellac.
29/2121	Nave ceiling, St. Peter, border with extended chevron pattern: *'rusty' brown stain on creamy/white paint.*	• lead white with a few dark inclusions and a few particles of red lead 250 µm	• dark coating 15 µm

The tables above give the location where each sample was taken, the sample number, its Courtauld archive accession number, and the stratigraphy of the various layers from the top layer down, with the thickness of each layer in microns (µm). Layers in italics are those which are likely to have formed part of the original scheme.