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Non-invasive survey of pre-restoration condition of the ceiling paintings by Peter Paul Rubens at the Banqueting House Whitehall, London, by means of Optical Coherence Tomography

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Abstract

This article presents the results of the examination by means of optical coherence tomography (OCT) of two of the nine monumental ceiling paintings by Peter Paul Rubens and his studio, still located in their original location at the Banqueting House, the only surviving building of the former Whitehall Palace in London. OCT is a non-invasive technique of structural imaging of layers semi-permeable to the infra-red radiation. The aim of the 2018 research campaign at the Banqueting House, conducted within the MOLAB programme under the IPERION CH project, was to determine the present condition of the paintings and thus inform decisions about future conservation planning for these unique paintings.

Keywords: materials science, optical methods, stratigraphy, non-invasive structural imaging, varnish, optical coherence tomography

Introduction

The nine ceiling paintings at the Banqueting House, Whitehall Palace, were painted by Peter Paul Rubens and studio in Antwerp and transported to London to be installed in 1636 (Martin 2005). The canvases were commissioned by King Charles I as a testament to the glory of the Stuart monarchy through the depiction of his father James I's life and achievements. Whitehall Palace was destroyed in a fire in 1698 and the Banqueting House, is the only remaining building from this vast palace. As one of the largest (243 m²) and most complex works by the master, and the only one surviving in-situ for nearly 400 years, the ceiling paintings are of immeasurable artistic and historic value. Since their creation, the paintings have been removed from the ceiling at least five times and treated at least nine times. These interventions included removing the canvases from their original stretchers and marouflaging them onto plywood boards in the beginning of the 20th century, cutting, removal and evacuation of the panels during World War II, followed by three restoration treatments (in the 1940s-50s, 1970s and 1990s).

Historic Royal Palaces' current Banqueting House conservation and re-presentation project provided a rare opportunity to carry out a first ever full and systematic technical conservation survey of the Rubens ceiling paintings. Scaffold access between February and April 2018 enabled among other activities the present research campaign, conducted with MOLAB multitechnique approach under IPERION CH project. A range of analytical techniques were applied to determine how the paintings were created, how they have changed over the years and to establish an accurate record of their present condition. This technical evidence will inform the future conservation approach of these important paintings.

In this article, results obtained with optical coherence tomography (OCT), one of the methods used during this onsite analytical work, will be presented. Due to time limitations, two paintings of the cycle were selected for OCT analysis: *The Apotheosis of King James I*, the large oval central painting, and *The Wise Rule of King James I*, the southernmost large rectangular painting, were examined in. The project team carefully selected eighty six areas in total for examination by means of OCT following assessment of the available high-resolution multispectral images, historic documentation, previous condition survey reports and results of earlier investigations (Frame et al. 2017).

Materials and Methods

Optical coherence tomography (OCT) (Targowski and Iwanicka 2012; as of Noveber 31, 2108, the complete list of papers on application of OCT to examination of artwork may be found at http://www.oct4art.eu) is an interferometric non-invasive technique of depth-resolved imaging within media scattering and/or absorbing near-infrared light moderately. Its ability of scanning centimetre-wide areas in order to obtain information about sequence, continuity and thickness of the subsurface layers makes it especially suitable for examination of easel paintings as well as other objects of art (Targowski et al. 2015; Striova et al. 2016; Targowski et al. 2018). Herein, a high resolution (2 µm axial, 12 µm lateral) spectral domain OCT instrument utilising near infrared (770–970 nm) radiation of 0.8 mW power beam at the object was employed. The measurements were *in situ*, with the instrument head pointing upwards.

In this contribution OCT cross-sections (tomograms) are presented in false colours. Warm colours correspond to high scatter/reflection of the probing light, whereas cold colours mark areas with low scatter. Transparent media (e.g. clear varnishes, glass or air above the surface of the examined object) or areas located beyond the range of penetration are shown dark. The vertical scale in OCT tomograms is elongated for better readability. All the tomograms presented herein were corrected for light refraction in the painting materials and comprise the scale bars equivalent to 200 µm in both directions. In this work three OCT post-processing modalities are used: for simple 2D imaging cross-sectional views (tomograms) and two others, where 3D cloud of points composed of 100 cross-sections collected from a square 12 x 12 mm area was utilized: depth-resolved scattering maps (gate images (Iwanicka et al. 2016), Fig. 3 c,d), and surface area profiles (3D models, Fig. 4c). For the former, the slice of voxels from a given depth under the surface of the object examined (further referred to as the depth of the gate) and of a given thickness (further referred to as the width of the gate) has been extracted.

During the scaffold access period between March and April 2018, eighty six areas were examined in total by means of OCT on both *The Apotheosis of King James I* and *The Wise Rule of King James I* paintings. Conservation issues addressed during these analyses included establishing the number, thickness and condition of the varnish layers, identifying evidence of past restoration treatments (i.e. overpainting) and assessing their impact on the current appearance and condition of the paintings. Moreover, some degradation processes were targeted with the OCT analysis, such as blanching and delamination of varnish layers, fading of organic dyes and presence of crusts on certain areas of the paintings. Rubens' original technique was also investigated during this on-site campaign with focus on the use of semi-transparent glazes. Figure 1 indicates the analysis areas discussed in this paper.

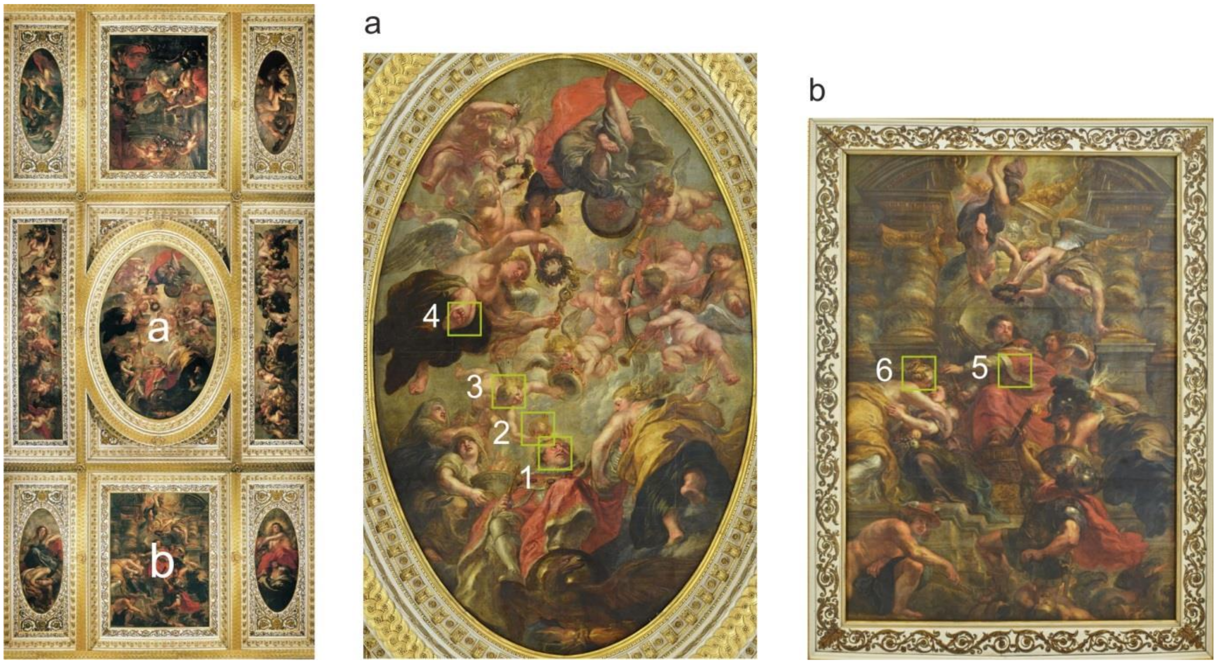

Figure 1. Peter Paul Rubens and studio, from left: overview of the ceiling the Banqueting House Whitehall, London. (a) *The Apotheosis of King James I*, (b) *The Wise Rule of King James I*; oil on canvas (9.73 x 6.20 m and 7.45 x 5.28 m respectively), installed in 1636. Visible light photographs, OCT examination areas described in this paper are marked with green squares.

Results

In most of the forty-four spots examined in the *Apotheosis of King James I* two or three varnish layers were found. The thickness of layers varies greatly, in average ranging from 25 microns to over 100 µm for the whole build-up.

In an OCT tomogram collected from the lips of King James I, the central figure of the *Apotheosis* (Fig. 2a) a thick layer of red glaze (1) is visible (40-80 µm), covered by two varnish layers (2,4; bottom layer: 15-25 µm, upper layer: 30-50 µm) which are separated by a thin layer (probably of dirt, 3) scattering the probing light. Although OCT is a technique sensitive to optical differences in materials, in practice the difference in refractive indices of different kinds of resins are not significant enough to create a clearly visible interface in OCT tomograms. Some deterioration phenomena, such as, for instance, oxidation of the varnish surface or presence of dirt, result in the identification of a distinct boundary between varnish layers. However, in the case of the second tomogram, presented in Fig. 2b, collected across the discolourations in the putto's thumb, the structure between the varnish layers (2) has a significant thickness (ca 10 µm). This layer is fairly absorbing the infrared radiation, as the signal from the surface of the original paint layer immediately below is locally decreased (yellow arrows in Fig. 2b). In this case the layer embedded in between varnish layers is a retouching, probably dating from the 1940s intervention, lying on a thick varnish layer (ca 40-50 µm), covered by an extremely thin varnish (ca 5 µm) and another, uppermost varnish (ca 15-30 µm).

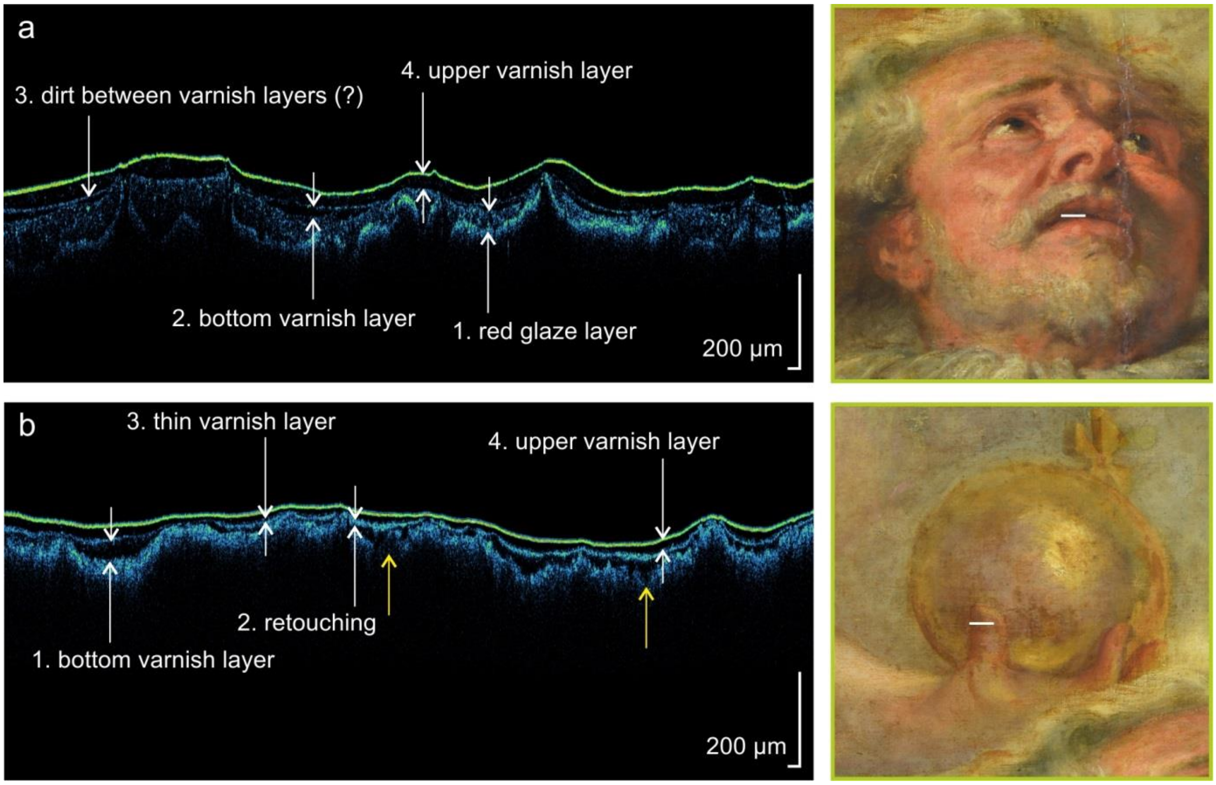

Figure 2. OCT tomograms of the *Apotheosis of King James I*. (a) The King's lips, spot 1 in Fig. 1; (b) right thumb of a putto holding a sphere, spot 2 in Fig. 1, yellow arrows mark loss of signal at the level of the paint layer due to absorption in the retouching layer. White lines in the visible light photographs mark the exact localisation of the OCT scanning.

OCT is also a useful tool regarding assessment of some of the deterioration phenomena. In Fig. 3 a,b two types of delaminations found in the *Apotheosis* painting are shown, both resulting in optical changes to the surface, namely blanching of the varnish. OCT examination revealed that in both cases lateral delaminations were present in the structure of the painting. Such detachments are generally well visible in the OCT tomograms. Due to a leap of refractive index at the interface of the delaminated layers, the intensity of the signal scattered in internal damages is comparable to the intensity of the radiation scattered at the uppermost surface of the examined object. In the false-colour scale used herein, they are represented as yellow lines. The localisation of the delaminations was, however, different for two examined spots: in the putto's hair there are delaminations between the uppermost varnish and the other two varnish layers (Fig. 3a), whereas in the dark green cloak of another angel (Fig. 3b) the blanching is caused by a lack of adhesion of varnish layers to the paint layer. Gate images obtained from the two areas (Fig. 3 c,d, see description in the Materials and Methods section) show different patterns of deterioration. In case of the area of the putto's hair blanching-causing delaminations correspond to craquelure (Fig. 3c), whereas in a green cloak they are in a form of patches (Fig. 3d).

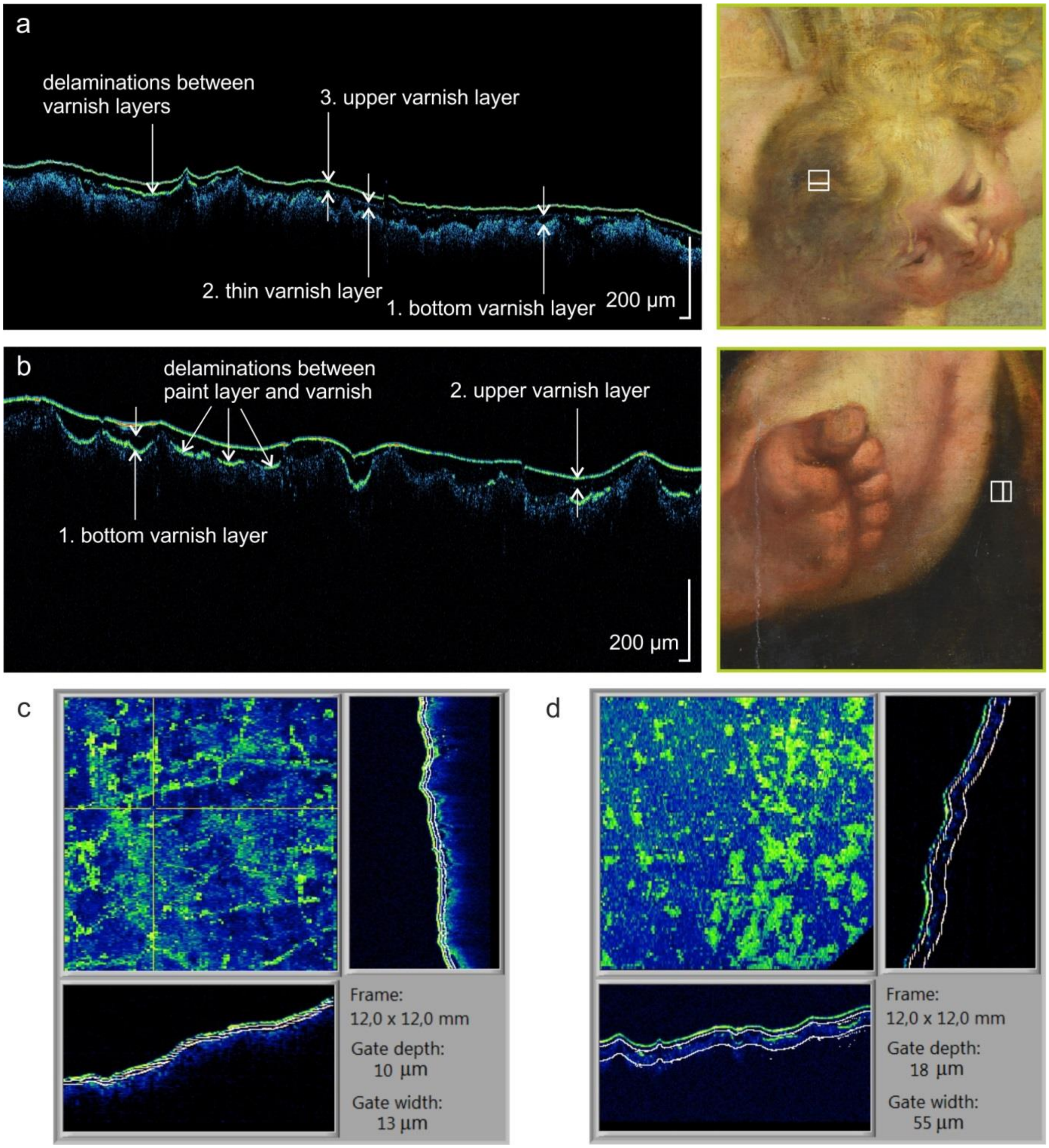

Figure 3. OCT tomograms and gate images of the *Apotheosis of King James I*. (a, c) The hair of the putto holding a sphere, spot 3 in Fig. 1; (b, d) the dark green cloak of the putto holding a caduceus and a laurel wreath, spot 4 in Fig. 1. White lines and squares in the visible light photographs mark the exact localisation of the OCT scanning (tomograms and gate images, respectively).

In the *Wise Rule of King James* I forty-two spots were examined by OCT. Generally, three or more varnish layers were found in most places, of an average thickness of the whole build-up rarely exceeding 50-60 microns.

Similarly to the *Apotheosis*, semi-transparent glaze layers were found in the red areas of the *Wise Rule.* In the tomogram recorded in the King's cloak (Fig. 4a) two glaze layers (35-45 µm) are visible, covered by three varnish layers of moderate thickness altogether (50 µm), evening out the roughness of the paint. In the second example from the *Wise Rule*, the uppermost varnish layer is, however, affected by drying wrinkles (marked by yellow arrows in fig. 4b), which change the outlook of the surface of the painting in this area, which can be evaluated better through the inspection of a 3D model of the surface, created from the OCT data (Fig 4c). The area of a female figure's hair also bears evidence of past cleaning attempts. In the left-hand side of the tomogram (cleaned area in the highlight), one can observe the remains of the semi-transparent paint layer (1 in Fig. 4b) preserved only in paint recesses in a thin layer (ca 15 µm). Conversely, in the uncleaned part (in a shadow between strands of hair), which is represented in the right-hand side of the tomogram, the same layer is continuous and much thicker (45-60 µm). This kind of arbitrary, time-effective surface cleaning approach, affecting only the areas of composition lighter in colour is of course not in line with today's conservation ethics, it was, however, not uncommon in the past, especially in case of paintings of such a large scale. It exaggerates the contrast in the paintings and interferes with the legibility of the artistic composition.

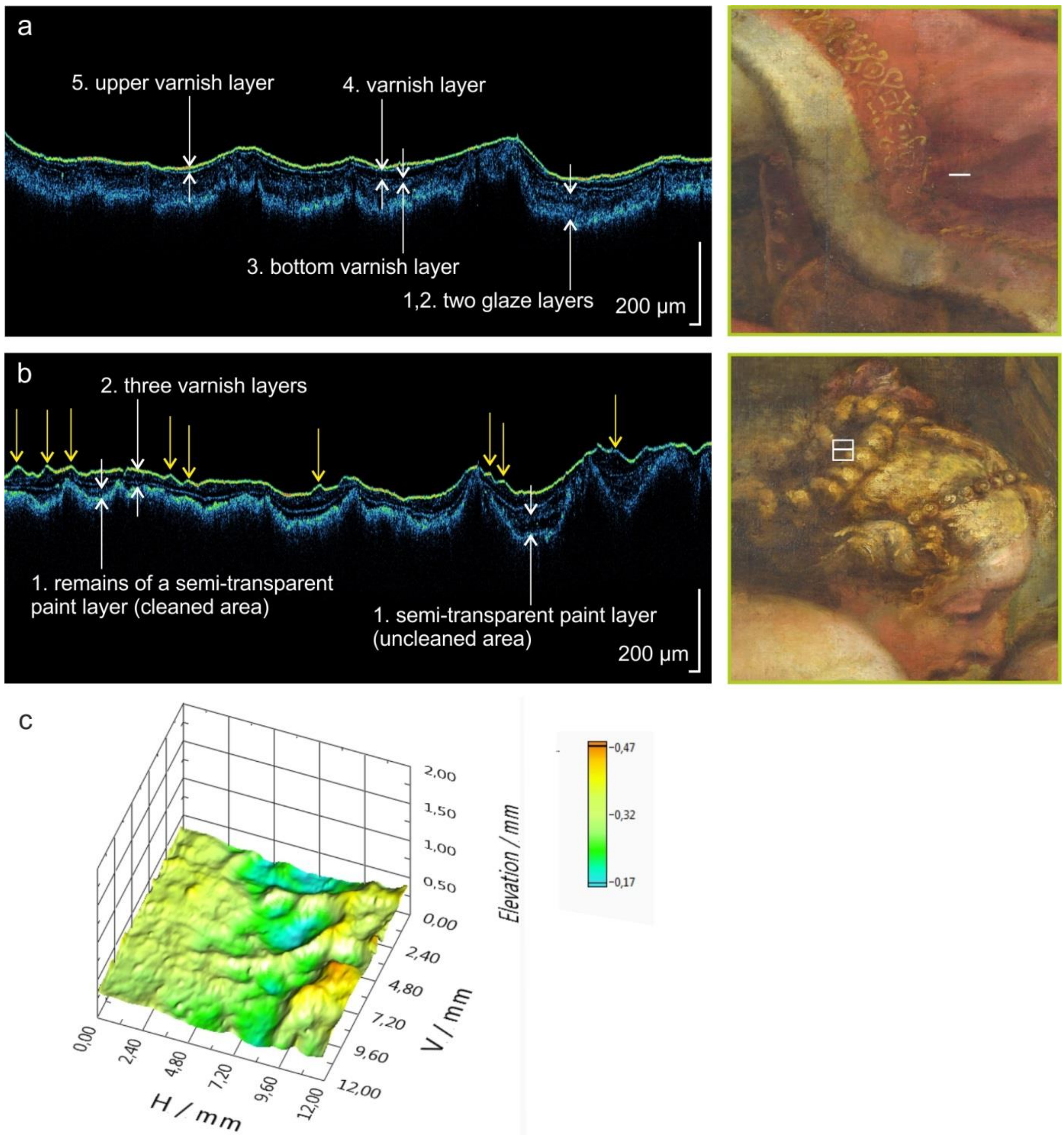

Figure 4. OCT tomograms of the *Wise Rule of King James I*. (a) The hair of a female figure to the left, spot 5 in Fig. 1; (b) the red cloak of the King, spot 6 in Fig. 1, yellow arrows mark drying wrinkles in the uppermost varnish; (c) 3D surface profile obtained from the same OCT data as in (b). White lines and square in the visible light photographs mark the exact localisation of the OCT scanning (tomograms and gate images, respectively).

Discussion

Based on the analysis of all the eighty-six spots examined with OCT on the *The Apotheosis of King James I* and *The Wise Rule of King James I*, two monumental Rubens' paintings, some general conclusions can be drawn.

The number of varnish layers are generally at least two in the *Apotheosis* and at least three in the *Wise Rule*, although in some areas (particularly dark background areas that were not cleaned thoroughly in previous campaigns) up to seven varnish layers (data not shown) could be identified by OCT. The overall thickness of varnish layers is greater in the *Apotheosis*, however the number of layers is greater in the *Wise Rule.* The uppermost varnish layer in the *Apotheosis* is significantly thicker than in the *Wise Rule*, which is not surprising in the light of the preserved documentation from the last restoration treatment – as the two paintings were treated by different conservation teams in the 1990s.

Regarding the investigation of Rubens' painting technique, some insight was attained into the use of semi-transparent paint layers. In both paintings red glaze layers of varied thickness have been found as highlights on some red and purple cloaks as well as on the faces; they were used to provide depth and shades in flesh tones.

Retouchings/overpaintings from different restoration campaigns were discovered. OCT was useful to identify areas of overpainting and showed that the most recent retouchings are not varnished, which confirms the observations of UV-induced fluorescence imaging. The cause of the brownish appearance of some areas of the paintings was identified as related to the presence of discoloured retouchings, residues of dirt between varnish layers or uneven past cleaning attempts..

Two types of varnish delamination were observed corresponding to the blanching that is extensively affecting both paintings. In the *Apotheosis*, the delaminations were localised either between varnish layers or at the interface between paint and varnish. However, in the *Wise Rule* only one type was identified, namely detachments of the varnish from the paint layer.

The authors are aware that it is difficult to transpose results of multiple local analyses into firm conclusions particularly in this case of such large scale paintings. There is, however, no true area-wise technique able to give insight on the stratigraphy of paintings. In this sense, we strongly believe that despite its limitations, OCT provides representative results regarding varnish build-up and thickness to classical sample analysis. It is important to note that although the *in situ* set up provided certain challenges such as positioning the OCT instrument's head pointing upwards as well as working on the scaffold platform which presented vibrations due to movement, a large number of measurements were acquired successfully due to great team effort and collaboration.

Acknowledgments

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Declaration of interest statement

The authors declare no conflict of interests.

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