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A Characterisation of the Protrusions on Liu Kang's *Boat scene* (1974) from the National Gallery Singapore

Damian Lizun [1,*] and Teresa Kurkiewicz [2]

[1] Islamic Arts Museum Malaysia, Jalan Lembah Perdana, Kuala Lumpur 50480, Malaysia
[2] Department of Painting Technology and Techniques, Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, ul. Sienkiewicza 30/32, 87-100 Toruń, Poland; teresak@umk.pl
* Correspondence: damianlizun@iamm.org.my or d.lizun@fineartconservation.ie

Abstract: This paper investigates the oil on canvas painting *Boat scene* (1974) by Liu Kang (1911–2004), belonging to the National Gallery Singapore (NGS). The focus is on disfiguring paint protrusions in a specific area and colour in the composition. Moreover, in search of the possible factors responsible for the creation of the protrusions, the structure and composition of the paint layers were determined. Three possible reasons were put forward to explain this phenomenon: deliberate textural effects, the expansion of metal soaps and unintentional paint contamination during the artistic process. Investigative techniques such as technical photography, digital microscopy, optical microscopy (OM), polarised light microscopy (PLM), field emission scanning electron microscope (FE-SEM-EDS) and attenuated total reflectance micro-Fourier transform infrared spectroscopy (ATR μ-FTIR) were employed to analyse paint layers, including protrusion samples. The analyses revealed that the protrusions resulted from an unintentional contamination of the oil paint during the artistic process by dry fragments of different pigment mixtures bound in drying oil. Zinc soaps were found in significant concentrations within the protrusions and other parts of the painted scene. Nevertheless, the metal soaps do not pose a direct risk to the integrity of the paint layers at the time of this research. The analyses highlight the potential challenges caused by the protrusions that conservators may face while caring for the painting. The research contributes to our ongoing comprehension of the artist's working process.

Keywords: paint contamination; pigments; metal soaps; Liu Kang; FE-SEM-EDS; ATR μ-FTIR

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1. Introduction

In 2016, during a routine condition survey at the Heritage Conservation Centre in Singapore, extensive surface protrusions were found on the oil on canvas painting *Boat scene* (1974) by Singaporean artist Liu Kang (1911–2004) (Figure 1a). The protrusions can be observed without magnification and are associated with the yellow-painted areas, depicting the sandy coast, which appear very gritty (Figure 1b–e). Close inspection allowed us to discern that the protrusions, due to their size, may be vulnerable to physical impact and considered a threat to the condition of the paint layer. Hence, a thorough investigation was initiated to understand if this paint feature relates to the artist's painting technique or reflects an ongoing deterioration process within the paint layer.

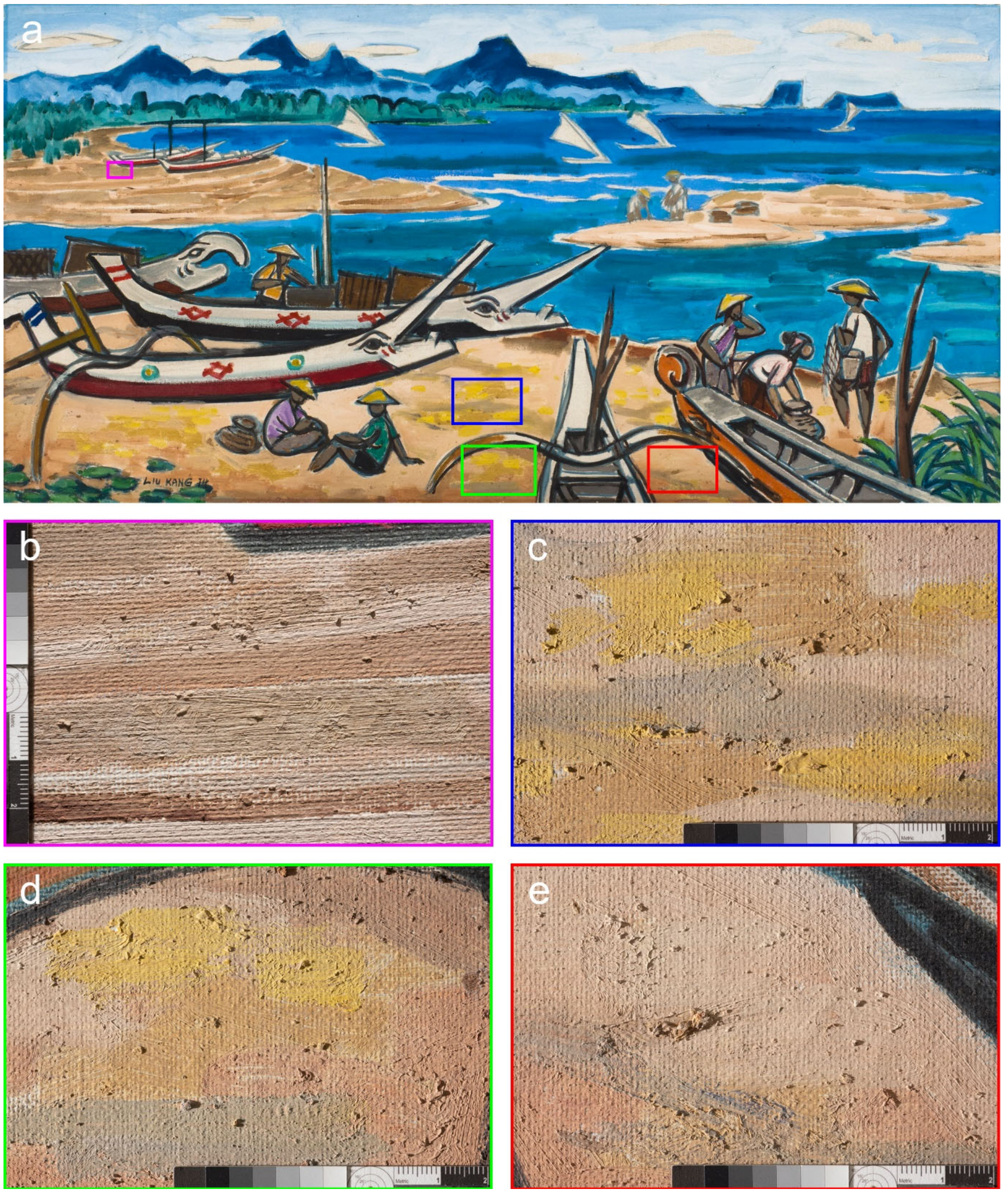

Figure 1. (**a**) Liu Kang, *Boat scene*, 1974, oil on canvas, 71.5 × 142.5 cm, showing four selected areas of the paint layer (pink, blue, green and red rectangles) and corresponding close-ups of the painting, revealing protrusions (**b**–**e**). The artwork was generously donated by the artist's family. Collection of the National Gallery Singapore. Image courtesy of the National Heritage Board, Singapore.

Liu Kang was born in China. He received formal artistic training in Shanghai (1926–1928) and, later, in Paris (1929–1932). In 1945, he made Singapore his permanent home and emerged as a prominent figure within the country's art scene, notably contributing to the development of the Nanyang style. The style was invented and popularised in Singapore from the late 1940s to 1960s; it combined influences from the School of Paris and Chinese painting traditions, while also integrating stylistic elements characteristic of batik techniques [1–3]. Although the painting *Boat scene* was created in 1974, it follows a sketch made in Bali in 1952 (Figure 2) and embodies the fundamental tenets of the Nanyang style in its use of local subject matter and an exposed white ground to enhance the elements of the composition.

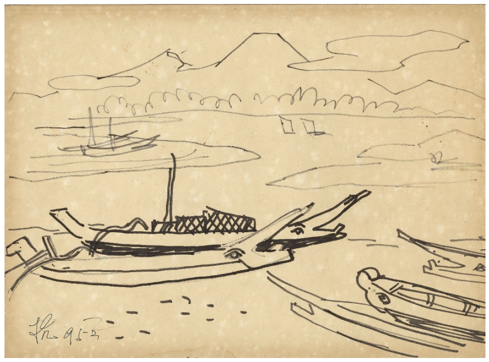

Figure 2. Liu Kang, *Boat scene*, 1952, pencil and pen on paper, 27.5 × 37 cm. Liu Kang family collection. Image courtesy of Liu family.

The painting was donated by the artist to the collection of the National Gallery Singapore in 2003. As the records do not mention the paint peculiarity in the yellow-painted areas of the composition, it is unknown whether the observed characteristic is consistent with the time of the artwork creation or occurred later as a result of a chemical process within the paint layer. Moreover, no study of *Boat scene* has been carried out.

Three potential explanations have been proposed to elucidate this phenomenon. The first is that, as the protrusions occur exclusively in one area of the composition, they may be an intentional aspect of the artist's textural approach rather than an aesthetic issue resulting from an ongoing deterioration process. Liu Kang extensively explored various painting techniques throughout his body of work. For example, his paintings depicting Huangshan and Guilin mountains, created between the 1970s and 1990s, are achieved with heavy impastos to characterise the rough structure of the rocks [4]. Although the artist usually achieved desired aesthetic effects through modifications of the painting technique, avoiding experimentation with the paint formulations [5], it is conceivable that, for the depiction of sand in *Boat scene*, Liu Kang might have modified the paint by adding some hard grains to achieve his artistic goals. However, the analyses of other paintings by Liu Kang did not point out any paint features similar to those observed in *Boat scene* [5]. Nevertheless, the enrichment of the texture values of paint layers is a common practice undertaken by artists. For example, Jean Dubuffet (1901–1985) added sand, pebbles and pieces of glass to the paint to create rich textures and define certain elements in the compositions [6]. Willem de Kooning (1904–1997) often mixed commercial paints with sand, charcoal, plaster of Paris, calcite, wax and ground glass to produce different textural effects [7]. Sand grains are found in some works by Francis Bacon (1909–1992) [8,9]; the grains are sprinkled onto the surface to reveal their colour. Elsewhere in the work, sand is blended evenly with oil paint and applied to provide texture. Dust is also reported as a material Bacon utilised in some artworks to achieve textural effects. Jack Chambers (1931–1978) preferred self-prepared texturised surfaces containing marble dust or coarsely ground mineral particles [10]. Hence, detailed analytical studies of the protrusions present in the paint layer of the *Boat scene* could expand our knowledge about Liu Kang's creative process, especially if the material responsible for enhancing the texture is identified.

Alternatively, the protrusions observed in *Boat scene* could also relate to metal soaps within the oil paint layer. Metal soaps are the products of reaction between metal ions from pigments or driers and fatty acids released during the cross-linking and hydrolysis of the oil binder. According to current research, lead and zinc soaps are the most commonly reported metal soaps responsible for the formation of metal soap aggregates, which deform the paint layers under which they grow resulting in paint embrittlement, delamination and cracking [11–16]. While calcium soaps are less frequently found in oil paint compared to lead or zinc soaps, they still have the potential to aggregate, resulting in disruptions to the paint surface or leading to brown discoloration [17]. A predominant presence of zinc soaps and a minor presence of lead soaps in the oil-based grounds and paint layers were confirmed in many of Liu Kang's paintings representing his artistic oeuvre. However, no signs of deterioration of the paint layers linked to metal soaps, such as protrusions, surface efflorescence, increased transparency and cleavage, have been observed in the investigated artworks [5]. As for *Boat scene*, despite the intensely protruded paint layer, other visual defects associated with the formation of metal soaps [18] are not manifested. Moreover, the protrusions are in a nascent state, and they do not display any signs of paint fracture or the eruption of the soap aggregates, as described by Boon et al. [19]. Nevertheless, the potential association of the protrusions with the formation of metal soaps encouraged the authors to rethink this hypothesis to avoid misinterpretation. The verification of the active expansion of soap aggregates in *Boat scene* could indicate its unusual chemical composition; by contrast, other previously investigated artworks by Liu Kang do not display signs of deterioration induced by metal soaps, although the latter have also been stored under the same controlled environmental conditions (temperature 22 °C ± 2 °C and RH 58% ± 2%) since the donation.

Finally, the protrusions detected in *Boat scene* could otherwise be linked to the unintentional contamination of the paint during the artistic process. However, this hypothesis prompted the question of what type of contaminant was involved and why the contamination occurred in only one colour. Archival photographs depicting the artist's studio reveal a somewhat disorderly workspace, providing insights into his materials and tools storage [4,20,21]. Therefore, it's conceivable that the tools might not have been cleaned between uses, allowing for the accumulation of dried paint over time, which could be a source of contamination of the paint layer.

Hence, there are three potential reasons for the existence of the yellow-paint protrusions in Liu Kang's *Boat scene*, and the aim of this research was to delve into the build-up of this mysterious paint feature. In addition, notwithstanding the study's focus on the protrusions, the investigation of the ground and paint layers' structure as well as the pigmentary palette was essential for understanding the material affinities and differences between the protrusions and other paint layers.

2. Materials and Methods

2.1. Materials

The study investigates the ground and paint layers of the painting *Boat scene*, by Liu Kang, which measures 71.5 × 142.5 cm. In total, 19 samples of the paint material were collected, comprising eight samples of the protrusions from the yellow paint layer. The protrusion samples are distinguished from other paint samples by the prefix "P", followed by a number in ascending order. Additionally, samples of the paint layer, representing the major pigment mixtures, are labelled with numbers arranged in ascending order. The specific sampling areas are highlighted in Figure 3. The structure of the painting support was not within the scope of the investigation strategy.

Figure 3. The image of the painting with two sets of sampling spots indicated by arrows. Extractions from the protrusion areas are indicated by red arrows, whereas extractions from other coloured passages are indicated by white arrows.

2.2. Methods

Emphasising non-invasive techniques, the multi-analytical investigation initially involved technical imaging using a modified Nikon D850 DSLR camera (Tokyo, Japan) capable of capturing the spectrum of electromagnetic radiation ranging from 360 to 1100 nm. The imaging in visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR) and near-infrared (NIR) was aimed at documenting the painting's condition and performing a preliminary characterisation of the pigments to guide subsequent comprehensive analyses. Additionally combination of VIS and NIR images facilitated the acquisition of infrared false-colour images for differentiation between the pigments of the same colour and their preliminary identification [22]. The photography and post-processing workflow followed the methodology outlined by Cosentino and American Institute of Conservation [23–26]. Digital microscopy using a Keyence VHX-6000 digital microscope (Osaka, Japan) enabled the studies of the surface of the protrusions.

Micro-invasive analytical techniques were essential, involving the extraction of samples from the paint layers, including the yellow protrusions. Performing the analyses directly on these samples enabled a collective and comprehensive investigation of their structure and chemical composition. The initial analyses were carried out on pigment particles using polarised light microscope (PLM) Leica DMRX (Wetzlar, Germany). PLM was conducted following the methodology devised by Peter and Ann Mactaggart [27]. The analyses of the protrusions and paint samples prepared as cross-sections were carried out with the same microscope using reflected VIS and UV light sources. Cross-sections of protrusions were prepared to record the structure of the layers from the top to bottom. Samples were documented with a Leica DFC295 digital camera (Wetzlar, Germany).

The structure and the elemental characterisation of the paint layers' cross-sections were investigated with a field emission scanning electron microscope Hitachi SU 5000 (Tokyo, Japan) integrated with Bruker XFlash® 6/60 (Billerica, MA, USA) energy dispersive spectroscope (FE-SEM-EDS). Final confirmation of the inorganic and organic compounds present in the structure of the paint cross-sections was achieved with attenuated total reflectance micro-Fourier transform infrared spectroscopy (ATR µ-FTIR) using a Bruker LUMOS FTIR Microscope (Billerica, MA, USA) equipped with a mid-band LN MCT detector coupled with an Alpha FTIR spectrometer.

Moreover, the complementary use of ATR µ-FTIR and FE-SEM-EDS was considered to have great advantage in exploring the hypothesis that the metal soap aggregates are responsible for the formation of the protrusions. ATR µ-FTIR is widely adopted for the analyses of metal soaps [28] because it detects the metal–carboxylate bond [29,30], while the scanning electron microscope in backscattered electron mode (SEM-BSE) and SEM-EDS are essential for studies of the morphology of metal soaps aggregates and the identification of metal cations involved in the saponification and mineralisation processes [11,28]. Details of the methodology undertaken are elaborated in Appendix A.

3. Results

3.1. Ground

Based on the visual observation of the white primer extended over the tacking margins and further analytical techniques, the painting was executed on a commercially-primed fabric with a white double-layered ground bound in drying oil confirmed by IR absorption peaks at ca. 2916, 2849, ca. 1731, 1176 cm^{-1}. The thick bottom layer is predominantly made of chalk (PW18) admixed with zinc white (PW4) and some titanium white (PW6), lead white (PW1) and barium white (PW21), based on the detection of Ca, Zn, Ti, Pb, Ba and S signals. However, the presence of lithopone (PW5) can also be considered (Figure 4a,b,d). Lead white features as the primary constituent of the top and thinly applied layer. The pigment was combined with titanium white and chalk as well as lithopone and/or barium white and zinc white (Figure 4a–c). As the availability of lithopone and lead white was diminishing from the market after the 1950s [31,32], it is possible that the painting support used by the artist was from old stock. Nevertheless, the structure and composition of the ground layer are consistent with the grounds frequently employed by the artist in the second half of the 20th century [5]. The ATR μ-FTIR analyses revealed the presence of zinc soaps in both ground layers. Interestingly, the bottom layer exhibits zinc soaps characterised by a stronger IR absorption peak at ca. 1540 cm^{-1} compared to the upper layer, as is visualised in Figure 5. However, no metal soap aggregates were detected in either ground layer, suggesting that the zinc soap formation does not directly correlate with the observed protrusions of the paint layer. Appendix B, Table A1 provides a summary of the painting's ground characteristics.

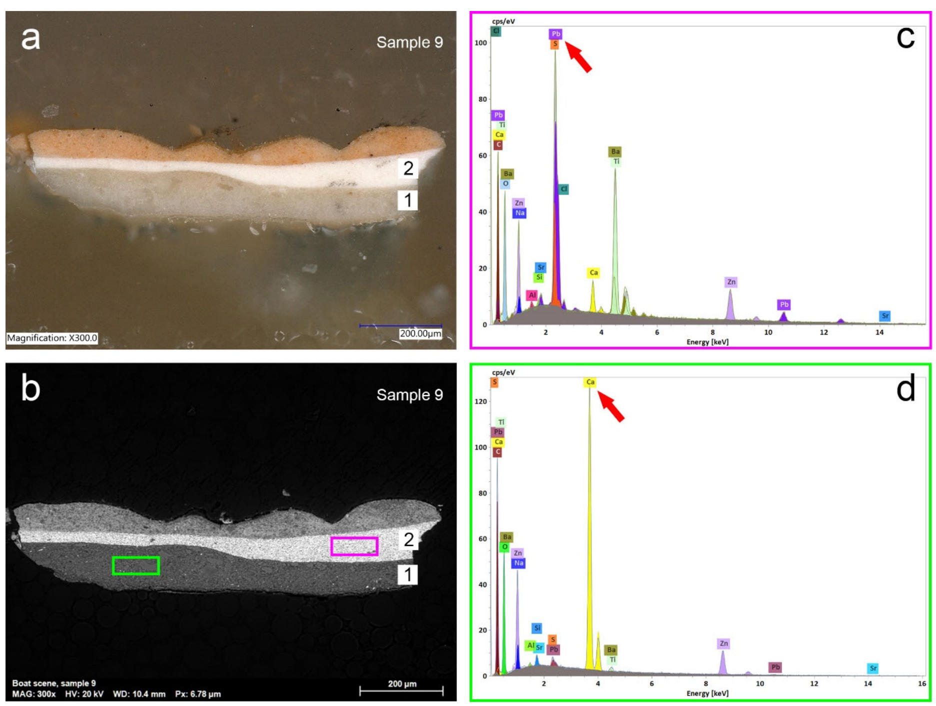

Figure 4. Optical microscopy (**a**) and corresponding BSE image (**b**) of the cross-section of sample 9 at 300× magnification, with marked bottom (1) and top (2) layers of the ground. The coloured rectangular outlines in the BSE image (**b**) show the SEM-EDS areas of analyses. The corresponding

spectra show strong Pb (**c**) and Ca (**d**) signals (indicated by red arrows), respectively, from the top and bottom layers of the ground.

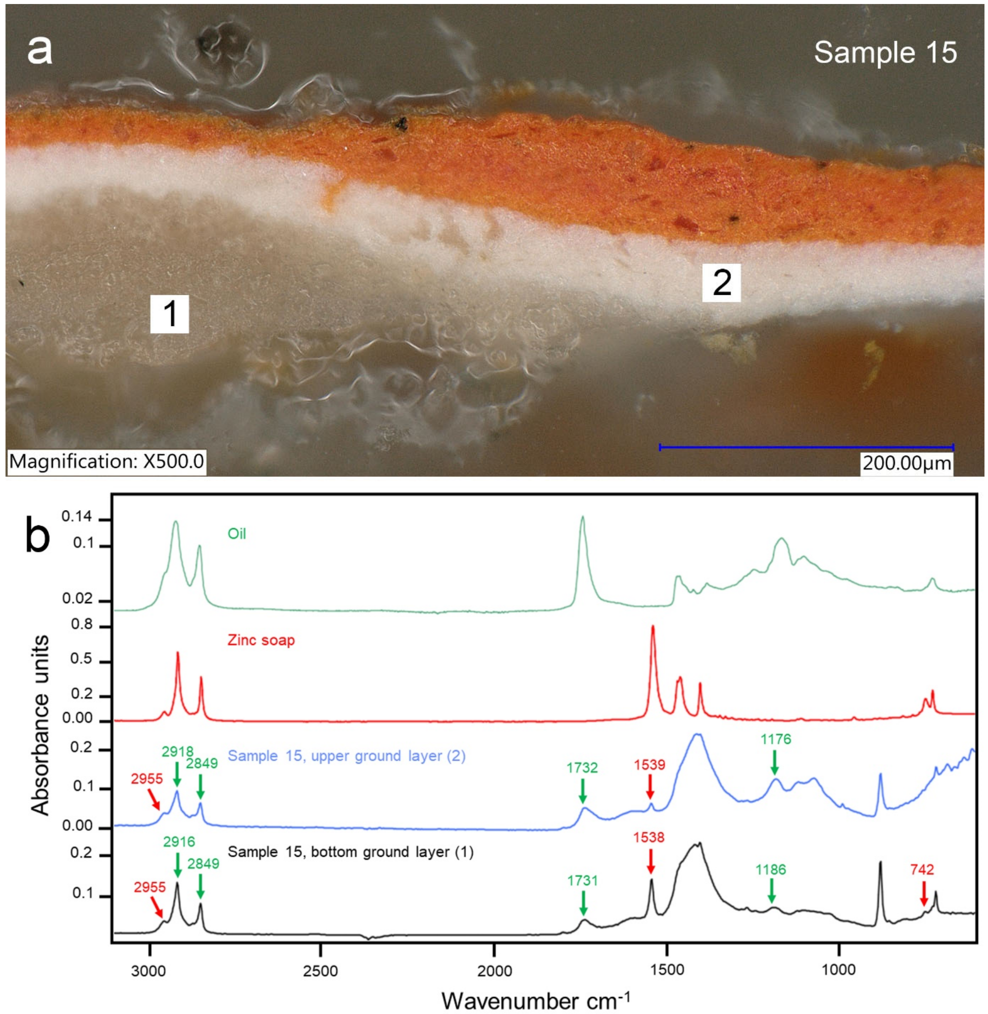

Figure 5. Microscopy image of cross-section of sample 15 from the orange paint viewed in VIS (**a**). ATR µ-FTIR spectra derived from the bottom (1) and upper layers (2) of the ground preparation with labelled marker peaks of zinc soap and oil along with reference samples of identical materials (**b**).

3.2. Pigments

The palette of colours employed by the artist was not extensive and the OM of the samples extracted from different areas of the paint layer revealed a homogenous structure, reflecting confidence in the paint application. The range of the pigments employed for the execution of *Boat scene* falls within Liu Kang's mainstream painting practice [5]. The binder for all characterised pigment mixtures was a drying oil detected by IR absorption peaks at 2920, 2850, 1735, 1460, 1400, 1165 and 720 cm^{-1}. The blue-painted areas indicated frequent use of ultramarine (PB29), followed by the probable addition of cobalt blue (PB28) and phthalocyanine blue (PB15). Ultramarine particles were observed with PLM (blue particles with low refractive index appear red with Chelsea filter). This outcome was validated through the SEM-EDS detection of Na, Al, Si and S elements; however, high-intensity absorption peaks of lithopone and/or barium white and zinc white present in the paint mixture likely hindered the ATR µ-FTIR confirmation of this blue pigment. The identification of cobalt blue was ambiguous and assumed based on the colocalisation of Co and Al, although the latter was also attributed to ultramarine. Unfortunately, the fundamental IR absorption peaks of cobalt blue falling outside the spectral range of the ATR μ-FTIR instrument did not provide a positive identification of this pigment. The presence of the phthalocyanine blue in the paint sample 3 was assumed by the detection of Cu signal and IR absorption peaks occurring at 1587, 1509, 1420, 1334, 1287, 1165, 1117, 1089, 901, 871, 753 and 720 cm^{-1}. The IRFC purple imaging of the blue-painted areas was inconclusive as ultramarine, cobalt blue and phthalocyanine blue turned different shades of purple with this technique. The range of blue tints is the result of the artist's addition of varied amounts of white pigments, mainly titanium white and barium white and zinc white and/or lithopone. Violet paint (sample 11) is mainly composed of synthetic alizarin lake (PR83:1), confirmed by IR absorption peaks at ca. 1640, ca. 1450, ca. 1360, 1274, 1049, 840, 773 and 720 cm^{-1} combined with phthalocyanine blue confirmed by IR absorption peaks at 1506, 1321, 1274, 1170, 1118, 1092, 935, 866, 840, 817, 811, 793, 773, 720 and 637 cm^{-1} and admixed with some white. Green-painted areas turn purple in IRFC, suggesting the presence of viridian (PG18), which was one of Liu Kang's major green pigments, or phthalocyanine green (PG7), which was used by him intermittently from the 1950s [5]. However, none of the analyses revealed the presence of green pigment in samples 8 and 12. Interestingly, the PLM and elemental analyses indicated a potential existence of ultramarine; however, this was not corroborated by ATR μ-FTIR measurements, possibly due to overlapping bands of other compounds present in the paint mixture. The yellow passages depicting the sandy coast (samples 13 and 14) were achieved with Fe-containing yellow earth pigment, as evidenced by the SEM-EDS analyses showing distinct Fe signals and ATR μ-FTIR detection of kaolinite (absorption peaks at 3691, 3651, 3619, 1027, 1007, 911 and 798 cm^{-1}) and iron oxide (absorption peak at 525 cm^{-1}). Admixture of Cr-containing yellow(s) is assumed based on the detection of Pb, Cr, Zn, Ca and Sr elements. Whereas addition of cadmium yellow (PY35) was inferred from co-location of Cd and S elements. However, a coinciding presence of intensive Ba and Zn elements suggests the potential presence of cadmopone (co-precipitated cadmium sulfide and barium sulfate) or variant of cadmium yellow modified with zinc [33]. Brown brushstrokes consist mainly of dark-yellow Fe-based earth pigment, inferred from PLM and SEM-EDS analyses as ATR μ-FTIR measurements were inconclusive due to the overlapping bands of lithopone and/or barium white and zinc white. Orange brush strokes (sample 15) were achieved with chrome yellow (PY34) inferred from Pb and Cr signals and confirmed by IR absorption peaks at 853, 835, 624 and 591 cm^{-1}, whereas peaks at 1095 and 1040 cm^{-1} were probably hampered by the overlapping IR absorption peaks of barium white which may be present in the paint mixture as part of lithopone or as admixture to zinc white. The red paint (sample 10) is primarily composed of synthetic alizarin lake, which complies with Liu Kang's predilection for intense reds [5]. The artist deliberately exposed the white ground throughout the painting process to enhance the shapes of the compositional elements. The sole occurrence of the application of pure white paint is observed on the shirt of one of the fishermen, which remains white in UVR, suggesting the application of lead white and/or lithopone (Figure 6) [23,25,26]. However, titanium white in combination with lithopone and/or barium white and zinc white as well as lead white were used primarily for lightening the other colours. Barium white is also a common extender of the lead chromates, lead white and lake pigments [34,35]. The artist did not incorporate black tones; however, the addition of bone black (PBk9) as a probable shade modifier was detected in the investigated blue, yellow and red paint samples. Appendix B, Table A2 provides a summary of the identified materials within paint mixtures.

Figure 6. VIS (**a**) and corresponding UVR image (**b**) of the painting, highlighting a strong UV reflectance of the white paint on the shirt of the fisherman (red arrow), implying the likely presence of lead white and/or lithopone.

Zn-based compounds are widely found in most of the investigated paint layers, being a source material for metal soap formation detected with ATR μ-FTIR measurements. However, no metal soap aggregates were detected except for its possible presence in paint sample 7. A cluster of partially mixed white paint composed mainly of lithopone and/or barium white and zinc white contains a high concentration of zinc soap, as confirmed with FTIR and visualised in Figure 7.

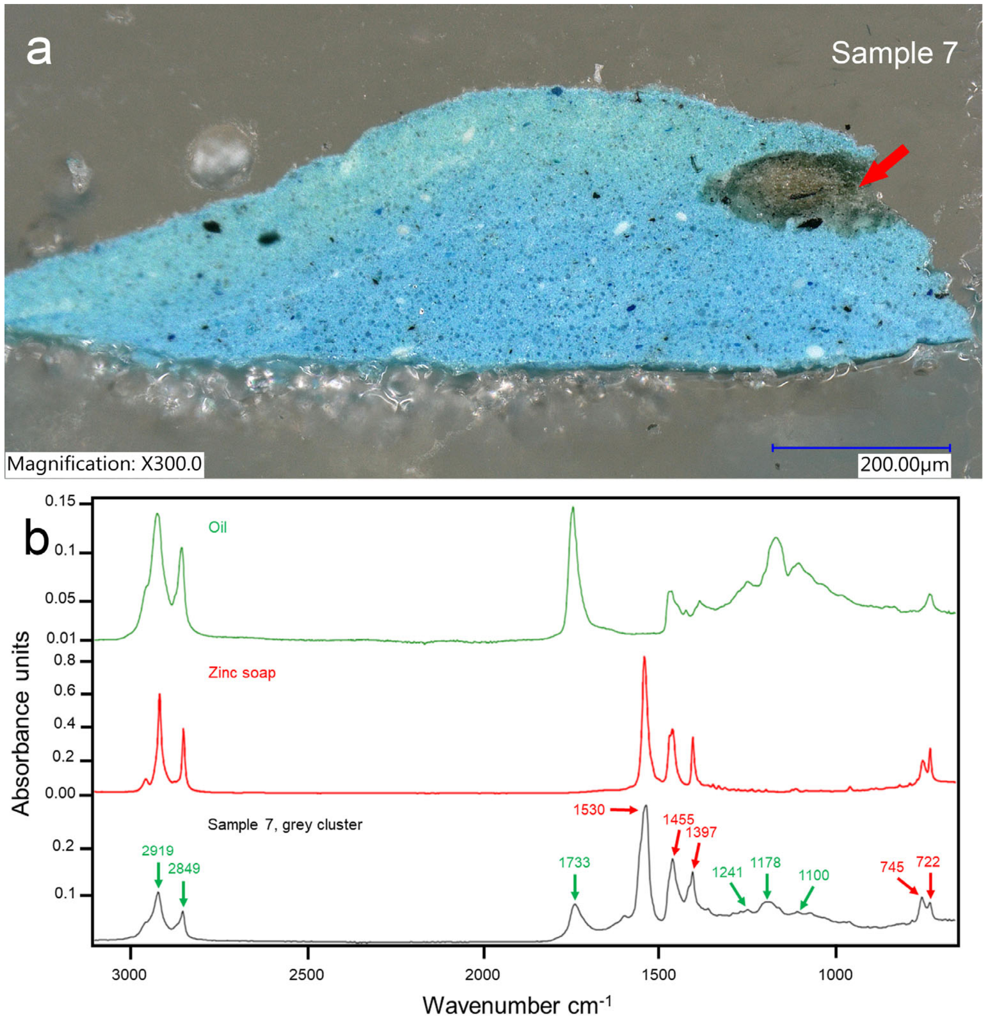

Figure 7. Microscopy image of cross-section of sample 7 from the blue paint viewed in VIS (**a**). The red arrow indicates the ATR µ-FTIR measurement spot in the cluster of partially mixed white paint. ATR µ-FTIR spectra derived from the grey cluster with labelled marker peaks of zinc soap and oil along with reference samples of identical materials (**b**).

3.3. Protrusions

VIS raking light photography and digital microscopy confirmed that the surface protrusions are present exclusively on the yellow-painted passages depicting the sandy coast. The protrusions occur in varied shapes, from spherical to complex structures, ranging from 181.74 µm (sample 14) to 512.34 µm (sample P1) in height. Some of them show an underlying dark brown and yellow colour, seen through the abraded top light-yellow layer or its cracks, as exemplified by the samples P1, P2, P7, P8 and 14 (Figures 8a,b,d,e and 9a,b,d,e,j,k).

OM of eight cross-sections of the protrusions revealed a heterogenous build-up due to the presence of large clusters of different colours (Figures 8c,f,i,l and 9c,f,i,l). Clusters of four colours were recorded: dark brown (Figures 8f,l and 9l), orange (Figures 8c,i and 9c), grey-yellow (Figures 8c,l and 9c,f,i,l) and black (Figure 8c). Sometimes, clusters of two or three colours coexist in one sample. The clusters of colours have defined edge lines, leading us to conclude that they were dry when mixed with the yellow paint used for depicting the beach.

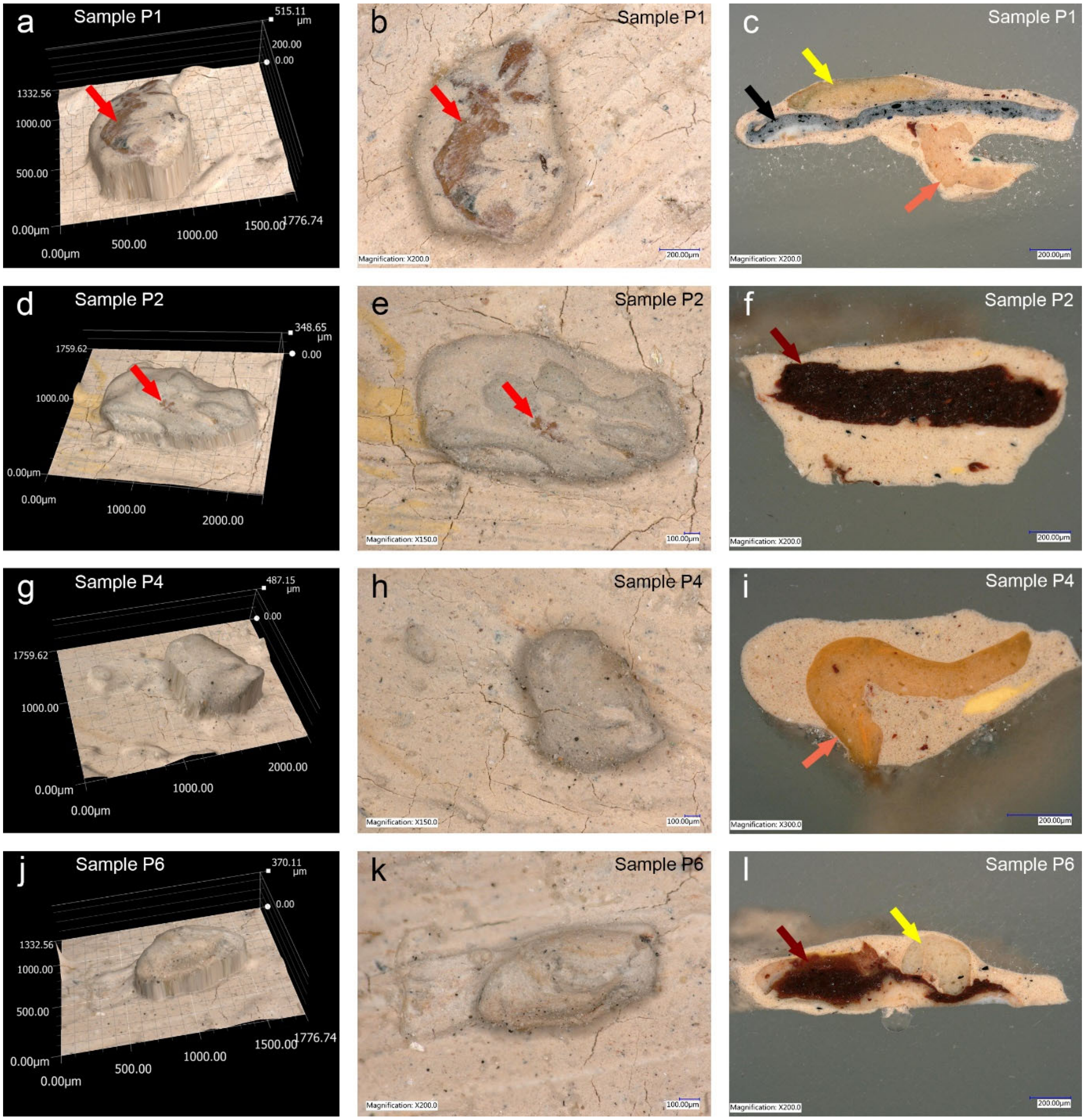

Figure 8. Microscopy images of the investigated protrusions. 3D surface topography of the protrusion (**left column**); followed by a 2D image at a magnification range of 150× to 200× (**central column**); and a cross-section of the extracted sample captured at a magnification range of 200× to 300× (**right column**). Red arrows point towards the underlying paint colour, seen through the abraded top light-yellow layer or its cracks. Yellow, orange, brown and black arrows correspond to different colour clusters.

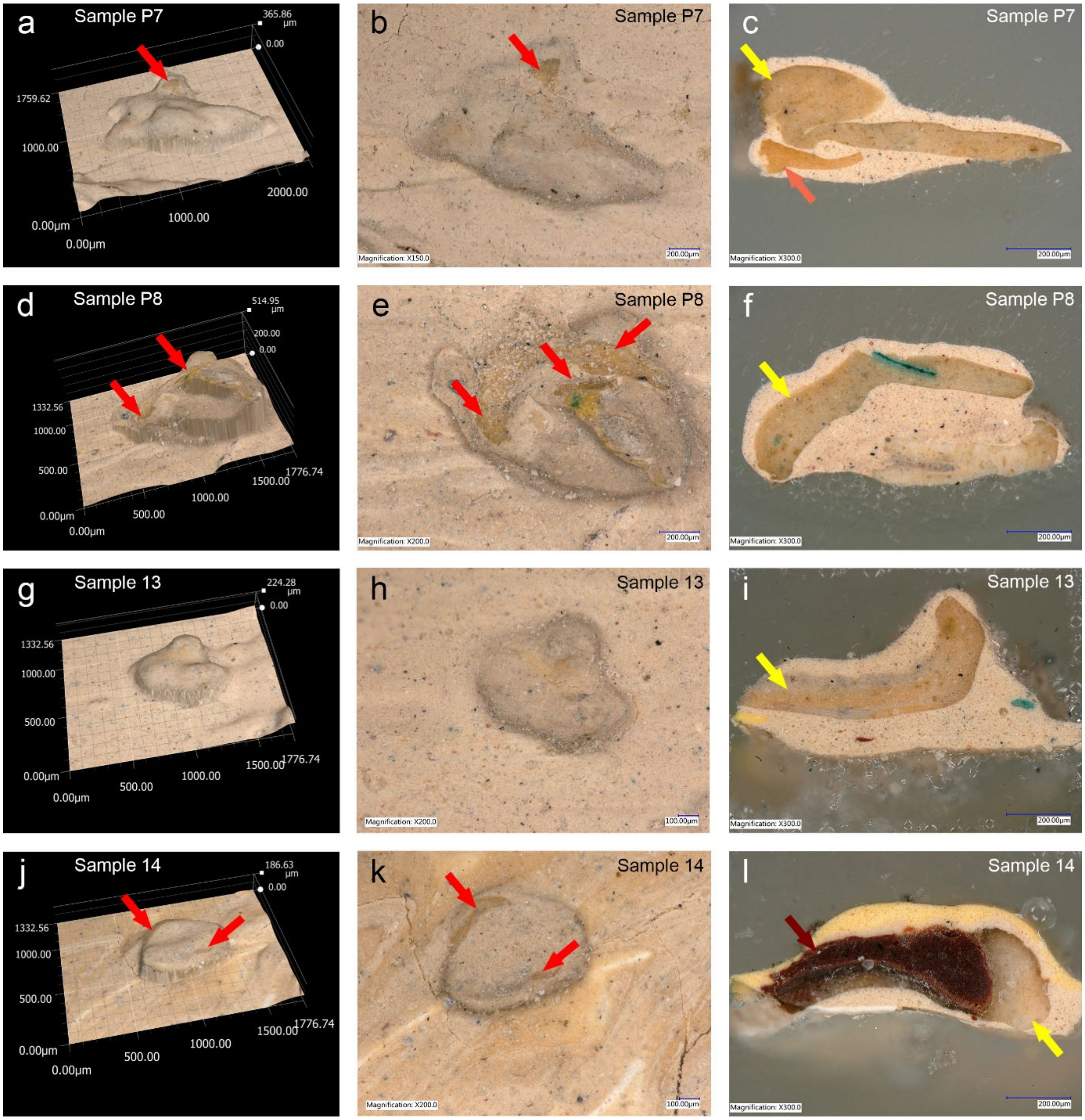

Figure 9. Microscopy images of the investigated protrusions. 3D surface topography of the protrusion (**left column**); followed by a 2D image at a magnification range of 150× to 200× (**central column**); and a cross-section of the extracted sample captured at a magnification of 300× (**right column**). Red arrows point towards the underlying paint colour seen through the abraded top light-yellow layer or its cracks. Yellow, orange and brown arrows correspond to different colour clusters.

The investigation of the chemical build-up of the protrusions started from the muted yellow paint, which accommodates other colour clusters. The primary component of the yellow paint appears to be Fe-containing yellow earth pigment, as evidenced by the SEM-EDS analysis showing distinct Fe signals and ATR µ-FTIR detection of kaolinite (absorption peaks at 3691, 3651, 3619, 1027, 1007, 911 and 798 cm^{-1}) and iron oxide (absorption peak at 525 cm^{-1}). Admixture of zinc white, barium white, and titanium white is assumed based on the detection of Zn, Ba, Ti and S signals, although lithopone can be considered as well. Trace presence of Pb may suggest lead white, which was confirmed by IR absorption peaks at 1400 and 680 cm^{-1}. A concomitant presence of Pb, Cr, Zn, Ca and Sr elements may indicate a minor inclusion of chrome yellow or other yellow chromates. However, ATR μ-FTIR measurements did not confirm these yellow pigments due to low-intensity peaks occurring within the range of 900 to 700 cm^{-1}. The co-location of Cd, S, Ba and Zn elements (samples P2, P4, P7, P8 and 13) may be indicative of the admixture of cadmium yellow or its variant. This finding was supported by the red UV fluorescence of partially mixed yellow paint in the sample P4 [26], along with elemental distribution maps, as illustrated in Figure 10. This yellow pigment was confirmed with ATR μ-FTIR only in samples P4 and P8 by IR absorption peaks at 1182, 1106, 1065, 983, 635 and 605 cm^{-1}. The ATR μ-FTIR measurements ascertained that drying oil was a binder for the investigated pigment mixtures.

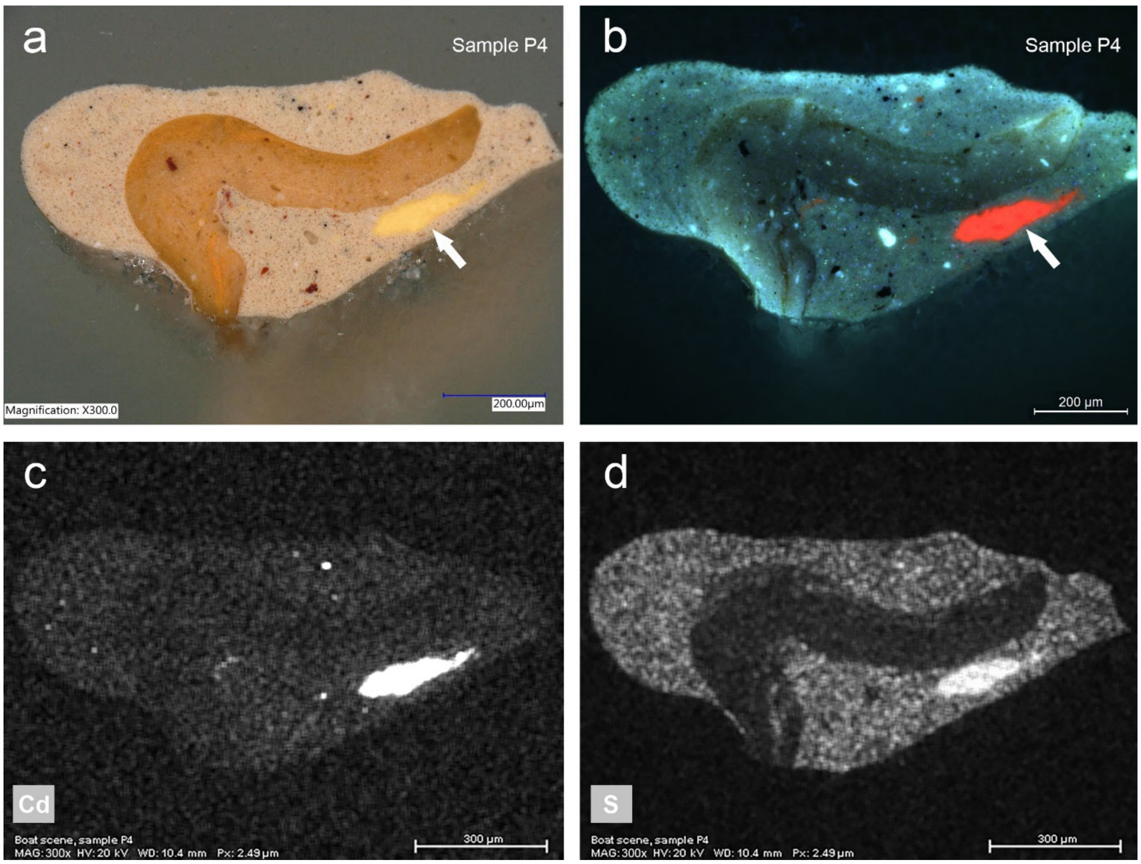

Figure 10. Microscopy images of cross-section of sample P4 at 300× magnification photographed in VIS (**a**) and UV (**b**) and corresponding SEM-EDS elemental distribution maps of Cd (**c**) and S (**d**). The intensity of the signal of each element is depicted by a range of grey tones, where white represents high intensity and black represents low intensity. The red fluorescence of yellow paint indicated by white arrows (**a**,**b**) and concomitant strong Cd and S signals suggest the presence of cadmium yellow.

Regarding the colour clusters, several pigments were found in the course of the investigation. The grey-yellow clusters in the samples P1, P6, P7, P8, 13 and 14 (Figures 8c,l and 9c,f,i,l) were probably a composition of lithopone and/or barium white and zinc white, titanium white and lead white with some Fe-containing yellow earth pigment. It was inferred that sample P1 and 13 contained traces of Cr-based yellow(s), while a minor addition of bone black was assumed in sample P1 based on the detection of Ca and P elements.

The orange cluster in samples P1, P4 and P7 (Figures 8c,i and 9c) is mainly composed of a high concentration of lithopone and/or barium white and zinc white, and titanium white admixed with Fe-containing yellow earth pigment. However, some lead white and Cr-containing chrome yellow(s) are assumed to be present in the mixture.

The principal component of the dark-brown clusters in samples P2, P6 and 14 (Figures 8f,l and 9l) is Fe-containing yellow earth pigment combined with lithopone and/or barium white, zinc white, titanium white, lead white and some bone black. The presence of bone black was confirmed through the detection of IR absorption peaks at 1024, 984, 601 and 556 cm^{-1} converging with the detection of calcium and phosphorus signals (sample 2).

The black cluster found in sample P1 (Figure 8c) is composed mainly of bone black particles as confirmed by the detection of Ca and P signals converging with the IR absorption peaks at 1024, 961, 602 and 550 cm^{-1}. The pigment was combined with some white paint, which was a mixture of lithopone and/or barium white, zinc white and titanium white.

Besides the identified pigments, the colour clusters contained zinc soaps, which were validated through certain infrared absorption peaks, specifically those at 2954, 1538, 1457, 1398, 742 and 721 cm^{-1}, as depicted in Figure 11. The soaps are homogeneously present and no aggregates were detected in the investigated protrusions. The analyses imply that the formation of metal soaps resulted from the chemical reaction between metal ions and fatty acid network within the paint but cannot account for the creation of protrusions [36].

The results of the analyses of the colour clusters within the protrusions are listed in Appendix B, Table A3.

The OM evidenced the absence of the sand grains admixed to the paint as texture-enriching material. Furthermore, the analyses suggest that the protrusions were induced by the contamination of the yellow paint with dry fragments of pigment mixtures. Hence, it was essential to investigate any possible correlation between the materials present in the colour clusters and the pigment combinations obtained for the execution of the painted scene.

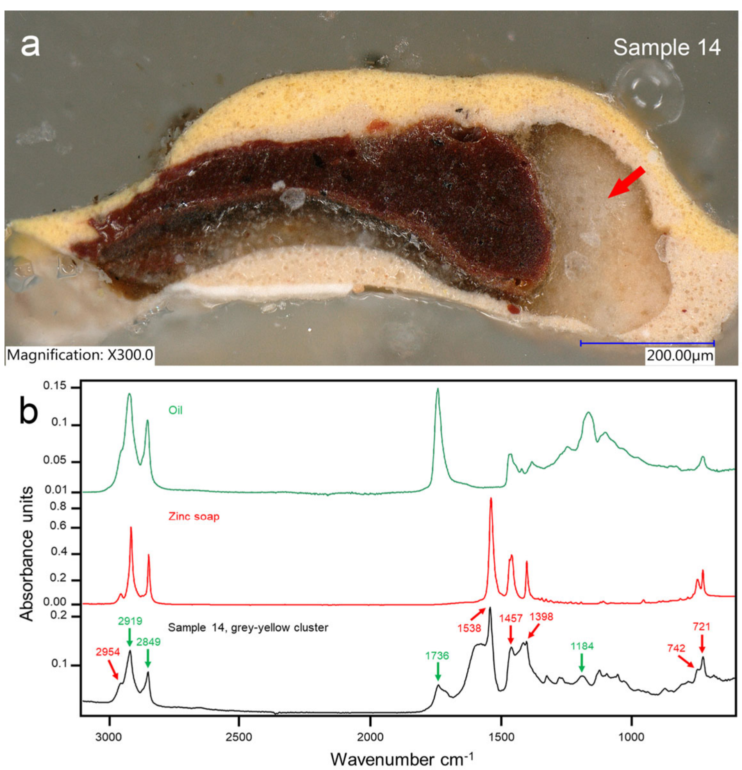

Figure 11. Microscopy image of cross-section of sample 14 from the yellow paint protrusion viewed in VIS (**a**). The red arrow indicates the ATR µ-FTIR measurement spot in the area of the grey-yellow

cluster. ATR μ-FTIR spectra derived from the grey-yellow cluster with labelled marker peaks of zinc soap and oil along with reference samples of identical materials (**b**).

4. Conservation Implications

The results of the analyses highlight some important aspects of future conservation care of the painting. The sensitivity of the protrusions to mechanical action puts the condition of the paint layer at risk, especially during preventive or interventive treatments. For example, they can be unintentionally broken, creating minute paint loss during dusting with brushes or more advanced dry and wet cleaning. Therefore, conservators should consider that the yellow-painted passages of *Boat scene*, characterised by the densely distributed protrusions, require a cautious approach in cleaning. While the paint layer exhibits a pronounced texture, any conservation treatment of the reverse side of the painting will necessitate the use of cushioning material to protect protrusions from potential crushing. Zinc soaps present in the ground and paint layers, along with the protrusions, introduces a risk of the development of soap aggregates and their subsequent migration. This could be triggered by the high humidity environment sometimes inherent in the conservation treatment or by inadvertent exposure to the tropical climate of Singapore during display or storage [18]. Researchers consistently align with the recommendation of minimising paint layer exposure to high relative humidity and the advocacy for maintaining cool conditions [15,18,37].

5. Conclusions

The study utilised non-invasive and invasive techniques to enhance the understanding of the protrusions present in Liu Kang's *Boat scene*; the protrusions are an uncommon paint layer feature not observed in other paintings by the same artist in the NGS collection. The analyses revealed that the protrusions had originated from the artist's tools, which bore dry fragments of various pigment mixtures bound in drying oil; these paint fragments inadvertently contaminated the oil paint mixtures in *Boat scene*.

Despite their unintentional creation, the protrusions appear to be inherent to the artwork. There was no indication of admixing texture-enriching material like sand grains into the paint, confirming the artist's reluctance to experiment with different paint formulations. The analyses verified the abundance of zinc soaps in both the colour clusters of the protrusions as well as in all layers of paint samples extracted from other areas of the painting. However, neither set of samples revealed metal soap aggregates that would distort the paint surface. While the primary objective of this investigation was to understand the causes of the occurrence of the protrusions, the results of the analyses afforded valuable information about the pigmentary palette used in the execution of the artwork. The artist painted the scene on the commercial double-layered ground with a significant amount of chalk in the lower layer and lead white in the upper layer. The choice of pigments selected by the artist was restricted to Fe-containing yellow earth, Cr-containing yellow(s), cadmium yellow or its variant, ultramarine, cobalt blue, phthalocyanine blue, synthetic alizarin lake and white pigments such as lithopone and/or combination of barium white and zinc white, lead white, titanium white and bone black. This pigment selection, along with the structure of the ground and paint layers, correlate well with known painting materials historically utilised by Liu Kang after the 1950s.

Continued investigation of Liu Kang's artworks and his choice of materials holds significant importance for art historians and conservators. Hence, this study contributes to the understanding of the nature of the paint defects found in *Boat scene* and highlights the potential conservation challenges that conservators may face.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Technical photography

Camera	Nikon D850 DSLR (Tokyo, Japan).
Lens	Nikon AF Micro NIKKOR 60 mm f/2.8D (Tokyo, Japan).
Illumination	• Two Lastolite Ray D8 (Cassola, Italy) lamps, each fitted with tungsten bulbs rated at 500 W and emitting light at 3200° Kelvin were used for VIS and NIR imaging. • Two CLE Design (London, UK) lamps featuring eight 120 cm long UV fluorescence tubes rated at 40 W, with a peak at 365 nm were used for UV and UVR.
Filters	• X-Nite CC1 (Carlstadt, NJ, USA) and B+W 420 (Bad Kreuznach, Germany) were used for UVF imaging. • B+W 403 (Bad Kreuznach, Germany) combined with X-Nite CC1 (Carlstadt, NJ, USA) were used for UVR imaging. • X-Nite CC1 (Carlstadt, NJ, USA) filter was used for VIS photography. • Heliopan RG1000 filter (North White Plains, NY, USA) was used for NIR imaging.
Control measures	• X-Rite ColorChecker Passport (Grand Rapids, MI, USA). • American Institute of Conservation Photo Documentation target (Washington, DC, USA).
Software	Adobe Photoshop CC (San Jose, CA, USA).

Digital microscopy

Microscope	Keyence VHX-6000 equipped with a VH-ZST zoom lens capable of magnifications ranging from 20× to 2000× (Osaka, Japan).
Software	Keyence VHX-H2M2 and VHX-H4M.

Preparation of samples

Samples for PLM	The mixtures of pigment particles were dispersed on microscope glass slides, then embedded in Meltmount (nD = 1.662) from Cargille (Cedar Grove, NJ, USA) and secured with a glass cover.
Samples for cross-sections	Samples were embedded in acrylic resin ClaroCit from Struers (Cleveland, OH, USA), followed by wet grinding and polishing on SiC Foils from Struers down to grade 4000 using grinder-polisher MetaServ 250 from Buehler (Lake Bluff, IL, USA).

OM and PLM

OM and PLM	Leica DMRX (Wetzlar, Germany), providing 100×–400× magnifications. PLM observations were conducted using transmitted VIS light, built-in polarising filters and a handheld Chelsea colour filter (London, UK). The paint cross-sections were examined using reflected VIS and UV light sources.
Camera	Leica DFC295 digital camera (Wetzlar, Germany).
Software	Leica Application Suite 4.8. (Wetzlar, Germany).

FE-SEM-EDS

Microscope	Hitachi SU 5000 FE-SEM (Tokyo, Japan) in BSE mode, operated at 20 kV acceleration voltage, 60 Pa chamber pressure, 50–60 intensity spot and 10 mm working distance. Elemental analyses of the samples were conducted using a Bruker XFlash® 6/60 EDS (Billerica, MA, USA) integrated with FE-SEM. Areas of interest on the samples were acquired in object mode after recording 250,000 counts (Precise acquisition), whereas the mapping mode was used with 180 s acquisition time to elucidate the elemental distribution within the samples.
Software	Bruker Espirit 2.0.

ATR μ-FTIR

Microscope	Bruker LUMOS FTIR microscope (Billerica, MA, USA) equipped with a mid-band LN MCT detector coupled with an Alpha FTIR spectrometer. The samples were brought into contact with the ATR objective (32×) equipped with a germanium crystal (100 μm in diameter). The spot size was adjusted between 1 and 50 μm. The spectra were averaged from 128 scans at a 4 cm^{-1} spectral resolution and 4000–650 cm^{-1} spectral region.
Software	Bruker Opus 8.7.

Appendix B

Table A1. Summary of the materials identified or tentatively determined in the ground layer for the painting *Boat scene*.

Sample	Layer	SEM-EDS * Detected Elements	SEM-EDS Tentative Assignments	ATR μ-FTIR Identification
4	2	**C, O, Pb, Ti**, Ba, Zn, S, Ca, Na, (Al, Si, Sr, Mg)	Lead white, titanium white, lithopone and/or barium white and zinc white, chalk	Lead white, lithopone and/or barium white and zinc white, chalk, oil
	1	**C, O, Ca**, Zn, Na, Pb, (Ti, Ba, Si, S, Al, Mg)	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	Chalk, oil, zinc soap
6	2	**C, O, Pb, Ti, Ba**, Zn, S, Ca, Na, (Al, Sr, Si, Cl)	Lead white, titanium white, lithopone and/or barium white and zinc white, chalk,	
	1	**O, C, Ca**, Zn, Na, Pb, (Ti, Si, S, Mg, Al)	Chalk, zinc white, lead white, titanium white	
8	2	**O, C, Pb, Ti**, Zn, Ba, S, Ca, Na, (Al, Si, Sr)	Lead white, titanium white, lithopone and/or barium white and zinc white, chalk,	Lead white, lithopone and/or barium white and zinc white, chalk, oil, zinc soap
	1	**O, C, Ca**, Zn, Na, (Ti, Pb, Si, Ba, S, Al, Mg, Cl)	Chalk, lithopone and/or barium white and zinc white, titanium white, lead white	Chalk, oil, zinc soap
10	2	**C, O, Pb, Ba**, Ti, Zn, S, Ca, (Na, Al, Si, Mg)	Lead white, lithopone and/or barium white and zinc white, titanium white, chalk	
	1	**O, Ca**, C, Zn, (Ba, Mg, Sr, Ti, Pb, S, Al, Si, Na, Cl)	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	
11	2	**C, O, Pb, Ti**, Zn, Ba, S, Na, Ca, (Al, Si)	Lead white, titanium white, lithopone and/or barium white and zinc white	Lead white, lithopone and/or barium white and zinc white, chalk, oil, zinc soap

	1	**O, C, Ca**, Zn, Na, (Pb, Ti, Ba, Si, S, Sr, Al)	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	Chalk, oil, traces of zinc soap
12	2	**C, O, Pb, Ti, Ba**, Zn, S, Na, Ca, (Al, Si, Sr)	Lead white, titanium white, lithopone and/or barium white and zinc white, chalk	Lead white, lithopone and/or barium white and zinc white, chalk, oil, zinc soap
	1	**O, C, Ca**, Zn, Na, (Ba, Ti, Pb, S, Si, Al, P)	Chalk, lithopone and/or barium white and zinc white, titanium white, lead white,	Chalk, oil, zinc soap
15	2	**C, O, Pb, Ba, Ti**, Zn, S, (Na, Ca, Al, Si, Mg, Cl)	Lead white, lithopone and/or barium white and zinc white, chalk	Lead white, lithopone and/or barium white and zinc white, chalk, oil, zinc soap
	1	**C, O, Ca**, Zn, Pb, (Ba, Ti, Si, S, Al)	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	Chalk, oil, zinc soap
16	2	**C, O, Pb, Ba**, Ti, Zn, S, Ca, (Na, Fe, Si, Al, Cl)	Lead white, lithopone and/or barium white and zinc white, titanium white, chalk, Fe-containing earth pigment	Lead white, lithopone and/or barium white and zinc white, chalk, oil, zinc soap
	1	**O, C, Ca**, Zn, (Si, Na, Ba, Pb, Ti, Fe, Mg, Al, S)	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white, Fe-containing earth pigment	Chalk, oil, zinc soap

* Major elements are presented in bold type, minor elements in plain type and trace elements in brackets.

Table A2. Summary of the materials identified or tentatively determined in the paint samples extracted from the painting *Boat scene*.

Sample	Colour	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	ATR μ-FTIR Identification
3	Blue	**C, O**, Ti, Ba, Zn, S, (Na, Cu, Al, Pb, Si, Sr, Cl, Co, Ca)	Titanium white, lithopone and/or barium white and zinc white, ultramarine, phthalocyanine blue, cobalt blue, lead white	Lithopone and/or barium white and zinc white, phthalocyanine blue
4	Blue	**C, O, Zn**, Ti, Pb, Ba, Na, Al, S, (Co, Sr, Ca, Mg, Si, Cl)	Lithopone and/or barium white and zinc white, titanium white, lead white, ultramarine, cobalt blue, chalk	Lead white, lithopone and/or barium white and zinc white, oil, zinc soap
5	Blue	**C, O, Ti**, Ba, Zn, S, (Na, Sr, Cl, Ca, Al, K, Si)	Titanium white, lithopone and/or barium white and zinc white, ultramarine	Lithopone and/or barium white and zinc white, oil, zinc soap
6	Blue	**C, O, Ti**, Ba, Zn, S, Na, Ca, Pb, (Al, Sr, Cl, Co, P, Si, Mg, K)	Titanium white, lithopone and/or barium white and zinc white, lead white, ultramarine, cobalt blue, bone black	
7	Blue	**O, C, Ti**, Ba, Zn, S, Na, (Pb, Sr, Ca, Ca, Cl, Al, Si, K, P)	Titanium white, lithopone and/or barium white and zinc white, lead white, ultramarine, bone black	Lithopone and/or barium white and zinc white, oil, zinc soap

11	Violet	**Zn, C, O**, Ca, (S, Al, Si, Pb, Ti, Ba, Cl)	Lithopone and/or barium white and zinc white, chalk, lead white, titanium white, organic red	Synthetic alizarin lake, phthalocyanine blue, chalk, lead white, lithopone and/or barium white and zinc white, oil
8	Green	**C, O, Zn**, Ti, Na, Ba, Ca, S, (Al, Pb, Sr, Cl, Mg, Si)	Lithopone and/or barium white and zinc white, titanium white, chalk, ultramarine, lead white	Lithopone and/or barium white and zinc white, oil, zinc soap
12	Green	**C, O, Ba**, Zn, Al, S, Na, (Ti, Cl, Si, Sr, Pb, Ca)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, lead white, chalk	Lithopone and/or barium white and zinc white, oil, zinc soap
13	Yellow	**O, Ba, C, Ti, Zn**, S, Na, Fe, (Al, Sr, Ca, Si, Pb, Cd, Mg, Cl, K, P)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, chalk, lead white, cadmium yellow or its variant, bone black	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, chalk, lead white, oil, zinc soap
14	Yellow	**O, C, Ba, Ti**, S, Zn, Pb, Al, Na, (Cr, Sr, Fe, Cl, Ca, Si, Mg, K)	Lithopone and/or barium white and zinc white, titanium white, lead white, Cr-containing yellow pigment(s), Fe-containing yellow earth pigment, chalk	Lithopone and/or barium white and zinc white, oil, zinc soap
15	Orange	**C, O, Pb**, Ba, Cr, Al, S, Zn, (Ca, Cl, Na, Ti, Mg)	Lead white, lithopone and/or barium white and zinc white, Cr-containing yellow(s), chalk, titanium white	Lithopone and/or barium white and zinc white, chrome yellow, oil, zinc soap
10	Red	**C, O**, Zn, Ca, Mg, Pb, (Al, Ba, S, Cl, P, Ti, Si)	Lithopone and/or barium white and zinc white, chalk, lead white, organic red, bone black, titanium white	Synthetic alizarin lake, chalk, lead white, lithopone and/or barium white and zinc white, oil, zinc soap
16	Brown	**C, O**, Fe, Zn, Ba, Ti, Si, Pb, S, Ca, (Na, Cl, Al)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white	Lithopone and/or barium white and zinc white, lead white, oil, zinc soap

* Major elements are presented in bold type, minor elements in plain type and trace elements in brackets.

Table A3. Summary of the materials identified or tentatively determined in the colour clusters of the samples of the protrusions extracted from the painting *Boat scene*.

Sample	Colour of the Cluster	SEM-EDS * Detected Elements	SEM-EDS Tentative Assignments	ATR μ-FTIR Identification
P1	Yellow	**Zn, C, O**, Ba, Na, Ti, S, Pb, (Fe, Si, Al, Sr, Mg, Ca, Cr, Cl, K)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, Cr-containing yellow(s), lead white	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, lead white, oil, zinc soap
P1	Grey-yellow	**C, Zn, O**, Na, Si, Fe, Al, (Ba, Ca, Ti, Mg, K, Pb, Cr, S, Cl, P)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, titanium white, bone black, Cr-containing yellow(s) or green, and traces of lead white	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, lead white, oil, zinc soap

P1	Orange	**C, Zn, O**, Na, (Ba, Ti, Fe, Si, Pb, S, Ca, Al, Mg, Sr)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, titanium white, lead white	Lithopone and/or barium white and zinc white, probably Fe-containing yellow earth pigment, lead white, oil, zinc soap
P1	Black	**C, Zn, O**, Na, (Ca, Ti, Ba, P, Si, S, Al, Mg)	Bone black, lithopone and/or barium white and zinc white, titanium white	Bone black, lithopone and/or barium white and zinc white, oil, zinc soap
P2	Yellow	**O, C, Ba, Ti, Zn**, S, Na, Fe, (Sr, Al, Pb, Si, Ca, Cd, Mg, Cl, Cr, K)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, lead white, Cr-containing yellow(s), cadmium yellow or its variant, chalk	Lithopone and/or barium white and zinc white, chalk, lead white, oil, zinc soap
P2	Brown	**O, Fe, C**, Ba, Si, Al, S, Ca, Zn, (Ti, Mg, K, Pb, Sr, Na)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, titanium white, lead white,	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, bone black, oil, zinc soap
P4	Yellow	**O, Ba, Zn, Ti, C**, S, Na, (Fe, Al, Sr, Ca, Si, Mg, Pb, Cl, Cd, K)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, lead white, cadmium yellow or its variant	Lithopone and/or barium white and zinc white, lead white, cadmium yellow or its variant, oil, zinc soap
P4	Orange	**Zn, O, C**, Na, Pb, Si, Fe, Al, Ba, (Ti, Mg, S, Cr, K, Ca)	Lithopone and/or barium white and zinc white, lead white, Fe-containing yellow earth pigment, titanium white, Cr-containing yellow(s)	Fe-containing yellow earth pigment, lead white, lithopone and/or barium white and zinc white, oil, zinc soap
P6	Yellow	**C, O, Zn**, Ba, Ti, S, Na, (Fe, Al, Sr, Si, Pb, Ca, Cl)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, lead white	Lithopone and/or barium white and zinc white, chalk, lead white, oil, zinc soap
P6	Brown	**O, Fe, C**, Ba, Si, Al., S, Zn, Ca, (Mg, Sr, Ti, Na, Pb, K, P)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, titanium white, lead white, bone black	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, oil, zinc soap
P6	Grey-yellow	**C, Zn, O**, Na, (Si, Fe, Al, Pb, Ba, Mg, Ti, S, Ca)	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, lead white, titanium white	Lead white, oil, zinc soap
P7	Yellow	**O, Ba, Zn, Ti, C**, S, Na, (Fe, Sr, Ca, Cd, Si, Al, Pb, Cl, K)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, cadmium yellow or its variant, lead white	Lithopone and/or barium white and zinc white, oil, zinc soap
P7	Grey-yellow	**Zn, O, C**, Na, Si, Al, Fe, (Ba, Pb, Mg, Ti, K, Ca, Sr, S, Cl)	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, lead white, titanium white	Fe-containing yellow earth pigment, lead white, lithopone and/or barium white and zinc white, oil, zinc soap

P7	Orange	**C, O, Zn**, Na, Si, Fe, Al, Ba, (Ti, Mg, Pb, Cr, Ca, S, K, Cl, P)	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, titanium white, lead white, bone black	Fe-containing yellow earth pigment, lead white, lithopone and/or barium white and zinc white, oil, zinc soap
P8	Yellow	**O, Zn, Ba, C, Ti**, S, Na, (Fe, Sr, Cd, Ca, Si, Al, Pb, Mg, Cl, K)	Lithopone and/or barium white and zinc white, titanium white, lead white, Fe-containing yellow earth pigment, cadmium yellow or its variant	Lithopone and/or barium white and zinc white, cadmium yellow or its variant, oil, zinc soap
P8	Grey-yellow	**Zn, O, C**, Na, Ba, Si, Ti, Al, Fe, (S, Mg, Pb, Ca, Sr, K)	Lithopone and/or barium white and zinc white, titanium white, lead white, Fe-containing yellow earth pigment	Fe-containing yellow earth pigment, lead white, oil, zinc soap
13	Grey-yellow	**C, Zn, O**, Na, Ti, Fe, (Ba, Al, Si, Pb, Mg, S, Cr, Ca, K, Cl)	Lithopone and/or barium white and zinc white, titanium white, Fe-containing yellow earth pigment, lead white, Cr-containing yellow pigment(s), chalk	Lithopone and/or barium white and zinc white, lead white, Fe-containing yellow earth pigment, chalk, oil, zinc soap
14	Brown	**C, O, Fe**, Ba, Si, Al, S, Zn, (Ca, Ti, Pb, Na, Mg, K, Cl)	Fe-containing yellow earth pigment, lithopone and/or barium white and zinc white, chalk, titanium white, lead white	Fe-containing yellow earth pigment, lithopone and/or barium white, zinc white, chalk, oil, zinc soap
14	Grey-yellow	**C, Zn, O**, Na, (Ba, Fe, Ti, S, Al, Si)	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, titanium white	Lithopone and/or barium white and zinc white, Fe-containing yellow earth pigment, oil, zinc soap

* Major elements are presented in bold type, minor elements in plain type and trace elements in brackets.

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