Article

Palmyrene Polychromy: Investigations of Funerary Portraits from Palmyra in the Collections of the Ny Carlsberg Glyptotek, Copenhagen

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Abstract: The current study is the first comprehensive investigation of the polychromy of Palmyrene funerary portraits. It presents the technical examinations of six portraits (ca. 150–250 CE) from the collection of the Ny Carlsberg Glyptotek, illustrating the marvellous splendour of the cultural heritage of ancient Palmyra. The six portraits were examined with various analytical methods, including microscopy, ultraviolet-induced visible fluorescence imaging and visible light-induced infrared luminescence imaging, X-ray fluorescence spectroscopy, scanning electron microscopy coupled to energy-dispersive X-ray spectroscopy, and Fourier transform infrared spectroscopy. Finally, two samples were collected for liquid chromatography–tandem mass spectrometry to obtain the amino acid sequence information. Various pigments were detected in the polychromy including lapis lazuli, pyromorphite, mimetite, yellow ochre, red ochre, a red lake, lead carbonate, zinc oxide, bone black, and charcoal black. The proteinaceous binding medium was identified as collagen-based and possibly also keratin-based animal glue. The examinations of the Palmyrene portraits in the Ny Carlsberg Glyptotek have proven that these artefacts, despite their current uniform, white appearance, originally presented themselves in a wealth of colours. This is illustrated by the digital reconstructions carried out of two of the examined portraits, which show how the original painting of these portraits would have given them an entirely different expression from what we see today.

Keywords: Palmyra; ancient polychromy; funerary portraits; pigments; binding media; XRF; SEM-EDS; FTIR; LC-MS/MS; digital reconstructions; imaging

1. Introduction

Palmyra, ancient Tadmor, was an oasis city located in the middle of the Syrian desert near the Eīfa spring, between the River Euphrates and the Mediterranean Sea, and thus strategically placed between the great empires of Rome and Parthia. The city was the most significant Syrian stop on the Silk Road and played a major role in the East-West caravan trade and it developed into a large, prosperous city with numerous public monuments. Its heyday was in the first three centuries CE. Palmyra is probably best known for Queen Zenobia, the first and only female ruler of the city, who reigned at the end of the 3rd century CE. Zenobia came to power when her husband died since her son was still a minor. She rebelled against Roman supremacy and expanded the Palmyrene Empire by conquering Egypt as well as large parts of Asia Minor. This was reciprocated by the Romans, who sacked the city during the reign of Emperor Aurelian in 272 CE [1].
Sadly, the story of ancient Palmyra is overshadowed by the current state of affairs in Syria. In 2011 uprisings against the ruling regime began in Syria, which led to an outbreak of a humanitarian catastrophe. In 2015, ISIS invaded the city, blew up ancient monuments, and plundered the site for artefacts of value. Today many of the city’s cultural artefacts have been destroyed or sold illegally on the black art market. As a result, the rich cultural heritage of the country has also suffered irreparable damage [2–4]. The situation in Syria is first and foremost a humanitarian tragedy and, unquestionably, Syria will never be the same again. Yet, as mentioned by Rubina Raja, “The catastrophe in Syria has also brought to the forefront that our joint cultural heritage can be shattered all too readily due to conflicts. Therefore, it is even more crucial that we across borders share information about these sites to keep the knowledge about them alive and protect them and their material culture as far as possible through documentation and publication of their archaeology and history.” [5] Thus, by carrying out research into the marvellous artefacts from ancient Palmyra and making the results globally available, we hope to preserve the cultural heritage of ancient Syria and to make it available to people worldwide. Our work is carried out with respect for the people who still suffer from the war in Syria, and we dedicate this study to them in respect of their cultural heritage.

From the first century CE until the destruction of the city in 272 CE, the people of Palmyra were buried in monumental tower tombs and later in underground tombs (hypogea). In these tombs, there were numerous vertical rows with burial niches, so-called loculi, in which the mummified bodies of the dead were placed. The most common type of funerary sculpture was the loculus relief, which was used to close off the burial niche in a tower or underground tomb. It is a bust made from local limestone. It is carved in relief and usually renders one person, but sometimes two, three, or even four individuals. Similarly, loculus stelae functioned to close off burial niches. However, in contrast to the loculus reliefs, they render the deceased, sometimes accompanied by another individual, in full figure [5]. Limestone sarcophagi were introduced in Palmyra in the second century CE and quickly became popular in Palmyrene funerary culture. Today, at least 600 sarcophagi are known. The lids often render banqueting scenes, illustrating a reclining man (probably the father of the family) and a seated woman (usually his wife) [5]. These various types of funerary sculptures, including loculus reliefs, locules stelae, and sarcophagi, comprise a vast corpus of funerary portraits of the people inhabiting the ancient city of Palmyra. In fact, more than 3600 such funerary portraits from Palmyra are known today [5].

Research into ancient sculptural polychromy has rapidly expanded during the past two decades. Many research institutions and museums now carry out advanced investigations of the polychromy of various groups of ancient artefacts. Focus has tended to be on Greco-Roman marble sculpture and architecture, e.g., [6–10], although the polychromy of ancient terracotta artefacts, for example, as well as Egyptian artefacts [11], has also received far greater attention during recent years. Yet, many groups of artefacts of different materials and from various geographical areas and chronological periods have still not received much scrutiny.

This is also the case for the art of ancient Palmyra. The Palmyrene portraits have received extensive scholarly attention during the past decade, primarily thanks to the Palmyra Portrait Project housed at the University of Aarhus, Denmark [12]. However, their original polychromy is usually omitted in scientific studies or only briefly mentioned e.g., [13–15]. A significant exception is an article by Clarissa Blume-Jung (2021), which addresses the polychromy of Palmyrene portraits, although not based on any technical examinations [16]. So far, two technical studies of Palmyrene interior decoration, specifically wall paintings, have been published [17,18]. Regarding funerary sculptures, only the Ny Carlsberg Glyptotek (NCG) has carried out technical examinations of the polychromy of this type of artefact. This has so far resulted in three publications. Two of them are case studies focusing on one artefact: The first concerns the funerary portrait of the so-called Beauty of Palmyra (IN 2795). The study was based on imaging techniques and X-ray Fluorescence spectroscopy (XRF). It was presented by Jan Stubbe Østergaard and Maria Louise Sargent.
at the 18th International Congress of Classical Archaeology in 2014 and is published in the proceedings of the conference [19]. The second case study presents a thorough study of the remarkable use of lapis lazuli for the polychromy of a female funerary portrait belonging to a sarcophagus lid (IN 1150) [20]. The study was performed in collaboration with the Center for Art Technological Studies and Conservation (CATS) and the Danish School of Conservation and involved various analytical methods. Finally, a publication focusing on the trade in pigments in Palmyra, based on the information previously published on IN 2795 as well the preliminary examinations of another seven funerary portraits from the collection, was published as part of the catalogue for the special exhibit, “The Road to Palmyra”, at the NCG in 2019 [21]. This article is thus the first comprehensive study of the polychromy of Palmyrene funerary portraits. It is a compilation of the technical examinations of six portraits from the collection of the Ny Carlsberg Glyptotek illustrating the marvellous splendour of the cultural heritage of ancient Palmyra.

2. Materials

2.1. The Palmyrene Collection at the Ny Carlsberg Glyptotek (NCG)

The NCG possesses the largest collection of artefacts from Roman Palmyra outside of Syria. The collection primarily comprises funerary sculptures, stucco fragments, and so-called banqueting tesselae, but also includes altars, sculptural and inscriptional fragments, and a few artefacts of faience and glass. The funerary sculptures are the core of the collection, comprising more than 120 artefacts. These include the most common types of Palmyrene funerary art, including stelae with full-figure portraits, loculus reliefs with half-figure bust portraits, banqueting reliefs, and fragments from sarcophagi.

The collection of Palmyrene art was compiled primarily in the 1880s by the brewer and founder of the NCG Carl Jacobsen through his contact with the Danish consul in Beirut, Julius Leytved (1836–1911). The collection is the first of its kind and it is thus one of the earliest collections of Palmyrene art in the Western world.1 The collection was enlarged by the Danish philologist Johannes Elith Østrup (1867–1938) and later by Harald Ingholdt (1896–1985) who excavated in Palmyra in the 1920s and in 1935/1936 [5].

A survey of the extensive collection of Palmyrene portraits in the NCG was carried out as a basis for the selection. Six artefacts were selected for closer examination due to their particularly promising visible traces of polychromy. The chosen artefacts include different motifs and types and represent different chronological periods from ca. 150 to 250 CE Figures 1–6.

1 For the correspondence between Jacobsen and Leytved regarding the acquisition of Palmyrene sculpture, taking place between 1882 and 1903, see [2].
2.1.1. Loculus Relief Depicting a Man

**Figure 1.** Loculus relief depicting a man. Ny Carlsberg Glyptotek, IN 1052. Photo: A. S. Berg.

| Inv. no.          | Ny Carlsberg Glyptotek, IN 1052 |
|-------------------|---------------------------------|
| Acquisition       | Acquired in Syria in 1888 by the Danish consul Julius Løytved (1836–1911) |
| Material          | Limestone                       |
| Measurements      | H: 61 cm. W: 48.5 cm. D: 26 cm. |
| Date              | 150–170 CE                      |
| Inscription       | To the left of the figure, in the top right corner. In Palmyrene Aramaic |
| Translation       | Malkû son of ‘Atê aqab. Alas!  |
| Original context  | Unknown                         |
| Polychromy        | Traces of red pigment in the inscription |
2.1.2. Loculus Relief Depicting a Man

![Figure 2. Loculus relief depicting a man. Ny Carlsberg Glyptotek, IN 1146. Photo: A. S. Berg.](image)

| Inv. no.          | Ny Carlsberg Glyptotek, IN 1146 |
|-------------------|----------------------------------|
| Acquisition       | Acquired in Syria by the German diplomat E. Puttmann (before 1894) |
| Material          | Limestone                        |
| Measurements      | H: 50 cm. W: 37 cm. D: 23 cm.    |
| Date              | 170–190 CE                       |
| Inscription       | Two inscriptions, one to the left and one to the right of the figure. In Palmyrene Aramaic |
| Translation       | [Yêdî] bel son of [Mojqîmû Kalbaî. Alas! |
| Translation       | Malkû son of Paşi’êl. Alas!     |
| Original context  | Unknown                          |
| Polychromy (visible) | Traces of black paint around his eyes and traces of red paint in the inscriptions |
2.1.3. Loculus Relief Depicting a Woman, the So-Called ‘Beauty of Palmyra’

**Figure 3.** Loculus relief depicting a woman, the so-called ‘Beauty of Palmyra’. Ny Carlsberg Glyptotek, IN 2795. Photo: A. S. Berg.

| Inv. no.          | Ny Carlsberg Glyptotek, IN 2795 |
|-------------------|---------------------------------|
| Acquisition       | Acquired in Syria by Harald Ingholt (1929) |
| Material          | Limestone                        |
| Measurements      | H: 57 cm. W: 39 cm. D: 20 cm.    |
| Date              | 200–250 CE                       |
| Inscription       | N/A                             |
| Original context  | Temple/house tomb of Qasr Abjad, Valley of the Tombs |
| Polychromy (visible) | Traces of yellow and black paint on her hair. Red paint is visible on the headdress chain, on her cheeks and her mouth. Her turban, veil, jewellery, and tunic all bear traces of yellow paint |
2.1.4. Standing Woman from a Sarcophagus Lid

Figure 4. Standing woman from a sarcophagus lid. Ny Carlsberg Glyptotek, IN 1150. Photo: A. S. Berg.

| Inv. no.       | Ny Carlsberg Glyptotek, IN 1150 |
|---------------|---------------------------------|
| Acquisition   | Acquired in Syria by the German diplomat E. Puttmann (before 1894) |
| Material      | Limestone                       |
| Measurements  | H: 58 cm. W: 29 cm. D: 24 cm.   |
| Date          | 210–230 CE                      |
| Inscription   | N/A                             |
| Original context | unknown                        |
| Polychromy    | Traces of black paint on her eyebrows and around the eyes. Traces of bluish paint on her garments. Her skin appears darker than the limestone substrate (visible) |
2.1.5. Standing Woman from a Sarcophagus Lid

![Image of a standing woman from a sarcophagus lid.](image)

**Figure 5.** Standing woman from a sarcophagus lid. Ny Carlsberg Glyptotek, IN 1065. Photo: A. S. Berg.

| Inv. no. | Ny Carlsberg Glyptotek, IN 1065 |
|----------|---------------------------------|
| Acquisition | Acquired in Syria in 1888 by the Danish consul Julius Løytved (1836–1911) |
| Material | Limestone |
| Measurements | H: 67.5 cm. W: 35 cm. D: 25 cm. |
| Date | 230–250 CE |
| Inscription | There are three inscriptions on the keys: Right key (Greek): Transcription: ΛΝΥ. Translation: Can be read as ‘ANY’ and be the date 451 (139/140 CE). Middle key (Palmyrene Aramaic): Translation: House of eternity. Left key (Greek): Transcription: ΘΕΛΙ. Translation: Unclear. However, various interpretations have been proposed. One interpretation is ‘Theou Eliou’, with the meaning ‘Belonging to Helios’ [5] |
| Polychromy (visible) | Traces of dark paint on her eyebrows and around the eyes. Traces of red paint in the inscriptions |
2.1.6. Loculus Relief Depicting a Man and a Woman

![Image of the Loculus Relief Depicting a Man and a Woman](image-url)

**Figure 6.** Loculus relief depicting a man and a woman, Ny Carlsberg Glyptotek, IN 1153. Photo: A. S. Berg.

- **Inv. no.** Ny Carlsberg Glyptotek, IN 1153
- **Acquisition** Acquired in Syria by the German diplomat E. Puttmann (before 1894)
- **Material** Limestone
- **Measurements** H: 45.5 cm. W: 53 cm. D: 19.5 cm.
- **Date** 230 CE
- **Inscription** Between the figures. The inscription cannot be translated, but some of the letters might be Nabataean or a later addition [5]
- **Polychromy** (visible) Traces of dark reddish paint in the inscription as well as the flowers depicted in the background. A dark patch on his left sleeve may also be related to the polychromy

3. Methods

The six funerary sculptures selected for the investigation were first examined visually. The techniques employed include microscopy with a surgical microscope (max 40×) and a handheld video microscope (max 220×). The artefacts were also examined and recorded utilising ultraviolet-induced visible fluorescence (UVF) imaging and visible light-induced infrared luminescence (VIL) imaging. All visual observations are supported by photographic documentation.

After the visual examination and technical imaging, handheld X-Ray Fluorescence (XRF) spectroscopy was performed. Informed by the non-invasive investigation, samples were collected for further investigations including cross-sectional analysis. The prepared cross-sections were analysed using an optical microscope (max 100×) whereafter a selection of them were analysed using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS). In addition, loose samples were analysed with Fourier transform infrared (FTIR) spectroscopy. Furthermore, two samples were collected from IN 2795 for liquid chromatography–tandem mass spectrometry (LC-MS/MS) to obtain amino
acid sequence information. For state-of-the-art methodology in chemical analysis applied to archaeometry, research references [22–26] provide a good overview.

3.1. Ultraviolet-Induced Visible Fluorescence (UVF) Imaging

Revealing the presence and spatial distribution of fluorescing materials by illumination with high-frequency radiation within the UVA range (340–400 nm), UVF is routinely utilised for the examination and documentation of polychrome artefacts. It is particularly useful for visual detection of organic adhesives, binders, and surface coatings as well as lake pigments.

Most UVF examinations and recordings were made using a Harolux lamp with eight Philips TL-D 18W Blacklight Blue lamps (340–400 nm) and an unmodified Canon EOS 5D Mark II camera fitted with a Tiffen Haze 2A UV-blocking filter. The images have been edited using Adobe Photosho Lightroom 2.7 and Adobe Photoshop CS6. For IN 2795, a modified Canon EOS 5D Mark IV camera body with a Canon EF 50 mm f/2.5 Compact Macro lens was used. Hoenle UVASPOT 400/T lamps with a Schott UG2A glass served as the excitation source and the visible fluorescence was passed through XNite CC1 (maxmax.com, accessed 9 May 2022), PECA 916 (ir-uv.com, accessed 9 May 2022), and Tiffen Haze 2E filters.

3.2. Visible Light-Induced Infrared Luminescence (VIL) Imaging

VIL imaging is an effective technique for the detection of the synthetic pigment Egyptian blue. This colourant emits infrared (IR) radiation in the 800–1000 nm range (peak around 910 nm) with a very high quantum efficiency upon excitation in the visible range. The spatial distribution of the pigment can be documented by capturing its luminescent emission with an IR-sensitive camera [27].

VIL imaging was carried out using two Excel Led RGB lamps ($\lambda_{\text{max}} = 470$ nm, 525 nm, and 629 nm) and a Canon 40D camera modified by removing the internal IR-blocking filter. The lens was fitted with a Schott RG830 visible light-blocking filter resulting in an image in the approximate IR range of 800–1000 nm. A Labsphere Spectralon 99% reflectance standard was included for the evaluation of potential luminescence. The images have been edited using Adobe Photosho Lightroom 2.7 and Adobe Photoshop CS6. For IN 2795, the same setup was used except for the camera body Canon EOS 5D Mark IV.

3.3. Cross-Sections

Samples were collected from paint traces representing the colours identified on each portrait. All samples, each no larger than a pinhead, were taken from fractured areas to minimise the damage caused by sampling. The samples were removed with a scalpel which was thoroughly cleaned with acetone prior to each sampling. Most of the specimens broke into smaller pieces during sampling. The pieces were documented with a handheld microscope and the most representative of them were selected for further processing. Each of the selected pieces was then placed in a mould on a bed of cured two-component epoxy resin. Owing to their minute size and fragile nature, most of the paint flakes were glued onto the surface with superglue before they were embedded in resin. After curing, the resin-embedded samples were polished manually on one side with increasing fineness (800–4000 grains/cm$^2$) on a polishing machine using water as a lubricant and then with polishing pads (8000 and 12,000 grains/cm$^2$). The finished cross-sections were examined at the NCG using a Leica DM2500M optical microscope (max 100×) in bright field (BF), dark field (DF), and UV. All observations were documented with a Canon EOS 5D Mark II camera mounted on the microscope.

3.4. Hand-Held X-ray Fluorescence (XRF)

XRF spectra were acquired with a handheld Bruker Tracer 5i equipped with a Rhodium tube. Two measurements at 15 kV, 15 µA, with no filter and 40 kV, 7 µA, with a Ti/Al filter
were taken for each location optimising the detection of low and high Z elements, respectively. The spectra were processed with the Bruker Artax software Spectra, Version 8.0.0.476.

3.5. Scanning Electron Microscopy Coupled with Energy-Dispersive X-ray Analysis (SEM-EDS)

A Hitachi S-3400 N SEM equipped with an energy-dispersive spectrometer (EDS) was used for the microstructural analyses. The spectrometer is a Bruker Quantax 200 EDS system with two Peltier-cooled XFlash silicon drift detectors. The detectors have an active area of 20 mm$^2$ each. The system allows the detection of low-energy X-ray photons so that even boron ($Z = 5$, $K\alpha = 0.182$ keV) can be detected. The observations were performed in variable pressure (VP) mode on non-coated polished sections and analyses were related to internal virtual standard profiles. The acquisition varied between 200 and 600 s.

3.6. Fourier Transform Infrared Spectroscopy (FTIR)

Scraping samples were analysed in transmission mode with a ThermoFisher (Waltham, MA, USA) FTIR spectrometer. The spectrometer was coupled with a Continuum microscope equipped with a cryogenic mercury–cadmium telluride (MCT) detector. A diamond cell was used for mounting the samples. Spectra were acquired in the 4000–590 cm$^{-1}$ range with a spectral resolution of 2 cm$^{-1}$. Resulting spectra were compared with reference libraries.

3.7. Liquid Chromatography–Tandem Mass Spectrometry (LC-MS/MS)

Protein sequencing was performed on two samples from IN 2795. They were collected from the yellow paint and the red paint of the headdress (Figure 7). Since there are several traces of pale pink in close proximity to the sampling areas, it is possible that the samples also contain traces of this paint.

![Figure 7. Detail of IN 2795: visible light photograph (left) and UV-induced visible fluorescence image (right). The locations for cross-sections 1 (yellow) and 2 (red), as well as LC/MS/MS 3 (red) and 4 (yellow), are marked on the left. Photos: J. Stenger.](image)

The samples along with protocol blanks were processed following a procedure already described in Mackie et al. [28] and reported in detail in Appendix A. Briefly, proteins were extracted from the solid micro-samples using an aqueous buffer of guanidinium chloride (GuHCl). The extracted proteins were then digested using two endoproteinases Lys-C and trypsin that cleave the peptide bond and break the proteins into smaller fragments called peptides. These peptides, once purified and collected on in-house made C18 extraction stage-tips [29], can be analysed using nano-liquid chromatography (nLC) coupled with
tandem mass spectrometry (MS/MS). After chromatographic separation, the samples were analysed on a QExactive HF, or an Orbitrap Exploris 480 (both: Thermo Scientific, Bremen, Germany).

The MS/MS spectra were identified with the MaxQuant software (MQ) [30] (version 2.0.1.0) matching them against four different databases of protein sequences. First, the spectra from all the raw files were matched against a reference database containing all the publicly available sequences of proteins contained in the most common proteinaceous artistic materials: animal glue, eggs, and milk. The software was set to match the MS/MS spectra against fully tryptic peptide sequences. Second, to investigate the presence of protein residues originating from other sources, the spectra were then matched against a larger database (SwissProt, from UniProt) containing all publicly available and manually reviewed protein sequences. The software was set to match the MS/MS spectra against fully tryptic peptide sequences. Third, following the results obtained with the SwissProt database for the raw files acquired in 2021, the spectra from these analyses were matched against a database containing keratins and keratin-associated proteins from Artiodactyls (even-toed ungulates). This search matched the spectra against semi-tryptic peptide sequences to account for the possible origin of the peptides from unspecific hydrolysis of the proteins. Fourth and finally, the spectra acquired in 2021 were matched against the publicly available proteome of *Sus scrofa* (pig). This search matched the spectra against semi-tryptic peptide sequences. All other parameters were the same in all searches and are specified in Appendix A.

The deamidation level was calculated using a deamidation tool freely available on GitHub (https://github.com/dblyon/deamidation, accessed on 9 May 2022). The workflow of this tool is described in detail in Mackie et al. [28].

4. Results: Constituents of the Polychromy

Since the materials and techniques used for Palmyrene sculpture are the focal point of this paper, the results are presented according to constituents. The pigments are presented according to hue, whereas the organic components are divided into proteinaceous components and conservation materials. For an overview of the results for the individual portraits, see Table 1.

Table 1. Summary of the painting materials identified on the six portraits.

| Artefact | Paint Colour | Pigment and Medium | Analytical Method |
|----------|--------------|--------------------|-------------------|
| IN 1052  | red          | red ochre (iron rich, silicon, potassium, and aluminium) | XRF, SEM-EDS     |
| IN 1146  | black        | carbon black       | optical microscopy|
|          | red          | red ochre (iron rich) | XRF             |
| IN 2795  | yellow       | yellow ochre (goethite, gypsum, quartz, calcite, pyromorphite, Egyptian blue? (contaminant?)) | XRF, FTIR, XRF, SEM-EDS, VIL |
|          | red          | red ochre (iron rich, quartz, kaolin, and calcite) | XRF, SEM-EDS, FTIR |
|          | pink         | red lake           | UVF              |
|          | black        | bone black (calcium phosphate) | FTIR            |
|          | gold         | gold leaf containing also silver | SEM-EDS          |
|          | paint medium | collagen-based, and possibly also keratin-based animal glue | LC-MS/MS         |
|          | clear restauration material | nitrocellulose | FTIR            |
| IN 1150  | blue         | lapis lazuli (lazurite, pyrite, and calcite), hydrocerrusite, cerrusite, zinc oxide, siderite (contaminant?), haematite (contaminant?), mimette (white particles), carbon-based black (charcoal) | optical microscopy, SEM-EDS, and Raman spectroscopy [20] optical microscopy, SEM-EDS, optical microscopy, SEM-EDS, optical microscopy, SEM-EDS, optical microscopy, SEM-EDS, optical microscopy, SEM-EDS, optical microscopy, SEM-EDS |
|          | paint medium | lipid              | FTIR [20]        |
| IN 1065  | red          | red ochre (iron rich) | XRF, optical microscopy |
| IN 1153  | red          | red ochre (iron-rich, silicon, potassium, and aluminium) | XRF, SEM-EDS, and optical microscopy |
4.1. Blue Pigments
4.1.1. VIL-Emitting Particles

VIL imaging has not revealed convincing traces of Egyptian blue (CaCuSi₄O₁₀) on most of the portraits examined. In some cases, a few brightly luminescing particles are observed. However, they seem to be unrelated to the polychromy. Firstly, the distribution of the luminescing particles appears quite random. Many of the particles are found on heavily abraded areas that have never been painted. Secondly, no blue particles have been identified in the corresponding locations. This would suggest that the luminescence observed is emitted by other materials with similar VIL properties to Egyptian blue. Another possibility is that single particles of Egyptian blue are present although not detected with microscopy. In this case, the random distribution points to contamination introduced in the workshop, the tomb, or the museum environment.

The only portrait whose polychromy might include minuscule inclusions of Egyptian blue is IN 2795. VIL images reveal a few luminescent particles, the majority of which appear to be related to the yellow paint (Figures 8 and 9). Yet, these particles are very few and are not grouped in clusters but rather are spread loosely in the yellow-painted areas. This indicates that they were not intentionally applied but rather constitute ancient contamination, e.g., from a dirty paintbrush or loose particles of Egyptian blue from the workshop. However, since no blue pigment particles have, thus far, been identified on the said portrait, it is not clear whether the luminescence observed is indeed related to Egyptian blue.

The overall absence of Egyptian blue is somewhat surprising since it is the sole blue pigment so far identified in ancient Palmyrene wall paintings and other interior decoration [18,31]. Moreover, Egyptian blue was widely used in contemporary sculptural polychromy in other parts of the Roman Empire [32].

4.1.2. Blue Paint Traces

The only visible traces of blue paint on any of the six sculptures are observed on the mantle of IN 1150. An examination with a microscope reveals heterogeneous dusty blue paint traces with dark and bright blue particles. The identification of lapis lazuli in these traces using Raman spectroscopy and other analytical tools and its unusual occurrence has been reported and discussed previously [20].
4.2. Yellow Pigments

Abundant traces of yellow have been identified on the greater part of the jewellery and the headdress of IN 2795 (Figures 3 and 7–9). The XRF investigation indicates that several of the yellow areas on IN 2795 contain lead, chlorine, and phosphorus. The signal strength correlates for the three elements (Figure 10). This suggests the presence of pyromorphite \( \text{Pb}_5(\text{PO}_4)_3\text{Cl} \) that forms a chemical series with the lead arsenate mineral mimetite \( \text{Pb}_5(\text{AsO}_4)_3\text{Cl} \), a pigment previously attested in wall paintings in Palmyra [18]. The anion groups \( \text{PO}_4 \) and \( \text{AsO}_4 \) are interchangeable so that intermediate compositions may be found [33]. The colour of pyromorphite is usually green, yellow, or brown, whereas mimetite is yellow, brown, white, or colourless. Based on the XRF data only, both members of the series could be present on the surface of IN 2795 since arsenic can be hard to detect in the presence of lead. The L-\( \alpha \) line of lead at 10.55 keV is very close to the K-\( \alpha \) line of arsenic at 10.54 keV and the K-\( \beta \) line of the latter is often too weak to detect.

To gain further information about the yellow lead-based mineral, a cross-section from the yellow turban (location 1 in Figure 7) was analysed with optical microscopy (Figure 11) and SEM-EDS. A relatively rough and heterogeneous mixture of pigment particles is observed. The layer consists of orange-yellow pigment particles of varying sizes with a considerable amount of clear, black, crimson, and bright-red inclusions. In several SEM-EDS spot analyses, the strongest signals stem from lead, phosphorus, and chlorine in agreement with the XRF results indicative of pyromorphite. Arsenic is not detected.
Figure 10. Three XRF spectra of yellow areas in IN 2795. In the area between 2 and 3 keV, the signal strength for phosphorus, lead, and chlorine correlates.

Figure 11. Cross-section from the yellow paint on the turban of IN 2795. A speck of gold is visible on top of the paint layer. Visible light, dark field, 50×. Photo: S. B. Hedegaard.
In the FTIR analyses on several yellow samples from areas with high lead, chlorine, and phosphorus, only the yellow iron oxide hydroxide goethite ($\alpha$-FeOOH), gypsum ($\text{CaSO}_4\cdot2\text{H}_2\text{O}$), quartz ($\text{SiO}_2$), and calcite ($\text{CaCO}_3$) were detected. The reason pyromorphite is not detected could be that the two characteristic low-frequency vibrations of pyromorphite [34] at 568 cm$^{-1}$ and 533 cm$^{-1}$ are outside the spectral region of the FTIR instrument and that the other fingerprint region bands between 800 cm$^{-1}$ and 1000 cm$^{-1}$ overlap with the absorption of other materials in the mixture. Figure 12 compares the FTIR spectra of a yellow sample from IN 2795 with a pyromorphite reference from the RRUFF database. The characteristic bands of goethite at 895 cm$^{-1}$, 801 cm$^{-1}$, and 3139 cm$^{-1}$ (broad) are seen in the spectrum from the yellow sample but none of the pyromorphite bands. The spectra indicating the presence of gypsum, quartz, and calcite also show no trace of pyromorphite (not shown). Consequently, the presence of pyromorphite could not be confirmed by FTIR and it remains unclear if its presence is due to intentional use or association with the earth pigment.

Figure 12. FTIR spectrum of a yellow sample from IN 2795 (upper trace, red line) and a reference spectrum of pyromorphite from the RRUFF database (lower trace, black line).

Two examples of pyromorphite have been attested in ancient Buddhist and early Islamic interior decorations in the modern-day Xinjiang Uygur Autonomous Region in China and northeastern Iran, respectively [35,36]. Palmyra was connected to both areas via the Silk Road, which leaves it open to interpretation whether pigment was locally sourced or acquired via trade.

4.3. Red Pigments

Red is the most frequently observed colour on Palmyrene funerary portraits in general. This also holds true for the collection in the NCG. Red is found in the inscriptions on IN 1052, IN 1065, 1146 (Figure 13), and IN 1153. Furthermore, extensive red paint traces are also observed on the headdress chain on IN 2795 (Figure 7).
According to the XRF measurements, all the red paint traces analysed contain significant concentrations of iron which is consistent with earth pigments dominated by the red iron (III) oxide, haematite (Fe₂O₃).

The red paint layers in the cross-sections representing IN 1052, IN 1065, IN 1153, and IN 2795 (Figure 7 (location 2) and Figure 14) are all based on finely grained, bright-red particles with a few, primarily sub-micron-scale, dark inclusions. In addition, the paint layer from IN 2795 contains numerous clear inclusions resulting in a slightly rougher and more heterogeneous appearance.

SEM-EDS analyses confirm that the red paint layers on IN 1052, IN 1153, and IN 2795 are rich in iron. Other elements elevated in this layer compared to the limestone substrate are silicon, potassium, aluminium, and, in the case of IN 2795, magnesium. This is expected for an earth pigment such as red ochre [33]. The red paint layer in the cross-section from IN 1065 appears similar but was not analysed with SEM-EDS.

The FTIR analysis performed on the red paint on IN 2795 showed signals for quartz, kaolinite (Al₄Si₄O₁₀(OH)₈), and calcite, which are typical components of a red ochre.
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Figure 14. Dark field (DF) visible light image, SEM backscatter image (BS), and SEM-EDS elemental maps of the cross-section of red paint from the headdress chain of IN 2795. The limestone substrate is calcium-based, whereas the red paint layer is iron-based. The metal leaf observed on top of the paint consists mostly of gold, but it also contains silver. A rough-looking layer is found on top of the polychromy. In the phosphorus map, the gold leaf shows up faintly because the P Kα line at 2.013 keV overlaps with the Au Mα line at 2.122 keV. Images: S. B. Hedegaard, SEM: J. Bredal-Jørgensen.

4.4. Red Lake Pigment

Pale pink paint traces are observed on the diadem (Figures 7 and 8), the piece of jewellery on the proper right upper arm, and in the folds of the turban and the tunic of IN 2795 (Figures 7 and 9). The pale rosy-pink traces on the turban, the diadem, and the jewellery on the proper upper arm all appear to have been applied on top of a yellow paint layer. The pinkish paint traces in the folds of the tunic are minuscule. There are no apparent traces of an underlying base colour in these instances.

Under UV illumination, the pink paint traces fluoresce in a strong pink-orange hue indicating the presence of a lake pigment such as madder lake (Figures 7–9) [37,38]. Interestingly, these paint traces also produce a weak VIL signal due to the long tail of the fluorescence band into the near-infrared (Figure 8). The organic lake was not identified.

4.5. White Pigments

There are no obvious white paint traces on any of the six sculptures examined for this study. However, a cross-section from the blue paint on IN 1150 contains mostly white
material (Figure 15 DF). Lead-containing small, occasionally rectangular grains could be lead carbonates as found in a previously published FTIR analysis from a related sample [20]. Furthermore, the strong correlation in the SEM-EDS elemental maps between lead, arsenic, and chlorine (Figure 15 Pb, As, Cl) suggests the presence of mimetite (Pb5(AsO4)3Cl) in a few and rather large white particles (10–20 µm). Additionally, a strong zinc signal suggests the overall similarity to the blue paint composition described in Brøns et al. [20] and the minor differences are probably due to the inhomogeneity of the paint.

Figure 15. Dark field (DF) visible light image, SEM backscatter image (BS), and SEM-EDS elemental maps of the cross-section of blue paint from IN 1150. The dark field image shows small blue and black particles, some large angular black particles, and a white matrix with larger white grains. Lead, arsenic, and chlorine correlate for the latter suggesting the presence of mimetite (Pb5(AsO4)3Cl). The large black particles are angular and have a low backscatter signal suggesting the presence of charcoal black. Photo: S. B. Hedegaard, SEM: J. Bredal-Jørgensen.
The rare pigment mimetite has been found previously in the decoration of a lunette in the tomb of the three brothers in Palmyra \cite{18}. Here, the pigment occurs not in its white, but in its yellow form. Buisson et al. point out in their comprehensive review of the pigment that the compound had previously only been found on four works from the Hellenistic period \cite{39–43}. Since this publication, mimetite has also been extensively discussed by Abramitis and Abbe \cite{44}. Li et al. report mimetite as a degradation product in a mixture of emerald green (\(\text{Cu(C}_2\text{H}_3\text{O}_2\text{)}_2\cdot3\text{Cu(AsO}_2\text{)}_2\)) and cerussite (\(\text{PbCO}_3\)) \cite{45}, which is, however, not relevant in this context since emerald green was introduced in about 1800. Moreover, Moon et al. found it on the Afrasiab murals near Samarkand, Uzbekistan \cite{46}, and it was identified on Roman sculptures from the province of Africa Proconsularis \cite{47}.

Only a small number of the assumed mimetite minerals are found on IN 1150. However, the concentration in the specific section is rather high, which could suggest that the pigment was used intentionally.

4.6. Black Pigments

The eyes and pupils on IN 1065, IN 1146, and IN 1150 are clearly outlined with black paint (Figure 16). Black paint traces are also visible on the hair on IN 1146 and IN 2795 (Figures 7 and 8).

![Image of eyes and pupils decorated with black paint](image)

**Figure 16.** Details of the eyes and pupils decorated with black paint on IN 1146, IN 1150, and IN 1065 (from top to bottom). Photos: A. S. Berg.

The FTIR performed on a sample from the black hair on IN 2795 identified calcium phosphate, which is the main constituent in bone and ivory black. The cross-section from IN 1150 (Figure 15) shows black pigment particles that are fibrous, angular, and often with a bluish, metallic lustre. Their morphological features are typical of charred wood \cite{48}. This is supported by their low SEM backscatter signal. Other much finer black particles are probably carbon-based soot.
4.7. Gold Leaf

Under the microscope, small traces of gold are visible on the jewellery and headdress of IN 2795. Gold leaf is found on top of yellow, pink, and red paint traces. The observed sequence is also documented in the cross-sections representing yellow from the turban and red from the headdress chain, respectively (Figures 11 and 14). In both instances, the gold leaf has been verified by SEM-EDS analysis.

4.8. Proteinaceous Components

Although the FTIR analyses of the paint on IN 2795 showed weak evidence of an amide I band, the binding medium was not identified with this technique. However, the proteomic analysis confidently detected proteinaceous materials in two samples from the red and the yellow paint residues (see Appendix B and Figure 7). Collagen alpha-2(I) from Artiodactyla (even-toed ungulates) was identified in the sample removed from the red paint residue (Table A1). The identification was only supported by three peptides in total, preventing a more specific determination of the species of origin of the material. Collagens are the most common proteins in connective tissues (skin, bones, and tendons) [49]. Therefore, the identification likely suggests the use of animal glue, a material produced by prolonged boiling of animal remains. The low number of peptides might indicate the presence of only a small amount of animal glue. It is possible that the glue was mixed with another, non-proteinaceous organic paint binder, such as a polysaccharide gum, which would not have been detected in the proteomic analysis and should be the object of future investigations.

Several keratins and keratin-associated proteins were confidently identified in both samples removed from the red and the yellow paint residues (Table A1). Keratins are the main constituent of many tissues in mammal organisms such as the outermost layer of skin, hair, fur, wool, nails, and hooves [50]. Human keratins are a very common contaminant in proteomics analyses, due to contamination in the laboratory environment and from human handling of objects and samples. However, for both samples, several peptides do not match the corresponding human sequence (Table A2), confirming that the presence of these proteins is not due solely to human contamination.

In the sample from the yellow residue, keratins unique to Sus scrofa (pig) and Ovis aries (sheep) were identified. In the sample from the red residue, only Sus scrofa was specifically identified as the biological origin of the keratins. In the latter sample, keratin peptides not matching the human sequence or the pig sequence were also found (Table A2). These results could lead to several conclusions: (i) the keratins derive from pigs and at least one other species; (ii) the remaining keratins derived from non-human contamination; or (iii) the remaining keratins derive from a species whose protein sequences are not currently present in publicly available databases and can therefore currently not be identified. In the last case, the identification of diagnostic peptides for other species is possible since the species-specificity of a peptide is always limited by the database.

The identified proteins and the corresponding diagnostic peptides are reported in Tables A1 and A2, respectively.

The deamidation level of identified proteins was calculated to evaluate protein damage. Deamidation is a protein modification occurring on asparagine and glutamine residues. It is usually regarded as an indicator of the damage to the protein since it naturally occurs over time [51–53], though factors such as temperature and pH are known to affect the rate of the damage reaction [54,55]. More recently, it has been used to discriminate between authentic ancient proteins and modern contaminants [56].

In the two samples analysed here, only the keratin peptides not matching the corresponding human sequence have been used to calculate the deamidation level, as they are not expected to derive from modern human contamination. Of these, only the peptides that contain asparagine and glutamine and can therefore undergo deamidation are used in the calculation (value indicated above each bar in Figure 17). This number limits the confidence of the calculation as at least 20 peptides should be used [57], whereas in this study, only the deamidation of asparagine in the yellow paint sample is calculated with
(just) more than 20 peptides. For the same reason, the deamidation level of collagen was not calculated because of its identification with only three total peptides.

Figure 17. Deamidation graph: Percentage of deamidation of asparagine (N) and glutamine (Q) residues in the two analysed samples. Error bars indicate standard deviation around 1000 bootstrap replicates. Sample identifiers are shown at the very top, whereas the number of peptides used for the calculation is indicated above each bar.

The level of deamidation of the keratins is very low (Figure 17). For an object produced about 2000 years ago, this could suggest that the non-human keratins observed derive from contamination and are not authentic. However, the limited confidence of the calculation does not allow us to state this with certainty.

If genuine, the presence of some of the animal keratins in the samples might be explained by the pigments in the paint. The main pigment in the sample was identified by XRF and SEM-EDS analyses as the lead-based yellow pigment pyromorphite. However, traces of pale pink paint, seemingly containing a red lake pigment, have been observed very close to the sample location of the yellow paint. It is therefore possible that, although yellow in appearance, this sample might contain traces of madder lake pigment. The manufacture of this organic pigment can involve its extraction from dyed sheep wool textiles. The extraction is carried out at high temperatures in alkaline conditions, causing the partial cleavage of the keratins of the wool and, consequently, the presence of proteins or peptides in the pigment particles [58,59]. Recent results have also confidently identified sheep keratins in paint mock-ups containing madder lake pigment extracted from dyed wool [60]. Therefore, the presence of traces of a lake in the sample from the yellow paint residues might explain the identification of sheep keratins in this sample.

It cannot be completely excluded that the identified sheep keratins are a result of modern contamination, for example, from wool clothing worn while handling the object and/or the sample. Nonetheless, since the samples have been removed and processed together, the lack of sheep keratins in the sample removed from the red paint suggests that their identification in the sample from the yellow residues is genuine.
The presence of pig keratins in both samples is hard to explain in connection with the manufacture of pigments. The area of red paint from which the analysed sample was removed contains haematite and no madder lake. It is possible that the identified keratins are traces of a paintbrush made with pig bristles, which are still in use nowadays. Although molecular traces of a paintbrush have never been observed before, to the best of the authors’ knowledge, the presence of significant amounts of protein residues from the brush cannot be excluded. This would indeed represent an interesting aspect to develop further in the future in order to learn more about the history and production of painted objects. It is also possible that the animal keratins indicate the presence of keratin-based glue such as hoof glue. Reports of the use of glues produced from animal hooves, namely cattle and horses, are not very common but can be found in various historical and geographical contexts, from Ancient Rome to Native American communities [60–62].

The identification of collagen in the red paint residue could also be due to the presence of traces of collagen in the keratin-based animal glue.

4.9. Conservation Materials

Nitrocellulose has been identified with FTIR in samples from yellow and red paint on the headdress of IN 2795 through vibrational bands at 1652 cm$^{-1}$, 1281 cm$^{-1}$, 1069 cm$^{-1}$, and 843 cm$^{-1}$. This clearly indicates a modern consolidation treatment. The material was patented in 1846 and has been used as a conservation material for many decades [63]. Today it is avoided in conservation treatments because of its instability [64].

5. Reconstructing Palmyrene Funerary Polychromy

Two portraits were chosen for experimental representations of their polychromy. The first portrait is the so-called ‘Beauty of Palmyra’ (IN 2795, Figure 3), which was chosen due to its very well-preserved polychromy. The second portrait is IN 1150, which was dubbed ‘Lady in Blue’ due to the exceptional discovery of lapis lazuli on its garments (Figure 4). Moreover, these two portraits represent different types of funerary portraits: a loculus relief and a sarcophagus, respectively, but they also display diverse ways of carving the local limestone: the Beauty of Palmyra is very smoothly and finely carved, whereas the Lady in Blue is more roughly executed.

The representation of the Beauty of Palmyra was created in 2019 for the special exhibition, “The Road to Palmyra”, at the Ny Carlsberg Glyptotek, where it was on display illustrating the rich polychromy of the city’s funerary portraits (Figure 18). The first reconstruction was published in 2020 [65]. However, since the representation was based on a preliminary investigation, it has been adjusted so that it now reflects our current understanding of polychromy. The second representation of the ‘Lady in Blue’, was carried out in 2021 for the present publication.

In both cases, it was decided to carry out digital representations, which were executed in Adobe Photoshop by graphic artist Lars Hummelshøj. The point of departure was digital colour images in high resolution of the two portraits in question.

For both representations, the colours chosen are first and foremost based on scientific, analytical data, that is, the identification of polychromy on the two portraits and the extrapolation of these data. However, in some places, the traces of colour are limited or even non-existent. Therefore, comparative material such as similar Palmyrene portraits as well as other contemporary archaeological material, including textiles and jewellery, were included to provide qualified suggestions for the reconstruction of the colours.
However, it should be stated that it can be difficult to interpret the minute traces of polychromy, since so little is preserved and since the colours might have faded or even changed their hue entirely. Moreover, although earth pigments do not change colour so easily, it can be difficult and indeed sometimes impossible, to differentiate between the earth pigments used for painting an artefact and the contamination from deposition in the ground for hundreds or even thousands of years. Furthermore, we cannot exclude the possibility that the original polychromy included pigments that have completely disappeared. This is also why we have chosen to use the term ‘representation’ rather than the more commonly used ‘reconstruction’ since this better reflects the level of uncertainty involved in making such models.

5.1. Representation 1 ‘Beauty of Palmyra’

The first step involved a reconstruction of all missing parts of the portrait including the nose, the left hand, and the upper part of the veil, as well as the smoothing out of the damage to her face and lips (Figure 19). Gilding was added to the jewellery in the second step. In a third step, colours were applied to the face (including make-up, eyebrows, and eyeliner) and the textiles. Finally, the jewellery was augmented with inlays [65].

5.1.1. Skin and Makeup

The portrait has no visible traces of painted skin colour. The lack of skin colour appears to be a common trait for most Palmyrene portraits and it is generally assumed that the skin of these portraits was left unpainted [65]. The skin was, therefore, left unpainted in the representation. Her red cheeks and lips are clearly visible and have been freshened up a bit in the representation to compensate for the degradation of the original polychromy.
5.1.2. Eyes and Hair

There are no traces of colour preserved in or around the eyes of the portrait. However, it appears to have been common to paint the edges of the eyes as well as the eyebrows (often indicated by an incised groove) black. This is the case for several of the portraits in the NCG, which depict primarily female (e.g., IN 1150 and IN 1065) but also male subjects (e.g., IN 1146) and which preserve clear traces of the original black eyeliner. The pupil/iris was usually carved in relief and/or simply painted but there are also examples of the use of inlays. The digital representation is inspired by the use of black glass inlays for a portrait dated to the 3rd century CE in LACMA (inv. no. M.82.77.2), whereas her eyebrows and eyeliner are indicated with sharp black lines similar to other female portraits. Finally, her hair has well-preserved black paint, which is rendered as such in the representation [65].

5.1.3. Garments

The Beauty of Palmyra wears a costume consisting of a tunic and over it, a mantle wrapped around the body and fastened at the left shoulder with a brooch, which was customary for women depicted in Palmyrene funerary portraits [66]. Besides this ensemble, she wears a yellow turban over which a long shawl-like veil is draped.
During the re-examination of the portrait, new knowledge of the polychromy of her headgear and dress came to light: Between the yellow turban and the head-chain, she wears an underlying, creased piece of textile. This has visible traces of a pink organic lake, which showed further decoration with minuscule traces of gold. A similar pink organic lake was identified during the re-examination of the portrait on the area of her right arm between the two golden arm rings. This area has an identical creased texture to the pink textile which forms part of the headgear. It was therefore decided to update the digital representation with the same pink colour for both areas and to add minuscule indications of gilding in both areas. The exact distribution of gold leaf in these areas is unknown. In the representation, the gilding was added in a pattern following the creases in the textile.

With regard to the pink nuance, the updated representation uses a darker pink nuance compared to the 2019 version, which rather represents the very pale pink paint traces visible today. This choice was made to compensate for the abrasion of the original polychromy. This observation is supported by the depiction produced by Charles Christensen in 1929 (Figure 20).

Figure 20. Watercolour of the ‘Beauty of Palmyra’ by Charles Christensen. Published in the Danish newspaper *Berlingske Tidende*, 22 December 1929. Courtesy of the Palmyra Portrait Project.
The veil, which covers the head and headgear, preserves traces of red, which are primarily found in the vertical folds. The tunic shows traces of red colouring as well as minor remnants of yellow. The latter, however, does not appear to be part of the original polychromy. It was therefore decided to use red for her garments. The use of red for textiles and garments in Palmyrene funerary art is attested in several portraits (e.g., in British Museum, inv. no. 125058; Palmyra Museum, inv. no. B2666/8967; American University of Beirut, Archaeological Museum, inv. no. 2733; Antikensammlung Basel und Sammlung Ludwig, inv. no. BS 1262). In the representation, different tones of red were therefore used for various garment items in order to be able to distinguish between the three garments. However, again, it is important to emphasize that we do not know if this reflects the original nuances of the polychromy. Moreover, the garments are rendered as monochrome in the representation but we cannot exclude the possibility that they were originally painted with ornamentation. For instance, there are several examples in Palmyrene portraiture of garments with sculpted ornamental borders, and many textile fragments with decorative patterns and motifs have been recovered in the necropoleis of Palmyra.

5.1.4. Jewellery
The Beauty of Palmyra wears 22 pieces of jewellery, which is a very large number compared to most other female portraits [14]. Her jewellery consists of a heavily embellished headdress with diadem and a head chain, earrings, seven necklaces, a round fibula, bracelets on both wrists, and three finger rings. The jewellery is sculpted, painted, and then covered in gold leaf. Although the gold leaf has only survived in a few places, all her jewellery with yellow or red paint traces has been gilded in the reconstruction. Since no paint traces have been identified on the uppermost necklace, it is rendered with white beads imitating pearls in the reconstruction [65].

As described above, the areas with pale pink paint traces have been updated with partial gilding accentuating the carved decoration without completely covering the red lake. The lake pigment is rendered in a much darker hue in the updated reconstruction since the light-sensitive pigment appears to have faded significantly.

Several of the pieces of jewellery have holes for inlays in other materials, primarily glass or semi-precious stones, which have now disappeared. For the reconstruction, it was decided to use carnelian for the inlays of the pendants, the brooch, and one of the rings based on the use of this stone for Palmyrene and Roman jewellery, e.g., [67,68]. With regard to the jewellery for the Beauty’s headdress and the rings on her left hand, lapis lazuli was chosen since it was available in Palmyra and also attested in Palmyrene polychromy [20]. It is important to note that these choices are not based on identifications of pigments on the original portrait, but rather on qualified “guesses” based on the available materials in Palmyra and comparisons with the polychromy of other Palmyrene portraits [65].

5.2. Representation 2 ‘Lady in Blue’
For this digital representation, the paint was added directly to the image of the portrait without restoring the missing parts (Figure 21). The polychromy of this portrait appears to have been less intricate so in contrast with the representation of the Beauty of Palmyra, which was carried out using four layers in Photoshop, the paint was added in one go.

5.2.1. Skin, Face, and Makeup
As with the representation of the Beauty of Palmyra, the skin of the portrait of the Lady in Blue was left unpainted since the examinations did not reveal any remains of polychromy. A small sample collected from a potential paint trace on the proper left cheek turned out to be a relatively large particle of hydroxylapatite, which occurs as detrital grains in limestone. In contrast to the Beauty of Palmyra, there are no remains of makeup. Nevertheless, it was decided to give the lips a light pink complexion. The examination of the portrait revealed renderings of black, hatched shading on the fingers of her right hand.
(Figure 22). Therefore, shading was added to the fingers in the digital representation to distinguish the fingers from each other.

Figure 21. Digital schematic representation of the polychromy of IN 1150, the so-called ‘Lady in Blue’. Created by C. Brøns and L. Hummelshøj.

5.2.2. Eyes and Hair

The portrait has well-preserved polychromy on the eyes and eyebrows: the eyebrows and the outline of the eyes are painted black, simulating black eyeliner. Finally, the pupils are simply painted on in black, not carved or incised. The examinations of her hair revealed two black paint traces on the lower part of her hair close to the face. The black paint has been intensified in the representation to compensate for the abrasion of the original polychromy.
5.2.3. Garments

The woman in the portrait is wrapped in a mantle that covers her entire upper body and the back of her head, only leaving her hands free. According to custom, she would have worn a tunic underneath but this is not visible in the portrait. In contrast with the representation of the Beauty of Palmyra, there is no doubt as to the colour of her dress. The blue colour of her garment is confirmed by careful examination of the polychromy, which was shown to be a mixture of cerrusite, hydrocerrusite, zinc oxide, ground lapis lazuli, and charcoal black [20] (Figure 23). The colour is a light blue and thus very far from the bright, almost luminous blue we know from the later pigment ultramarine that was extracted from lapis lazuli and used for, e.g., illuminated manuscripts and paintings, particularly during the 14th, 15th, and 16th centuries [69].

This light blue-grey colour is attested in several places on the portrait and there is no doubt that its application is intentional. The exact same colour seen on the portrait was therefore chosen to render the mantle and there is thus no guesswork involved. So far, there are no other attestations of blue garments in Palmyrene funerary portraiture, although, admittedly, this field of research is still in its infancy. Yet, although we can be quite certain of the colour of her garment, we do not know if the shades were given a darker colour (black, darker blue, or both) and we cannot be entirely certain if the garment was originally decorated with painted details or painted in a solid colour (as shown in the representation). This is, in fact, also the case for the representation of the Beauty of Palmyra.

More than 2000 textile fragments belonging to the period from the 1st century BCE to the 2nd century CE have, so far, come to light at Palmyra, which makes them one of the largest collections of ancient textiles of proven origin e.g., [70–73]. This provides an excellent opportunity to compare the garments rendered in funerary iconography with real-life textiles. The textiles are recovered from the necropoleis of the city and have almost preserved their original colours due to the dry climate and darkness in the tombs [70]. The textiles represent a wealth of colours. Although reds and purples appear to have been particularly popular, there are also numerous remains of textiles dyed in bright blue nuances [74]. Some of these are monochrome, whereas others are patterned, e.g., checkered or decorated with figural motifs. The archaeological finds thus confirm the assumption that the garments rendered in portraits, at least to some extent, resemble the textiles and garments worn in real life.
5.2.4. Jewellery

The woman wears relatively simple jewellery compared to what is seen in Palmyrene female funerary portraiture. Her adornment consists of earrings, a necklace with a simple pendant, and a bracelet. The jewellery has no preserved traces of paint or gilding. For the representation, it was decided to render the jewellery in yellow paint with no gilding, inspired by other Palmyrene portraits where the jewellery retains traces of yellow and no gold has been observed. These include the portrait of a woman from the Hypogeum of Shalamallat (Palmyra Museum, inv. no. 1762/6586) [13, cat. no. 638] or the portrait of a woman in the British Museum (inv. nos. BM 125019) [13, cat. no. 742]. However, since these two portraits have not been scientifically analysed, we cannot exclude the possibility that they might have been gilded too.

5.3. Reconstructing Ancient Palmyrene Colours

The two digital schematic representations of the polychromy of the ‘Beauty of Palmyra’ and the ‘Lady in Blue’ clearly illustrate the bright and varied polychromy of Palmyrene funerary art. The original painting of these portraits, whether loculus reliefs, stelae, or sarcophagi, would have given them an entirely different expression from what we see today. Their polychromy would thus have been a significant way to make the individual portraits, all carved from white local limestone, stand out from each other. This would have been particularly important considering their original placement in row above row in the tower tombs and hypogea, where they were used to close the loculi housing the deceased individuals portrayed. The use of polychromy would also have provided an opportunity to indicate further details such as decoration and specific colours of dress and adornment. Such details could possibly indicate individual aspects of the status of the deceased—aspects which we are overlooking today when studying the portraits due to the loss of the original polychromy.

However, the two schematic representations also demonstrate the methodological challenges that are associated with the representation of ancient polychromy. As shown, considerable “guesswork” is involved in making such representations of ancient polychromy. This is an important point to stress since such representations are not as straightforward or reliable as one might expect. In fact, they tend to rely on information from other sources, in this case, primarily other portraits, archaeological textiles, and jewellery, as well
as data obtained via scientific analyses of the paint traces. Moreover, as exemplified by the representation of the Beauty of Palmyra, sometimes new knowledge comes to light that prompts adjustments. This again emphasises the level of uncertainty involved in making such representations, even in cases where the polychromy is well-preserved. However, colour representations are still exceedingly helpful when seeking to disseminate ancient polychromy since nothing communicates colour better than the colours themselves.

6. Conclusions

The examinations of the Palmyrene portraits in the NCG have proven that these artefacts, despite their current uniform, white appearance, originally presented themselves in a wealth of colours. The current study has thus identified a range of colours, including blue, yellow, red, pink, white, black, and gold, used for the polychromy of the Palmyrene portraits.

The blue pigment on one of the portraits (IN 1150) was previously identified as ground lapis lazuli, which is a quite extraordinary find [20]. Only one of the portraits (IN 2795) revealed the potential presence of a few particles of Egyptian blue. However, these particles appear to be from contamination of ancient or modern origin. They, thus, do not form part of the intentionally applied polychromy.

Yellow pigments were identified on one of the portraits (IN 2795), which were shown to be pyromorphite and goethite. However, it remains unclear whether the presence of pyromorphite was intentional or due to its association with the earth pigment.

Several portraits revealed traces of red paint, which were shown to be based on earth pigments dominated by haematite. One portrait (IN 2795) revealed a pale-pink colour. The strong pink-orange UV fluorescence emitted by the paint traces is indicative of a red lake. Unfortunately, the dyestuff and the lake substrate have, so far, not been identified.

The white pigments found in a pigment mixture on one of the portraits (IN 1150) were identified previously as hydrocerrusite, cerrusite, and zinc oxide [20]. The present study also found evidence for the presence of mimetite in its white form.

Several portraits revealed the use of black paint. On IN 2795 the black paint was identified as bone black, whereas on other portraits, the black paint appears to consist of carbon black. The black inclusions in the blue paint on IN 1150 were identified as charcoal black.

Finally, small traces of gold leaf are visible on IN 2795, where it is found on top of yellow, pink, and red paint traces.

A ground layer or preparatory sizing of the limestone surface was not detected on any of the sculptures.

Two samples of the red and yellow paint on IN 2795 showed the presence of keratin and collagen from pigs, identifying protein as the major component of the binding medium.

When comparing the six individual portraits examined in this study, it is evident that IN 2795 (the so-called ‘Beauty of Palmyra’) stands out due to its distinct polychromy: Not only does this portrait preserve far more of its original paint in comparison to the other examined artefacts, it also displays a different and more varied palette including an organic red lake and gilding. IN 1150, on the other hand, stands out due to the presence of lapis lazuli and mimetite, which are not attested for the polychromy of the other portraits. It could be interesting to investigate whether this difference in the choice of pigments for the polychromy is related to the various types of portraiture, specifically between the sarcophagi (IN 1150) and loculus reliefs (IN 2795, IN 1052, IN 1146, IN 1065, and IN 1153).

As previously stated, so far only a few studies of Palmyrene polychromy have been published. The thorough study of the wall paintings from the Tomb of the Three Brothers is to date the only comparative study available [18]. The Tomb of the Three Brothers is a hypogeum, located in the Southwest necropolis at Palmyra. The wall paintings, dating to the 2nd century CE and thus contemporary with the Palmyrene funerary portraits, were constructed using a variety of pigments including red and yellow ochre, red and
yellow oxide, carbon black, Egyptian blue, green earth, and mimetite. Moreover, huntite or
dolomite were used to lighten the green hue in some places [18].

By comparison with the funerary portraits under study here, it is clear that there
are several overlaps in the choice of pigments, e.g., red and yellow ochres and possibly
carbon black. This is not surprising, considering that these pigments were probably locally
sourced and readily available. Interestingly, the present paper has also attested to the use
of mimetite for one of the portraits (IN 1150), which, according to Buisson et al., is a rare
find. Perhaps this could indicate that mimetite was, in fact, a more common staple in the
painter’s palette used in Palmyra.

Yet, there are also significant differences. As an example, the wall paintings use
green earth, which is not attested on the portraits. Another fundamental difference lies in
the choice of blue pigments for the various media: Egyptian blue was used for the wall
paintings; however, this specific pigment is not attested on any of the portraits, which
appear to have used ground lapis lazuli instead to render the blue colour. This is a very
interesting discovery since Egyptian blue was widely used across the Roman Empire [32]
and also in Palmyra and its absence from the polychromy of the funerary portraits is
clearly intentional.

There are thus clear discrepancies in the choice of pigments used for the polychromy
in the various media. The motifs rendered, e.g., a winged victory, the scene of Achilles
disguised as a girl by his mother Thetis on the island of Skyros, as well as the abduction
of Ganymede by the Eagle of Zeus, in the paintings in the tomb are claimed to be clearly
inspired by Greco-Roman iconography and contrast with the usual tomb decorations at the
site [18]. This could possibly be an indication that the wall paintings were done by itinerant
artists/workmen, which could explain the differences in the choice of pigments between
the wall paintings and the funerary portraits.

Many of these suggestions obviously need further substantiation since they are
based on only a few examined artefacts. There is no doubt that future research into
the rich polychromy of ancient Palmyra will reveal deeper insights into its ancient colours
and potentially provide us with information on how to understand and interpret these
precious artefacts.

Future research will examine the polychromy of the remaining part of the collection
of Palmyrene limestone portraiture in the NCG, which comprises around 130 artefacts.
Specific avenues for future research into the collection include an analysis of the binding
medium of IN 1150 and IN 1153 with GCMS to determine whether a drying oil is present.
The preservation of binding media appears to be extremely rare on the Palmyrene funerary
portraits, most likely due to the dry desert climate; thus far, only IN 2795, IN 1150, and IN
1153 in the collection of the NCG have shown potential for such analyses, which makes
identification of their organic compounds even more significant for our understanding of
Palmyrene polychromy. Moreover, it would be significant to identify the constituents of the
UV-fluorescing, pale-pink paint traces on IN 2795 focusing on the organic lake pigment and
verify the attestation of pyromorphite in the yellow paint layer with Raman spectroscopy
and/or X-ray diffraction (XRD). Such examinations will undoubtedly reveal new and
exciting insights into ancient Palmyrene polychromy.

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resources, C.B.; data curation, J.S., F.D.G. and J.B.-J.; writing—original draft preparation, C.B.,
J.S., F.D.G. and L.Ø.B.; writing—review and editing, C.B. and J.S.; visualization, J.S., C.B.
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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Methodology—LC-MS/MS

The samples, along with a protocol blank per experiment, were processed following the protocol described in Mackie et al., (2018) [28]. The samples were placed in separate Protein Lo-Bind tubes (Eppendorf, Germany). Protein residues were extracted over a 2 h incubation at 80 °C using 100 µL of an aqueous buffer containing: 2 M guanidinium chloride (GuHCl), 10 mM tris(2-carboxyethyl)phosphine) (TCEP), 20 mM chloroacetamide (CAA), and 100 mM trisaminomethane (Tris). The pH of the extraction solution was monitored to be around 8.0 throughout the protein extraction. The first protein digestion was performed in-solution with 0.2 µg rLysC (Promega, Stockholm, Sweden) for 2 h at 37 °C under agitation. The solution was diluted to a final concentration of 0.6 M GuHCl using 25 mM Tris in 10% acetonitrile (ACN) in water. A second enzymatic digestion was performed overnight with 0.8 µg Trypsin (Promega, Stockholm, Sweden) under agitation at 37 °C. The digestion was then quenched by acidifying the solution to pH 2 using 10% trifluoroacetic acid (TFA). The resulting peptides were collected on in-house-made C18 extraction stage-tips [29]. Stage-tips were stored at −18 °C and the extracted peptides were eluted using ACN in water right before analysis: for the 2016 samples, 20 µL 40% ACN + 0.1% TFA and then 10 µL 60% ACN + 0.1% TFA (the two solutions were merged for each sample); for the 2021 samples, 30 µL 40% ACN + 0.1% formic acid. The volume of the solution was reduced to approximately 3 µL by placing the tubes in a vacuum centrifuge at 40 °C. The peptides were then recovered with 5 µL of 0.1% TFA, 5% ACN and separated on a 15 cm column (75 µm inner diameter) in-house laser pulled and packed with 1.9 µm C18 beads (Dr. Maisch, Ammerbuch, Germany) on an EASY-nLC 1200 (Proxeon, Odense, Denmark). The set of samples processed in 2016 was analysed on a QExactive HF (Thermo Scientific, Bremen, Germany) with the following parameters. A 77 min gradient was used. Buffer A was milliQ water; buffer B was 80% ACN and 0.1% formic acid. The gradient used increasing buffer B, going from 5% to 30% in 50 min, then to 45% in 10 min, finally to 80% in 2 min, and was held at 80% for 5 min before dropping back down to 5% in 5 min and holding for 5 min. Flow rate was set at 250 nL/min. An integrated column oven was used to maintain a column temperature of 40 °C. A wash-blank, injecting 0.1% TFA and 5% ACN was run in between samples to hinder cross-contamination. The mass spectrometer was operated in data-dependent top 10 mode with spray voltage 2 kV, and S-lens RF level at 50. The heated capillary was kept at 275 °C. Full scan mass spectra were recorded at a
resolution of 120,000 at $m/z$ 200 over the $m/z$ range 300–1750 with a target value of $3 \times 10^6$ and a maximum injection time of 20 ms. HCD-generated product ions were recorded with a maximum ion injection time set to 108 ms, a target value of $2 \times 10^5$, and resolution of 60,000. Normalised collision energy was set at 28% and the isolation window was $1.3 \ m/z$, with dynamic exclusion set to 30 s. The second set of samples, processed in 2021, was analysed with similar parameters to the first set but on an Orbitrap Exploris 480 (Thermo Scientific, Bremen, Germany). The following parameters were changed with respect to the first experiment: MS range 350–1400 $m/z$, maximum injection time of 25 ms, MSMS isolation window 1.2 $m/z$, collision energy 30%, maximum ion injection time set to 118 ms, dynamic exclusion 20 s.

The MS/MS spectra were identified with the MaxQuant software (MQ) [30] (version 2.0.1.0), matching them against four different databases of protein sequences. First, the spectra from all the raw files were matched against a reference database containing all the publicly available sequences of proteins contained in the most common proteinaceous artistic materials: animal glue, eggs, and milk. The matches were against fully tryptic peptide sequences. Second, in order to investigate the presence of protein residues originating from other sources, the spectra were then matched against a larger database (SwissProt, from UniProt), containing all publicly available and manually reviewed protein sequences. The matches were against fully tryptic peptide sequences. Third, following the results obtained with the SwissProt database for the raw files acquired in 2021, the spectra from these analyses were matched against a database containing keratins and keratin-associated proteins from Artiodactyls (even-toed ungulates). This search was matching the spectra against semi-tryptic peptide sequences, to account for the possible origin of the peptides from unspecific hydrolysis of the proteins. Fourth and finally, the spectra acquired in 2021 were matched against the publicly available proteome of *Sus scrofa* (pig). This search was matching the spectra against semi-tryptic peptide sequences.

All other parameters were the same in all searches. A maximum of five modifications per peptide was allowed. The following variable modifications were considered: oxidation of methionine, acetylation of the N-terminus, deamidation of asparagine and glutamine, conversion of N-terminal glutamine to pyroglutamic acid, conversion of N-terminal glutamic to pyroglutamic acid, and hydroxyproline. Carbamidomethylation was set as a fixed modification. The minimum peptide length was set to 7, with up to two missed cleavages. The false discovery rate (FDR) was set to 0.01, whereas the minimum score for unmodified and modified peptides was set to 40. Proteins were considered confidently identified if at least two unique non-overlapping peptides were observed unless otherwise specified. Peptides were considered species-diagnostic when, after BLAST search against the entire nrNCBI protein database (i) they were assigned to a single species, or (ii) they were a match with a limited number of species among which only one can be considered plausible, based on the nature of the samples and their geographic and historical origin. Contaminant proteins were assessed using the contamination.fasta provided by MaxQuant, containing common laboratory contaminants (http://www.coxdocs.org/doku.php?id=maxquant:start_downloads.htm, accessed on 9 May 2022) such as primate keratins (likely from the laboratory space or through human handling of the object and/or samples), excess trypsin, and Bovine Serum Albumin (a common laboratory reagent). Peptides assigned to recurrent contaminant proteins were filtered out and not considered further.

The deamidation level was calculated using a deamidation tool freely available on GitHub (https://github.com/dblyon/deamidation, accessed on 9 May 2022). The workflow of this tool is described in detail in [28].

Appendix B. Protein and Peptide Identifications
Table A1. Protein Identifications: Observed proteins and their taxonomic origin. All proteins except for one (*) were identified when matching the raw files acquired in 2021 against the database containing Artiodactyla keratins and keratin-associated proteins. * This protein has been identified when the corresponding raw file, acquired in 2016, was matched against the database containing the most common proteinaceous paint binders. ** The taxonomical origin has been identified by intersection of the possible matches for the diagnostic peptides (Table A2 peptides).

| Sample          | Accession nr | Protein Name                             | Taxonomical Origin              | Total Peptides | Unique Peptides | Total Sequence Coverage (%) | Sequence Length | MS/MS Spectra |
|-----------------|--------------|------------------------------------------|----------------------------------|----------------|-----------------|----------------------------|----------------|---------------|
| Red paint residues | A0A52RHE5    | Collagen alpha-2(I) *                    | Artiodactyla                     | 3              | 3               | 2.7                        | 1364           | 3             |
|                 | -            | Keratin                                  | Artiodactyla                     | 21             | 0               | 33.5                       | 1126           | 44            |
|                 | -            | IF rod domain-containing protein          | Placentals—not matching Homo sapiens nor Sus scrofa | 17             | 1               | 31.1                       | 488            | 26            |
|                 | -            | Uncharacterized protein (cuticular keratin?) | Placentals—not matching Homo sapiens nor Sus scrofa | 5              | 0               | 27.4                       | 1824           | 37            |
|                 | -            | Keratin, type I microfibrillar 48 kDa, component 8C-1 | Placentals—not matching Homo sapiens | 4              | 3               | 12.9                       | 827            | 11            |
|                 | -            | Uncharacterized protein (cuticular keratin) |                        | 3              | 0               | 48.5                       | 404            | 34            |
|                 | -            | Keratin                                  | Placentals—not matching Homo sapiens | 3              | 0               | 45.2                       | 403            | 40            |
|                 | F6PF7        | IF rod domain-containing protein          | Mammals—not matching Homo sapiens | 3              | 0               | 28.9                       | 433            | 22            |
|                 | -            | IF rod domain-containing protein          | Vertebrates—not matching Homo sapiens nor Sus scrofa | 2              | 2               | 16.8                       | 493            | 18            |
|                 | E3VW76/A0A452G3C7 | Keratin 33B                           | Oris aries/Capra hircus **         | 32             | 0               | 52.8                       | 405            | 58            |
|                 | A0A6F76W7O9/A0A452F6C2 | Keratin, type II cuticular Hb1 | Oris aries/Capra hircus         | 27             | 0               | 49.9                       | 507            | 41            |
|                 | -            | Uncharacterized protein (cuticular or microfibrillar keratin?) | Oris aries/Capra hircus/oryx dammah/orix aries | 9              | 0               | 26.3                       | 1824           | 55            |
|                 | W5Q6L1       | IF rod domain-containing protein          | Oris aries                       | 6              | 2               | 46.1                       | 362            | 27            |
|                 | -            | IF rod domain-containing protein          | Bos spp., Capra hircus/oryx dammah/orix aries | 6              | 0               | 45.0                       | 493            | 37            |
|                 | A0A6F73E7K8  | keratin-associated protein 13–1-like     | Bos spp., Capra hircus/oryx dammah/orix aries | 4              | 4               | 24.4                       | 164            | 5             |
|                 | I3LJ7        | IF rod domain-containing protein          | Sus scrofa                       | 4              | 0               | 41.5                       | 422            | 43            |
|                 | A0A52RHE5    | IF rod domain-containing protein          | Sus scrofa                       | 2              | 2               | 32.0                       | 488            | 25            |
|                 | C0LJG3       | Keratin associated protein 6              | Oris aries/Capra hircus           | 2              | 2               | 31.3                       | 83             | 2             |
**Table A2.** Peptide identifications: Observed species-diagnostic peptides. The underlined species are the ones considered most likely in the historical and geographical context of the production of the Beauty of Palmyra. All proteins except for one (*) were identified when matching the raw files acquired in 2021 against the database containing Artiodactyla keratins and keratin-associated proteins. * This protein has been identified when the corresponding raw file, acquired in 2016, was matched against the database containing the most common proteinaceous paint binders.

| Sample | Protein (Accession nr) | Peptide Sequence | BLAST Matches | Length | Mass | MQ Score | MS/MS Spectra |
|--------|------------------------|------------------|---------------|--------|------|----------|--------------|
|        | Collagen alpha-2(I) *  | ICQPAGAVGPAGIR   | Artiodactyla  | 13     | 1191.67 | 53.7     | 1            |
|        | Keratin                | SQQQEPLVCPNQSYFR |               | 17     | 2142.98 | 281.5     | 2            |
|        | IF rod domain-containing protein (A0A5C2RHE5) | TKYTEEGLGLR EVELAEDSRR LLEGEEQLGEGYAVNVCVSSSR DSELTITEETEAR | Artiodactyla | 10     | 1208.64 | 135.6     | 1            |
|        | IF rod domain-containing protein | TVNALEVELQAHNLIR YSSQLAQVQGLNVEAQLAER | Placentals—not matching Homo sapiens | 11     | 1174.55 | 205.8     | 1            |
|        | Keratin type I microfibrillar 48 kDa, component 8C-1 | ARLESEINTYR | Placentals—not matching Homo sapiens | 11     | 1350.69 | 243.0     | 2            |
|        | IF rod domain-containing protein (F4PW7) | YSSQLAQVQGLNVEAQLAER | Homo sapiens | 23     | 2486.31 | 186.9     | 1            |
|        | IF rod domain-containing protein keratin, type II cuticular Hb3 | CCHIAAEPYRGSCYR KSDELANEALIIQEIDFLR SDLELANEALIIQEIDFLR ARLESEINTYR DSELTITEETEAR SLIVNESSLAEIR | Mammals—not matching Homo sapiens | 15     | 1832.81 | 126.7     | 1            |
|        | Keratin 33B (E3VW78/A0A452G3C7) | SQQQEPVCPNQSYFR SYNFCLPNLSFR TVNALEVELQAHNLIR | Mammals—not matching Homo sapiens | 12     | 1516.71 | 225.0     | 1            |

*Note: The species listed under 'BLAST Matches' are the ones considered most likely in the historical and geographical context of the production of the Beauty of Palmyra.*
| Sample | Protein (Accession nr) | Peptide Sequence | BLAST Matches | Length | Mass  | MQ Score | MS/MS Spectra |
|--------|------------------------|------------------|---------------|--------|-------|----------|---------------|
| keratin, type II cuticular HB1 (A0A6F7DWQ9/A0A452F6C2) | GLGGFGSR | Placentals—not matching Homo sapiens | 9 | 850.43 | 113.1 | 1 |
| | LEAAVTQAEQGEEALADAK | Capra hircus, Ovis aries | 20 | 2013.00 | 320.6 | 2 |
| | LSSELNSLQEVLGKYK | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Bubalus bubalis, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus elaphus hippelaphus, Cervus hanglu yarkandensis, Muntiacus musk, Muntiacus reevesi, Odocoileus virginianus texanus, Oryx dammah, Ovis aries | 16 | 1807.92 | 226.9 | 1 |
| | LSSELNSLQEVLGKYKK | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Bubalus bubalis, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus elaphus hippelaphus, Cervus hanglu yarkandensis, Muntiacus musk, Muntiacus reevesi, Odocoileus virginianus texanus, Oryx dammah, Ovis aries | 17 | 1936.02 | 241.9 | 1 |
| | MDNSRDLNMDNIVAEIK | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Bubalus bubalis, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus elaphus hippelaphus, Mammals—not matching Homo sapiens, Sus scrofa | 16 | 1976.93 | 77.1 | 1 |
| Uncharacterized protein (cuticular or microfibrillar keratin?) | SKCEEIKATVR | Placentals—not matching Homo sapiens | 12 | 1432.70 | 69.9 | 1 |
| | SQQEPPLLCPNQSYFR | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Bubalus bubalis, Capra hircus, Cervus elaphus hippelaphus, Oryx dammah, Ovis aries | 17 | 2156.99 | 261.7 | 2 |
| | GGVACGGGLTYSSTAGR | Capra hircus, Ovis aries | 16 | 1512.70 | 128.9 | 1 |
| | QIASGPSVTGSITVLPADCQP | Mammals—not matching Homo sapiens | 24 | 2381.20 | 199.0 | 2 |
| | LCEGVQGAVNVCSVSSR | Artibeus jamaicensis, Bos indicus, Bos indicus x Bos taurus, Bos taurus, Bubalus bubalis, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus hanglu yarkandensis, Loxodonta africana, Muntiacus reevesi, Odocoileus virginianus texanus, Oryx dammah, Ovis aries | 16 | 1692.79 | 157.5 | 1 |
| Yellow paint residues | LEAAVTQAEQQGEEALADAK | Placentals—not matching Homo sapiens | 20 | 2112.04 | 256.8 | 2 |
| Keratin 83 | LLEGEEQRLCEGVQNVCSVSSR | Placentals—not matching Homo sapiens | 24 | 2647.27 | 202.2 | 1 |
| | QANISDTSVIK | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Camelus bactrianus, Camelus dromedarius, Camelus ferus, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus elaphus hippelaphus, Cervus hanglu yarkandensis, Diceros bicornis minor, Muntiacus reevesi, Odocoileus virginianus texanus, Oryx dammah, Ovis aries, Vicugna pacos | 12 | 1273.69 | 95.5 | 1 |
| | TCGFSTVSCFGSR | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Capra hircus, Oryx dammah, Ovis aries, Vicugna pacos | 14 | 1418.62 | 142.1 | 3 |
| | VILQANISDTSVIK | Bison bison bison, Bos indicus, Bos indicus x Bos taurus, Bos mutus, Bos taurus, Camelus bactrianus, Camelus dromedarius, Camelus ferus, Capra hircus, Cervus canadensis, Cervus elaphus, Cervus elaphus hippelaphus, Cervus hanglu yarkandensis, Diceros bicornis minor, Muntiacus reevesi, Odocoileus virginianus texanus, Oryx dammah, Ovis aries, Vicugna pacos | 14 | 1485.84 | 229.2 | 1 |
| Sample | Protein (Accession nr) | Peptide Sequence | BLAST Matches |
|--------|------------------------|------------------|---------------|
| keratin-associated protein 13-1-like (A0A6P5F7K8) | SSFYRPTFSSR | *Bos bison* bison, *Bos indicus*, *Bos indicus x Bos taurus*, *Bos grunniens*, *Bos mutus*, *Bos taurus*, *Capra hircus*, *Muntiacus muntjak*, *Oryx dammah*, *Ovis aries*, *Prionailurus bengalensis* |
| IF rod domain-containing protein (I3LUJ7) | YSSQLAQVQLIGNVEAQLAEIR | *Sus scrofa* |
| IF rod domain-containing protein (A0A5G2RHE5) | EAELVEADGR | *Ceratotherium simum* simum, *Dipodomys spectabilis*, *Sus scrofa* |
| Keratin associated protein 6 (C0LJG3) | LGCGYGCGYGYGSR | *Capra hircus*, *Odocoileus virginianus lemnus*, *Ovis aries* |

| Sample | Protein (Accession nr) | Peptide Sequence | BLAST Matches |
|--------|------------------------|------------------|---------------|
| keratin-associated protein 13-1-like (A0A6P5F7K8) | SSFYRPTFSSR | *Bos bison* bison, *Bos indicus*, *Bos indicus x Bos taurus*, *Bos grunniens*, *Bos mutus*, *Bos taurus*, *Capra hircus*, *Muntiacus muntjak*, *Oryx dammah*, *Ovis aries*, *Prionailurus bengalensis* |
| IF rod domain-containing protein (I3LUJ7) | YSSQLAQVQLIGNVEAQLAEIR | *Sus scrofa* |
| IF rod domain-containing protein (A0A5G2RHE5) | EAELVEADGR | *Ceratotherium simum* simum, *Dipodomys spectabilis*, *Sus scrofa* |
| Keratin associated protein 6 (C0LJG3) | LGCGYGCGYGYGSR | *Capra hircus*, *Odocoileus virginianus lemnus*, *Ovis aries* |
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