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ORIGINAL PAPER

# Unveiling the paint stratigraphy and technique of Roman African polychrome statues

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## Abstract
If ancient written sources and the visual analysis of polychromies have recently revealed the complexity of the technique of painting on statues and their frequent restoration, the non-invasive punctual chemical analyses carried out do not allow one to access the chemical composition of the different paint layers. This paper presents the analysis of three statues from Roman Africa discussing the results obtained from this understudied territory and chronology. By combining visual observation (VIS, UVL), video microscopy and MA-XRF imaging, we propose here a non-invasive protocol to determine the chemical composition of the different paint layers. This allows one to unveil the complexity of the 'know-how' of a sculpture painter and sheds light on the evolution of the original appearance of the statues.

**Keywords** Polychromy · Roman sculpture · Pigments · Imaging technique · MA-XRF · Ancient restorations

## Introduction

Multidisciplinary studies carried out in recent decades have focused on reinstating the existence of ancient polychromy in contrast with the received eighteenth-century idea of white classical sculpture (Jockey 2015; Østergaard 2018). While these studies demonstrated the omnipresence of colour on Greek statues through a systematic and collective approach, the tradition of specific studies on the Roman period is a more recent phenomenon, and therefore, our knowledge in this specific field is very limited, especially as concerns the middle and late Imperial period, and in particular for provincial contexts (Abbe 2015). Furthermore, the use of colour on sculpture in Rome seems more ambiguous, because the fashion for copying Greek statues developed at that time a taste for the material support of the statues (coloured marbles and metal), expressing a social and religious status (e.g. Pliny, *Naturalis Historia*, XXXIV, XXXVI) (Liverani 2014; Şare Ağtürk 2021). It is not known if this ambiguity is the result of a shortage of studies on the subject or derives from a different conception of colour.

Recent studies on the literary sources describing the technical processes involved in paint application on statues (Henke 2020), and visual observations corroborated by observations and chemical analyses of micro-samples (Verri et al. 2010; Bourgeois 2014; Lazzarini et al. 2019; Şare Ağtürk 2021) have demonstrated a multi-layered polychromy with preparatory layers of different compositions, as well as binders of differing natures. Furthermore, according to ancient sources, the surface of the statues was in fact subject to frequent renovations, which included erasure, washing, re-painting of the statue and *ganosis* operations (Leka 2014; Bourgeois 2014, 2016). As underlined by recent studies, already in Antiquity, the polychromy could undergo restorations that maintained the original aspect or altered it during the Greek (Bourgeois 2014, 2016) and Roman periods (Liverani 2014, Neri et al. 2022). There is little information on these operations in the sources of the Roman Republican and Imperial times, but the early Christian sources ($2^{nd}$–$4^{th}$c. CE) describe the ritual care of statues and the attention paid to restore their colour (e.g. Arnobius, *Adversus nationes*, VI, 16, 6; Caseau 2014).

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Lastly, systematic studies have been conducted on the remains of paint on marble sculptures, but few analytical publications contain a description of the analytical methodology (Brons et al. 2020; Magrini et al. 2019; Bracci et al. 2020; Alfeld et al. 2017; Aggelakopoulou and Bakolas 2022; Abbe and Şare Ağtürk 2019). The commonly defined non-invasive standard protocol involves the use of multispectral imaging and video microscopy coupled with non-invasive punctual spectroscopies (Raman, XRF, FTIR) corresponding to the areas where the remains of colour are observed (Østergaard 2018). However, as has been demonstrated in an earlier publication (Alfeld et al. 2017), spot analysis makes it difficult to match visual observation with physico-chemical data. Consequently, contaminations from soil or from the iron elements that connect the different parts of the marble statues can be misinterpreted as traces of pigments. The colours that are not visible to the naked eye are not taken into consideration, and the stratigraphy—the layer structure of the chromatic traces—was rarely evaluated in the interpretation of the analytical data. This has led to an underestimation of the complexity of the technical and aesthetic aspects of the polychromy.

This paper documents three unpublished examples of polychrome statues for a period and a region in which the issue of the polychromy has received little attention: Proconsular Africa in the Roman Imperial period, for which only a single paper has been published to date (Kopczynski et al. 2017). Combining visual observations in white and UV light, video microscopy and MA-XRF imaging, this paper aims to bring to light the phases and the techniques of the chromatic finishing of the statues under consideration. This approach should enable a better interpretation of the analytical data, improving our knowledge on the 'know-how' of a sculpture painter, and consequently of the history of work of art and of the evolution of the use of the colour code.

## Materials and methods

### Materials

The three Roman statues analysed belong to the collection of the Bardo Museum in Tunis (Tunisia).

The first piece of sculpture is a male foot (height 29 cm) from Carthage (inv. 010,326 345) (Fig. 1a), meticulously polished and accurately detailed, which may have been part of a masculine deity or an Imperial representation.

The second is a female portrait identified as the sister of Marcus Aurelius, Annia Cornificia Faustina (height 36 cm) (inv. C926) (Fig. 1b), mainly on the basis of the hairstyle but also of the craftsmanship (Baratte et al. 2022b). The head, dated 2 c. CE, was found in the cisterns of the Odeon of Carthage, dated between 3$^{rd}$ and 5$^{th}$ C., during Gauckler's excavations in 1900–1901 in what was probably a secondary context with numerous other statues (Letellier-Taillefer 2017, Baratte et al. 2022a).

The third is a female torso from the so-called summer baths of Thuburbo Maius (inv. 010,326 13) (height 59 cm) (Fig. 1c). It was discovered during excavations by the Directorate of Antiquities in 1914 and 1915 and subsequently stored together with other statues, which may not necessarily belong to the decoration of the baths (Merlin 1916).


**Fig. 1** The statues analysed from the collections in the Bardo museum (stored in Carthage): **a** male foot (inv. 010,326,345), 2$^{nd}$C. CE from Carthage; **b** female portrait, late 2$^{nd}$C. CE (inv. C926) from the Odeon of Carthage; **c** female torso (inv. 01,032,613) from the summer baths of Thuburbo Maius, 2.$^{nd}$ C. CE

## Methods

Visible and ultraviolet luminescence images were acquired in order to spatially characterise the presence of the painting materials. Guided by these results, elemental analysis by macro-X-ray fluorescence imaging (MA-XRF) was carried out to better characterise the painting materials on the surface. Visual documentation and details were acquired through visible photography (Vis) and a portable optical microscope. All sculptures and traces of colour were first observed with a Dino-lite video microscope (20–200 × magnification, AnMo Electronics Corporation, New Taipei City, Taiwan) under visible and UV light (approximately 200 observation points per statue). The colour calibration is provided using standard colour charts (GretagMacbeth ColorChecker®) for the photography and through the internal calibration procedures of the microscope.

In situ measurements were carried out by means of an in-house built MA-XRF scanner. The instrument acquires elemental distribution images by moving the measurement head over the surface of the object. The instrument consisted of a Pd-anode transmission X-ray tube operated at 30 kV, 100 μ Moxtek MAGNUM (Orem, UT) with a 0.8-mm Pd collimator and an SD detector (25 mm$^2$ active area, collimated to 17 mm2, X-123FAST SDD, Amptek, Bedford, MA). The position of the X-ray tube, detector and collimator was fixed by a 3D-printed plastic holder. The instrument was previously described elsewhere (Alfeld et al 2017). 18 scans were carried out on the objects discussed in this article. Typical step sizes are 0.5 mm with a dwell time of 0.5–0.8 s per pixel. All elements indicated were detected by their K-lines with the exceptions of Pb and Hg, which were detected by their L-lines.

As the 3D shape of the archaeological objects influences the working distance of the MA-XRF scanner and thus influences the sensitivity, an algorithm is previously developed (Alfeld et al 2017) and here applied. However, this was not necessary in this paper, because the identification of pigments is based on qualitative information on the presence of elements.

## Results and discussion of the visual and chemical analyses

### Visual observation and microscopy: the display and the stratigraphy of the paint

The visual examination showed the presence of several paint layers the relative sequence of which can be reconstructed by associating the micro-stratigraphic insights gained by optical microscopy in the different observation points. The stratigraphic sequence was analysed according to Harris's principles, commonly applied in archaeological excavation, to define different phases of the chromatic finishing (Harris 1968).

The foot presents a translucent orange layer on the strap of the sandal, laid directly on the marble, above which one can observe a yellow-orange layer in the sole. This one is in turn covered by a layer of red–orange paint, and in the thickness of the sole, this red layer is partially covered by the trace of a brushstroke, probably a retouching (Fig. 2a, c).The most superficial layer of paint is characterised by blue dots.

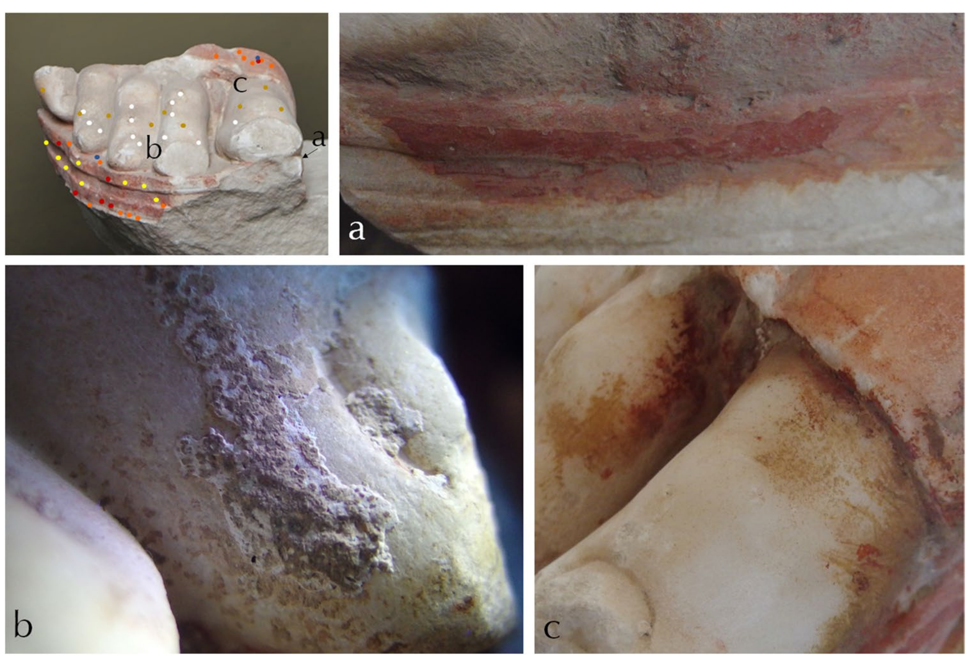


**Fig. 2** Visual observation of the male foot: coloured spots indicate the points of the video microscopy observations and the colour documented. The letters indicate the areas of the macrophotographs: **a** stratigraphy of the painting on the sole (orange layer on the marble, yellow layer, red layer, dark red layer on the surface); **b** stratigraphy of the skin of the fourth toe: yellow on the marble; white on the surface; **c** colour on the strap and on the skin

The skin has a first yellow layer directly laid on the marble, which is darker in the part between the big toe and the sole, where brushstrokes seem to create shading, in accordance with a technique usually found in Roman paintings (Fig. 2c). Between the toes and on the toenails, a very thick white layer with brown spots has been applied over the yellow one (Fig. 2b). Under UVL illumination, the white layer appears below the superficial black spots, and we can exclude that the white layer is an incrustation. The superficial red layer of the sandal partly covers the yellow one of the skin, between strap and toes, between the toes and between the sole and the skin.

The video microscopy confirms the distribution of the colours: red tones in the sandal, yellow ochre in the skin and the overlay of the red layer on the yellow and the orange and the white over the yellow.

It can be deduced that the sole and strap have been repainted several times, while the skin has only been restored once. As the more superficial layers cover the underlying ones, there are at least two phases of the polychromy in the statue: one with yellow ochre skin and a yellow-orange sandal and the second with white skin and a dark red sandal.

The female portrait preserves traces in certain areas of the hair of an orange-red colour painted directly on the marble (Fig. 3a, b), corresponding to the furrows of the loops which separate the locks of hair. The rest of the hair has a yellow and orange colour. The flesh tones are observed on the skin with blue dots in the shaded areas, such as in the lachrymal commissures and defining the outline of the face (Fig. 3d, e). The blue pigment could be interpreted here as an addition to the lead white, as it is known to have been used to counteract the yellowing (Verri et al. 2010). However, the distribution in the shaded areas of these traces of blue, if they are not the result of the randomness of preservation, could indicate a desire to create a darker colour in the areas where the volume of the statue already provides a natural shadow, thus emphasising its three-dimensionality. A red line underlines the eyes, and red is observed in the protruding lip (Fig. 3c).

The female torso features a translucent red colouring on the tunic, directly laid on the marble and overlaid with a brown-purple layer, which has only been preserved in the folds (Fig. 4a, b). On the left, between the lock of hair and the drapery, there is a line that traces the external profile of the lock of hair. The trace indicates that in this case the colour was used first to draw the outlines before painting the surface (Fig. 4c).

On the cloak and on the hair, there is a similar sequence: a red and yellow layer, depending on the area, directly laid on the marble covered by a brown-purple layer (Fig. 4d). The belt, on the other hand, preserves only the bright yellow colour directly applied onto the marble (Fig. 4a). The skin has no trace of colour. Optical microscopy confirms the stratigraphical sequences. Moreover, the UVL microphotograph of the brown-purple layer shows a white preparation layer (Fig. 4e, f). Since the brown-purple layer covers the tunic, cloak and hair with part of the colours laid on the marble,

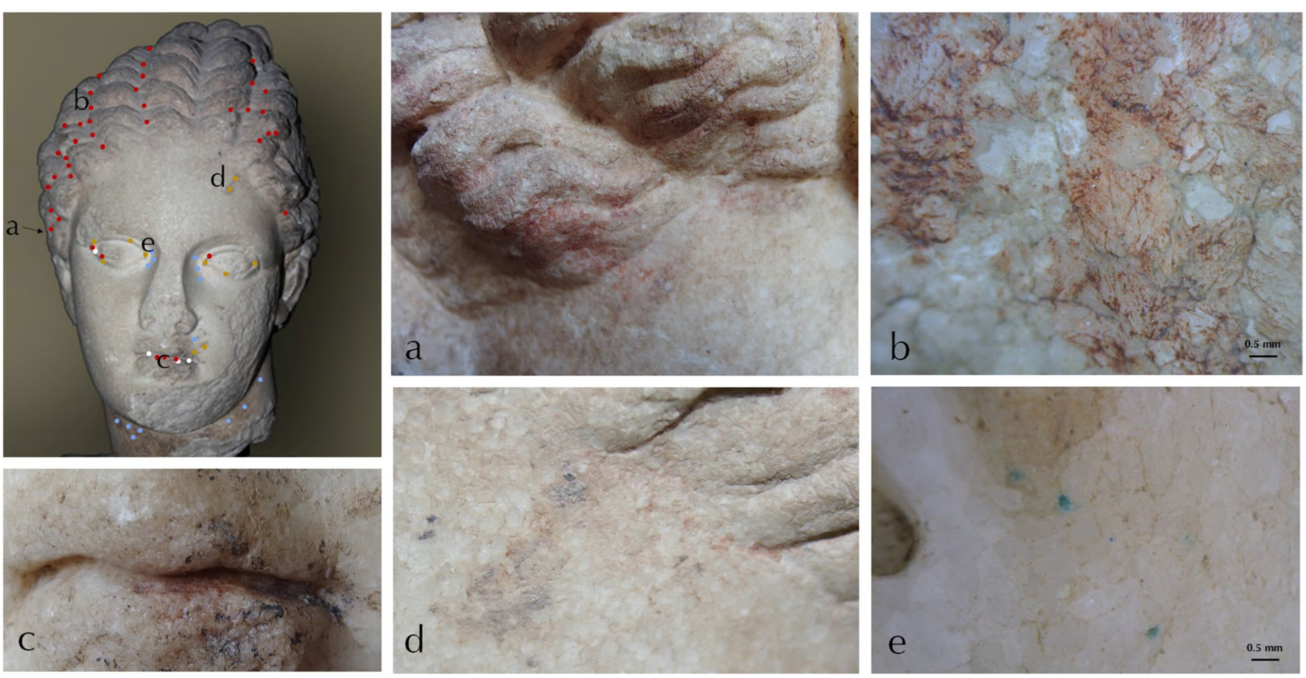


**Fig. 3** Visual observation of female portrait: the coloured spots identify the points of the video microscopy observations and documented colour, and the letter indicates the area of the macro- and microphotographs: **a** remains of the colours in the hair; **b** red paint on the marble; **c** red paint on the lips; **d** flesh tone in the forehead; **e** blue dots in the lachrymal commissure

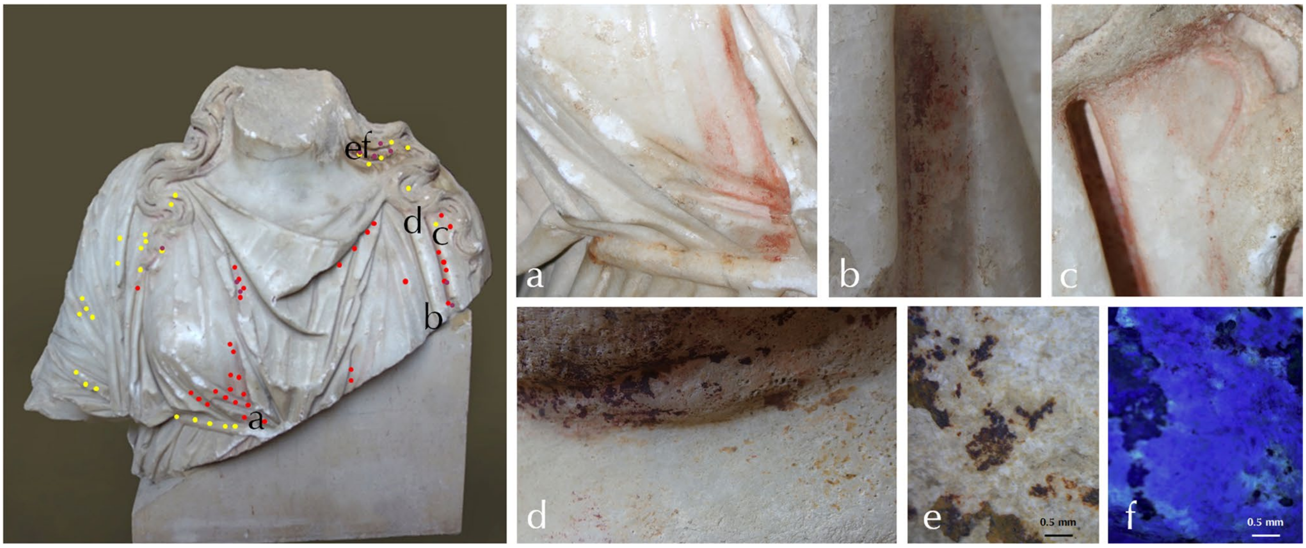


**Fig. 4** Visual observation of female torso: coloured spots indicate the points of the video microscopy observations and the colour documented, and the letters indicate the area of the macro- and microphotographs: **a** remains of colours in the tunic and the belt; **b** stratigraphy of the tunic, brown purple covers the red layer; **c** line that traces the external profile of the lock of hair; **c** stratigraphy of the hair, brown purple covers the red layer; **e** purple-brown layer in the hair in visible light; **f** purple-brown layer observed in UVL light. The preparation layer appears white

two phases of polychromy can be hypothesised: one with the colours laid directly on the marble in shades of red and yellow and one monochrome brown-purple layer.

## MA-XRF analysis: identification of pigments and stratigraphy

The results obtained on the 14 areas analysed labelled in Fig. 1, which shows the localisation of these areas, are summarised in Table 1 below, showing the elements detected area by area and layer by layer. In fact, the association between the stratigraphy, identified by the visual and microscopic observations, and the compositional elements is carried out observing the spatial distribution of the elements. The comparison between the visual imaging and the MA-XRF cartography allows to attribute the elements to the layer, as discussed below.

MA-XRF provides the spatial distribution of chemical elements. By combining the visual information on colour to the chemical elements, the chemical composition can be interpreted layer by layer.

We will first discuss the identification of the pigments and in the second instance the stratigraphy and the composition of the different layers.

The presence of pigments has been assessed on each of the sculptures investigated: the common presence of lead mixed with iron (from ochres), as well as the copper, arsenic and mercury, shows an intentional use of colours not only due to external contamination (accretions or earths). The interpretation of pigments is summarised in Table 2. Some hypotheses had to be made and are further discussed below. Most of the identified pigments were commonly used at this period (Gliozzo et al. 2021). Interpretation had to take into account additional peaks characteristic of surface contamination of buried and altered sculptures or due to the marble substrate (diffraction peaks). The diffuse presence of some elements over the whole surface (Sr, P, Cl) is considered to be the result of the marble (Sr), contamination generated by the burial of the statues or corrosion of the pigments (P, Cl). Traces of zinc are present in all three sculptures but only on some spots. It could be a contaminant, because it is not associated to other elements.

### Earths: yellow, red, orange

The yellow-orange colours in the different sculptures are related to the use of earth pigments (indicated by iron oxide, as for red earths). It is not possible to state whether the composition is different between the red and yellow earths used in the same sculpture: the compositions of the earths are quite similar in the reds and in the tonal variations of yellow-orange. Moreover, if it is not associated with a visible colour trace, the iron signal could also come from soil contamination.

### Red

The colocalisation of lead and iron on the sole of the foot, on the tunic of the female torso and on the eyes of the female portrait could suggest the use of the *sandyx*

**Table 1** MA-XRF results. Main elements detected in the different layers, identified by visual and microscopic observation. Small amounts of P, Cu, Zn, V and Cl with no relationship to colour were detected at all points and considered as contaminants

| Statue | Zone of analysis | Stratigraphy by visual observation | Chemical elements detected by MA-XRF |
|---|---|---|---|
| Foot | 1. Sole (thickness on the right) | 0. Marble | Ca, Sr |
| | | 1.Orange on the marble | Fe |
| | | 2.Yellow on the orange | Hg, Pb |
| | | 3. Red on the yellow | Fe |
| | | 4. Dark-red on the red | Fe, Pb |
| | 2. Sole | Blue spots | Cu, Si |
| | 3. Skin (nail of the fourth toe) | 0. Marble | Ca, Sr |
| | | 1. Brown-yellow | S, Fe |
| | | 2. White | Pb |
| | 4. Skin (middle of the fourth toe) | 0. Marble | Ca, Sr |
| | | 1. Brown-yellow | S, Fe |
| | | 2. White | Pb |
| | 5. Skin (top of the fourth toe) | 0. Marble | Ca |
| | | 1. Brown-yellow | S Fe |
| | | 2. White | Pb |
| Female portrait | 1.Skin (nasal commissure on left) | 0. Marble | Ca |
| | | 1. Flesh tone | S, Pb, Fe |
| | 2. Lips | 0. Marble | Ca |
| | | 1. White | S, Pb |
| | | 2. Red | Pb, Fe |
| | 3.Eye (left) | 0. Marble | Ca |
| | | 1. Red (underlines the eye) | S, Pb, Fe |
| | 4.Neck | 0. Marble | Ca |
| | | 1. Flesh tone | S, Fe |
| Female torso | 1.Belt | 0. Marble | Ca |
| | | 1. Yellow | Fe, Pb, As |
| | 2.Tunic (near the belt) | 0. Marble | Ca |
| | | 1. Red | Fe, Pb |
| | 3.Tunic (near the hair on the left) | 0. Marble | Ca |
| | | 1. Red | Fe, Pb |
| | 4. Coat (on the bottom) | 0. Marble | Ca |
| | | 1. Yellow | Fe, Pb, As, Zn |
| | 5. Tunic (on the bottom) | 0. Marble | |
| | | 1. Red | |
| | 6.Hair | 0. Marble | Ca |
| | (on the bottom) | 1. Yellow | Fe, Pb, Zn, As |
| | 7–8.Hair | 0. Marble | Ca |
| | (on the front, beside tunic on the right) | 1. Yellow | |
| | | 2. Brown-purple | S, Fe |

or *sirycum*, referred to by Pliny (NH, XXXVI, XXIII): a mixture of *minium* and red ochre. *Minium* is obtained by heating either litharge (to 450 °C) or lead white and is commonly found in Roman painting (Gliozzo and Ionescu 2022), used rubrics and epigraphs and Pliny refers the practice to paint the face of the participant of triumphal procession and the statue of Jupiter in the Capitol (Pliny, NH, XXXIII, 122). The presence of mercury on the sole of the foot suggests the presence of cinnabar, which is frequently found in Antiquity in Roman paintings (Gliozzo 2021). To date, its presence is only confirmed in some sculptures of the Roman period (IN 2468, sarcophagus; IN 1436 Quintus Hostius Capito; IN 823 Maximus in the database www.trackingcolour.com). In all cases the

**Table 2** Identification of pigments by MA-XRF. Colours are identified by optical observation, as previously discussed. In bold the elements detected used to propose the identification of the pigments

| Colours | Pigment | Composition | Statues |
|---|---|---|---|
| Red | Haematite | $\mathbf{Fe}_2O_3$ | Foot/female torso/female portrait |
| | Sandyx | $\mathbf{Pb}_3O_4+\mathbf{Fe}_2O_3$ | Foot |
| | Minium | $\mathbf{Pb}_3O_4$ | Foot |
| | Litharge | α-**PbO** | Female torso |
| Yellow | Vermillion/cinnabar | α-**HgS** | Foot |
| | Goethite | α-**Fe**O(OH) | Foot/female torso/female portrait |
| | Orpiment | $\mathbf{As_2S_3}$ | Female torso |
| | Mimetite | $\mathbf{Pb_5(AsO_4)_3Cl}$ | Female torso |
| | Massicot | β-**PbO** | Female Torso |
| Blue | Egyptian blue (EB) | $\mathbf{CaCuSi_4}O_{10}$ | Foot |
| White | Gypsum | $\mathbf{Ca}SO_4.2H_2O$ | Foot/female torso |
| | Lead white | $\mathbf{Pb}CO_3$ | Foot/female portrait |

cinnabar corresponds to red colours. In our case, it corresponds to an orange-yellow layer. It is possible that the cinnabar is mixed with an earth (Fe) or an arsenic-based pigment as some traces of arsenic were detected.

### Yellow

Arsenic has been detected in the yellow-orange decoration of the female torso and could indicate the use of orpiment, which is an arsenic trisulphide, the presence of which has recently been confirmed in Egyptian paintings (see Gliozzo 2021 for the list of the attestations); known deposits exploited in the colour industry in Antiquity are St John's Island in the Red Sea and Urmia in Asia Minor. The association with lead could also suggest the use of mimetite that it is a yellow-coloured lead arsenate ($Pb_5(AsO_4)_3Cl$). Although mimetite is unusual as a pigment, it has already been detected in several paintings from the Hellenistic period (Rouveret and Walter 2004; Brecoulaki 2006) and recently in a Roman context by Buisson et al. (2014) in the wall paintings of the Tomb of the Three Brothers in Palmyra. In particular, the use of mimetite has been attested in the polychromy of Greek statues (Bourgeois and Jockey 2005), in the Roman 'Beauty of Palmyra' (IN 2795 in the database www.trackingcolour.com) and in a Roman head of Athena from Oudna (Kopczynski et al. 2017). The presence of lead and chlorine and the colocalisation of these with arsenic could corroborate the identification of the presence of mimetite. Lastly, the combined use of orpiment and a lead-based pigment such as massicot or litharge cannot be excluded. Various occurrences are found in the literature in ancient paintings, especially the latter. However, no identification has been ascertained in statuary (Gliozzo and Ionescu 2022).

### Blue

The small size of the blue dots on the female portrait might have prevented its chemical identification. Only on the foot the high content of copper, colocalised with silicon, indicated the use of Egyptian blue. It is mainly composed of $CaCuSi_4O_{10}$ and was commonly used during the Roman Empire (Švarcová et al. 2021). The production process is described in the 1st c. AD by Vitruvius: the pigment (*ceruleum*) is formed as the result of the firing in a furnace of small particles consisting of copper, fine sand and *nitrum*, previously ground and moistened.

### White

The white paint layer, identified on the skin of the foot and in the female portrait, consists of lead white, confirmed by the presence of lead not associated with other elements (Gliozzo and Ionescu 2022). The presence of lead white is often confirmed in paint used on ancient sculptures because it adds volume to the paint, facilitates adhesion to the support and increases resistance to alteration, being resistant to water. In some cases, as on the foot, it is used to whiten the epidermis of the marble, in others to brighten the painting, as is probably the case in the face of the female portrait. In the latter, it is probably also used as a preparatory layer on the lips. The identification of sulphur distributed over large areas, in the hair of the female torso for instance, may indicate a preparatory layer, similar to stucco, as has been documented in other cases (Kopczynski et al. 2017).

By correlating the morphology of the spatial distribution of chemical elements and that of the colours observed visually in the same area, it is possible to attribute a precise composition to the various layers.

On the foot, in which two phases of paint have been identified through visual observation, the orange paint (layered on the marble of the sandal) corresponds to the distribution of iron, characterising earth pigments. The yellow-orange layer covering the orange one corresponds to mercury distribution. This allows one to propose cinnabar as the pigment. The more superficial red layer corresponds to the distribution of lead, suggesting the use of minium in the last phase. However, the colocalisation between lead and iron does not allow us to exclude the use of *sandyx* (Fig. 5a). In correspondence with a blue spot on the sole, a point of copper correlated to silicon is documented, suggesting the use of Egyptian blue (Fig. 5b). Two phases are also documented on the skin: a yellow–brown one corresponding to an area of sulphur density associated with iron and a second one in lead white. The sequence and the composition are confirmed in the three areas analysed (Fig. 5c).

In the female torso, for the tunic and the cloak only, the phase adhering to the marble cracks could be documented for geometrical reasons: the second layer is in fact only preserved in the folds of the tunic, which could not be reached by the XRF instrument used. The area delimiting the belt corresponds to the colocalisation of lead, arsenic and iron. This could suggest the use of mimetite mixed with goethite or that of orpiment with massicot or litharge (Fig. 6a). The coat and the hairs indicated the presence of the same chemical elements, corresponding to a dark yellow layer suggesting the use of same pigments. In the tunic, the colocalisation of lead and iron suggests the use of *sandyx* (Fig. 6b). In the hair on the front of the statue, alongside the tunic on the right, only the most superficial phase of brown-purple is documented covering the yellow layer. The localised presence of sulphur and iron could suggest a layer probably made of stucco and earths that provide the brown-purple colour. This interpretation is corroborated by the presence of a layer of preparation beneath the purple-brown layer, documented in the UVL microphotograph.

The skin of the female head, on the neck and on the nasal commissure on the left, shows a broad distribution of sulphur colocalised with spots of iron corresponding to a white layer with traces of flesh tones. In the lips and in the eye, lead and iron have a distribution corresponding to the red traces of pigments. The lead is probably used as a preparatory layer because its area of distribution is broader than the iron signal. It could be a lead white layer overlaid with earth-based pigments.

As was observed visually, since the distribution of the lead covers the marble cracks in the lips, we can state that the polychrome phase is posterior to the formation of these cracks (Fig. 7a). This confirms what we have argued through visual observation: the colouring is posterior to the cracks and marks a new phase in the life of the statue, as observed in another case (Abbe 2010). In the eye, we observe the diffuse presence of sulphur, as in the other parts of the skin, and a distribution of lead in the corner and along the bottom edge.

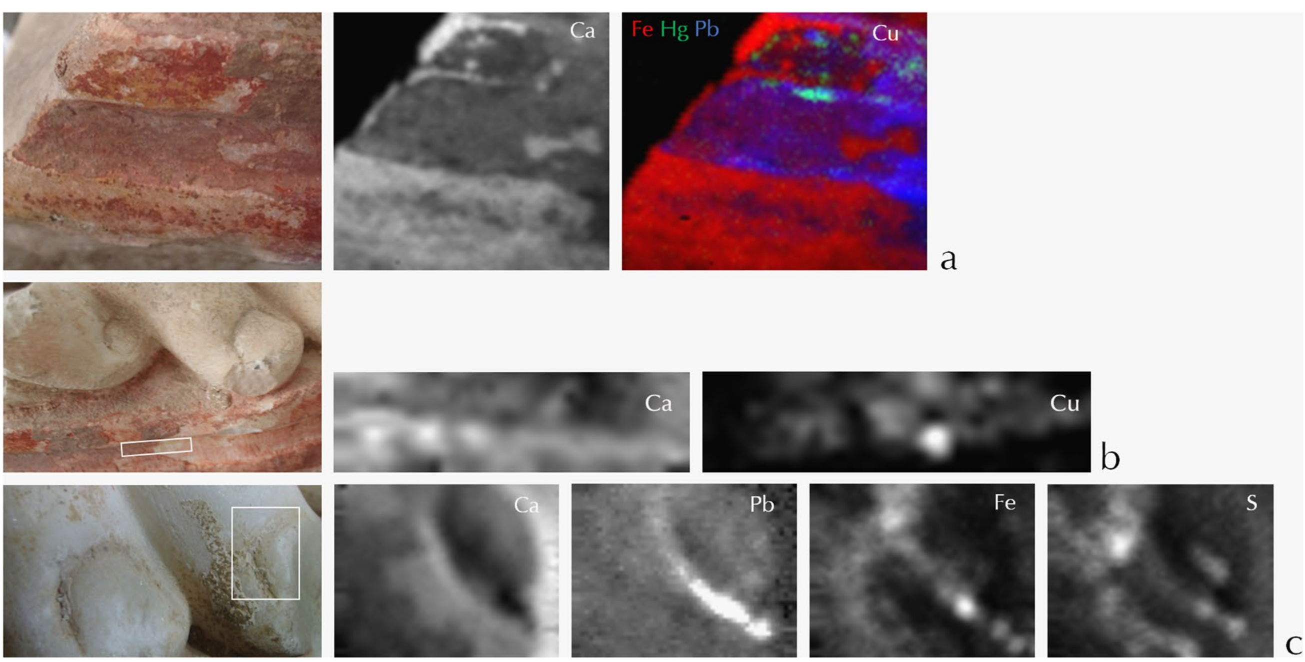


**Fig. 5** Male foot: macrophotographs of the analysed area and MA-XRF cartography showing the distribution of chemical elements (a–c: zones 1–3). The upper two scans were acquired with a step size of 0.5 mm and a dwell time of 0.5 s. The lower one with a step size of 0.25 mm and a dwell time of 0.8 s: **a** the stratigraphy of the sole, orange corresponds to iron distribution (red), yellow to the mercury (green) and red to lead (blue); **b** presence of a blue spot corresponding to a copper spot; **c** the stratigraphy of the skin, yellow corresponds to iron and sulphur and white to the lead

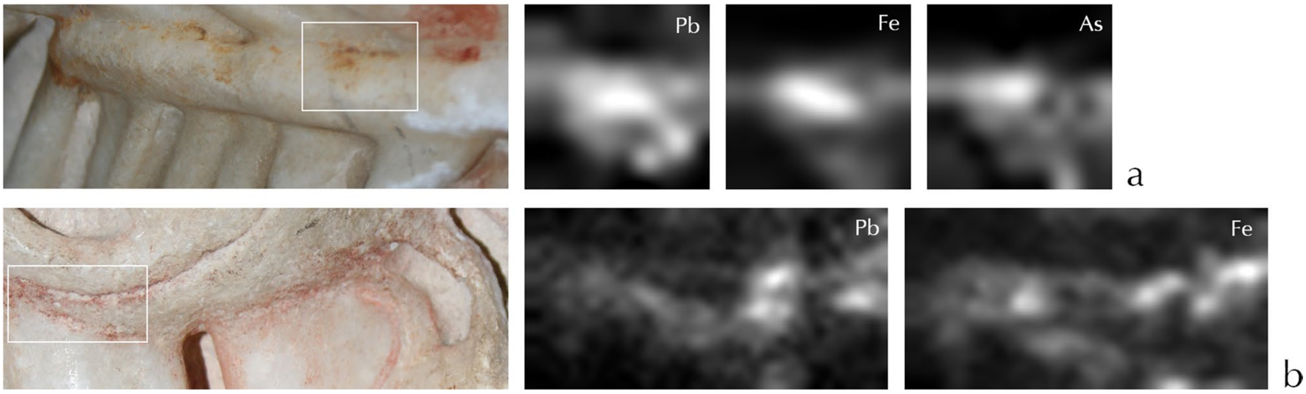


**Fig. 6** Female torso: macrophotographs of the analysed area and MA-XRF cartography showing the distribution of chemical elements (**a**–**b**: zones 1 and 3). The top scan was acquired with a step size of 1 mm and a dwell time of 2 s. The lower scan was acquired with a step size of 0.5 mm and a dwell time of 0.8 s: **a** the belt, yellow corresponds to the iron, arsenic and lead; **b** tunic, red corresponds to the lead and iron

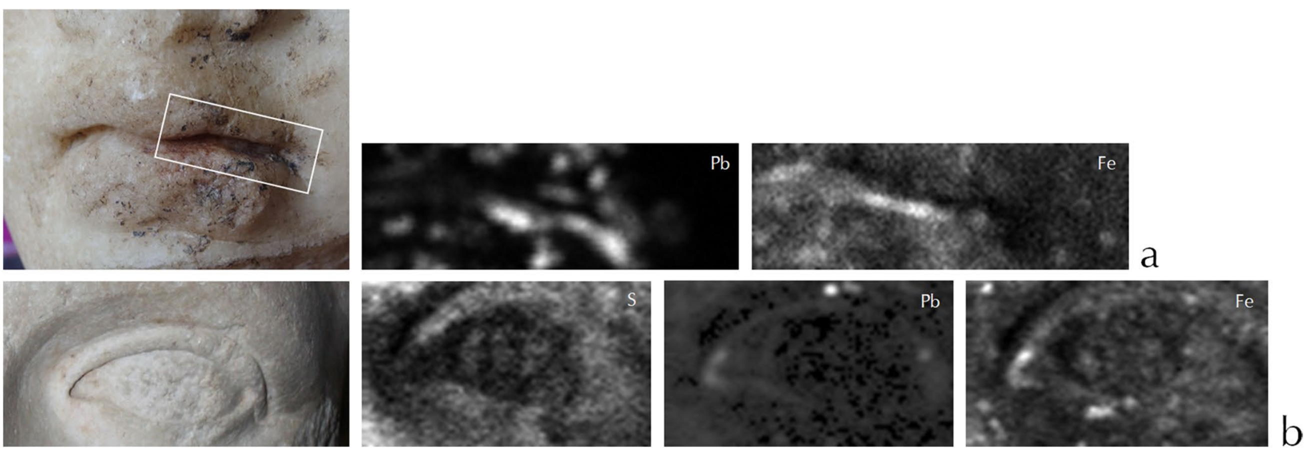


**Fig. 7** Female portrait: macrophotograph of the analysed area and XRF cartography showing the distribution of chemical elements (**a**–**b**: zones 2 and 4). Both scans were acquired with a step size of 0.5 mm and a dwell time of 0.5 s: **a**. lips: the white layer corresponds to the lead distribution and red to iron distribution (lead and iron are not colocalised); **b** the eye

## Painting technique and phases of the polychromy: some deductions

The analysis carried out allows an effective comparison between the visual and chemical analyses and enables us to go beyond the simple identification of the pigments that define the palette.

The extant colour is dominated by iron-based reds, oranges and browns, with a more limited use of a mercury-based orange (presumably vermilion), of arsenic-based yellow (probably mimetite) and lead-based orange-reds. Different shades of copper-based Egyptian blue are also documented.

If the palette is restricted, characterised only by red, yellow, orange, blue and brown-purple and made up of a limited number of known pigments, the technique with which the colour is layered on the statues varies. The thickness, brightness and chemical composition of the paint layers are characteristic of tonal differences, as well as of the nature of the binder, which could not be detected with this method of analysis. The stratigraphy and the distribution of colours allow one to better evaluate the techniques of colour application. Three techniques can be observed in the corpus analysed:

1. A direct application onto the marble, such as in the first phase of the female torso, as frequently highlighted in polychrome statues, such as on the Augustus of Prima Porta (Liverani 2014)
2. An application on a lead white preparation, such as in the lips and eye of the female portrait, as is hypothesised for other African examples (Kopczynski et al. 2017) and documented in the eyes of the Treu head (Verri et al. 2010)

3. An application onto a preparatory stucco layer, characterised by the presence of sulphur, such as in the second phase of the female torso or in the skin of the female head, as documented on the hair of the Treu head (Verri et al. 2010) or in another African case (Kopczynski et al., 2017)

Unfortunately, it is impossible to define the use of calcite, the use of which as a preparatory layer is documented in other cases (Bourgeois and Jockey 2005; Abbe 2010; Verri et al. 2010), because of the analytical technique used; the calcium signal is also pertinent to marble.

Moreover, the analysis conducted reveals the presence of a multi-phase polychrome finishing that invites one to consider the traces of painting also on other polychrome statues as perhaps the result of complex refinishing, recolouring and restoring of the colour of the statues.

In the corpus analysed here, when a coloured layer covers an earlier colour, it can be considered a subsequent phase. The identification of the different phases helps to imagine the chromatic effect that the statue must have had and the evolution of the colour code in the different phases of its life. Two cases might exemplify a change in the colour code rather than just a reprise of the colour finish as is the case in the third example. The first phase of the foot is characterised by yellow and orange tones, involving also the naked parts. The second phase of the foot shows a brighter contrast with a red sandal and white skin. The female torso would have presented a first red and yellow phase, with a white skin of apparent polished marble. The second phase switched to a purple-brown homogeneous finish with white skin: possibly an imitation of polychrome marble statues with a contrast between porphyry and a white marble. The female portrait, on the other hand, only shows a reprise of the colours rather than an entire overhaul and remaking. The restoration seems to affect only the damaged part on the lips.

## Conclusions

The analysis of the polychromy of three African statues adds new examples of multi-layered polychromy in a region of crucial importance to the Roman Empire but which has been little studied in relation to this issue. Through the analytical protocol presented in this publication, we were able to correlate elemental composition with visual observation of the colour of the pigment residues. This allowed us to combine the information from surface colour, stratigraphic insights and elemental composition in the comparatively limited time frame of one day per object on site. By doing so, we were able to document the technical function of the layers (preparatory layers or coloured finishing layers) and also to detect repairs and restoration of colours.

If this protocol were extended to a large corpus of statues, it would allow the development of a chronological and geographical seriation of the techniques, understanding if these vary according to workshops, chronology, availability of materials or the aesthetic effect sought. The study of ancient restorations of the paint would also allow us to understand if and how the colour codes changed, as in the female torso, or how it was maintained, as in the foot and female portrait.

If the methodological strength of this study is the combination of visual observation and chemical distribution of the elements, it is restricted by its limitation to 2D imaging methods that did not take the 3D shape of the objects into account; in the future, we expect to combine our spectroscopy with 3D imaging techniques, such as photogrammetry. This would allow a better understanding of the distribution of colours as well as light and shadow effects, commonly found in two-dimensional Roman painting, but neglected in the most widespread reconstructions of the polychromy of statues.

The documented remains of colour reveal the complexity of the colour history of the statues, illustrating that the repair and restoration of polychromy was very probably rather common in Ancient Rome. Looking at this history could have a significant influence on our understanding of the past and present reception of the works.

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## Declarations

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