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# Recovery of the traditional colours of painted woodwork in the Historical Centre of Lugo (NW Spain).

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**Abstract**

The rehabilitation of the degraded old quarter of *A Tinería*, in Lugo (NW Spain) regarded the recovery of the traditional colours on plasters and woodwork. To achieve this aim, the painting materials on wooden elements (window frames and doors) have been characterised firstly by means of colour measurements on site, with a portable solid reflection spectrophotometer, and secondly by pigment analysis of paint samples, using OM, SEM-EDS and MRS. The results revealed that the predominant colour in the cityscape of the 19$^{th}$ and early 20$^{th}$ century was red, and that the paintings were elaborated with red ochre of a local origin, in some cases with the addition of red lead. Other minor colours were identified as well: blue paintings were constituted by ultramarine blue or Prussian blue, yellow paintings contained lead monoxide and green paintings were based on copper pigments or on a mixture of Prussian blue and yellow lead monoxide. Extenders like barite, gypsum or calcite were often added to the paintings. Finally the turquoise paintings were applied in recent times, as titanium white and phtalocyanine green (both industrially synthesised in the 20$^{th}$ century) were identified in their composition. These results have contributed to the elaboration of the Colour Plan of the Historic Centre of Lugo. The rehabilitation of *A Tinería* stills ongoing and has received one of the United Nations´ International Dubai awards 2008, recognizing good practices and local leadership.

**Keywords:** Cityscape, colour measurement, pigment analysis, rehabilitation, traditional colours.

## 1. Introduction

The city of Lugo (Northwest of Spain) is known by its Roman walls from the 3$^{rd}$ century, one of the finest surviving examples of late Roman military fortifications (Fig.

1a-c), which was declared World Heritage by UNESCO in 2000. Related to this recognition, efforts have been made during the last years to restore the old quarter near the Roman walls, called *A Tinería*, which was in a serious state of neglect and deterioration (Fig. 1d). This quarter arose as a medieval village located between the Cathedral and a section of the Roman wall that ran from the *Porta do Minho* to the ancient access of the Roman road from *Brigantium* (Fig. 1a). *A Tinería* has developed and suffered transformations for centuries until its current appearance, and even though there are still medieval features as fountains and remains of towers, most of the constructions correspond to rural houses and urban emblazoned houses from the 19$^{th}$ century. The programme of architectural rehabilitation included the elaboration of the Colour Plan of the Historic Centre of Lugo, which would lead to the recovery of the traditional colours of plasters and painted woodwork on the buildings from *A Tinería*.

The study of the ancient colours of the cityscape has been the aim of many scientific studies yielding important results in the field of restoration and rehabilitation. Thus, the traditional image of the 18$^{th}$ century Rome's façades changed after Lange´s studies, where a Rome crowded of light coloured palaces: light blue, light green, light red, light grey was described instead of the assumed golden façades [1]. In the same way, the original colours in Pompeiian cityscape were investigated using different methods: study of excavation reports, artists´ reproductions, Roman documents on pictorial techniques and materials and analyses of pigments found in Pompeii. The results revealed that the Pompeiian houses presented a rather dark base (mainly red, but also black and yellow) and an upper part painted in white or light colours, in streets paved with dark grey stone [2].

Other studies focused on the use of colours as identity signs. Kjellström [3] presented the local colouring tradition at dwellings from the 19th century in rural areas of southern Sweden as an important factor in regional identity, and recognized four different geographical areas from the colour results obtained. Furthermore, the colours of *La Boca* quarter (Buenos Aires) were studied trough the pigment composition of paint remains of the façades and the colour studies of the works of artists that depicted the quarter throughout its history. A connection between local colouring tradition and cultural identity of the Italian immigrants that populated the area since 1880 can be established as the bright colours used in the façades of La Boca correspond to the traditional colouring of houses from the Mediterranean basin, so Italian immigrants would have brought their own colouring tradition covering their need of differentiation from the rest of the relatively colourless city [4].

However, most of the studies of the cityscape colours focus on dating the different interventions on the buildings and on orientating the selection of colours and materials to use during restoration works. Examples are the investigations carried out on a *Mudéjar* Palace in Seville [5], on painted architectural elements from a 18th century building in Cádiz (Spain) [6] and on coloured walls of the Cistercian Abbey of Stična and the Manor of Novo Celje (Slovenia) [7]. In those cases the colour, mineralogical phases and/or chemical composition of the original paintings were characterized by techniques like visible spectroscopy, optical microscopy (OM), micro-Raman spectroscopy (MRS) and scanning electronic microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS). In the three cases the determination of the original colour layers composition was necessary for a successful restoration of painted walls and finishing coats, and also allowed the researchers to compare the use of various pigments in buildings from different historical periods.

In the present work, the traditional colours of woodwork (window frames and doors) in *A Tinería* (Fig.1 e-f) were fully characterised by reflectance spectrophotometry, optical microscopy, scanning electronic microscopy coupled with energy dispersive X-ray spectroscopy and micro-Raman spectroscopy, with the aim of obtaining useful information to recover the traditional colours of the urban landscape and guiding the restorers in their choice of the materials during the architectural rehabilitation of the quarter. At the moment, the restoration of *A Tinería* is ongoing and has received one of the United Nations´ International Dubai awards 2008, recognizing good practices and local leadership [8].

## 2. Material and Methods

Eight ancient buildings were selected in the old quarter of Lugo, *A Tinería*, in order to characterize their painted woodwork (doors and windows). On site colour measurements were performed on the oldest remaining paint layer (that one placed directly over the wood) of thirteen woodwork, as it is the most interesting layer to reconstruct the traditional colours of the quarter. Five readings with replacement on each area studied were carried out with a portable solid reflection spectrophotometer GretagMacbeth CE-XTH, equipped with OptiviewSilver/i QC Basic software. The measuring conditions were: illuminant D65, observer 2º (CIE 1931) and a 5 mm diameter target area. The measurements were made by spectral reflectance, using the diffuse illumination geometry with an integration sphere, and were observed with the specular component included in 8º in relation to normal (d/8º). Colour measurements were analysed by considering the CIELAB colour space with the scalar coordinates: L*, lightness of the colour, which varies from 0 (absolute black) to 100 (absolute white); a*, associated with changes in redness-greenness (positive a* is red and negative a* is green) and b*, associated with changes in yellowness-blueness (positive b* is yellow and negative b* is blue). This colour space is currently recommended by the *Commission Internationale de l'Éclairage* (CIE) (in English: International Commission on Illumination) and is widely accepted by both the scientific community and industry.

In addition, Munsell colour notation was employed; L*a*b* coordinates were transformed into Munsell Hue, Value, and Chroma with help of OptiviewSilver/i QC Basic software. The Munsell values (Hue, Value/Chroma) correlates better with visual perception than CIELAB coordinates (L*a*b*), representing the colour perception attributes of Hue, which refers to the dominant wavelength, Chroma, which expresses the intensity or saturation of a colour; and Value, which represents the overall brightness or lightness [9, 10]. The Munsell system is cylindrical in nature with a central lightness axis (Munsell Value) surrounded by Chroma planes arranged in a Hue circle. The Hue circle (Figure 2) is divided into 10 sectors of the same size (separated by dotted lines), 5 principal hues: red (R), yellow (Y), green (G), blue (B) and purple (P); and 5 intermediate hues such as yellowish red (YR), bluish green (BG), etc. Each of these 10 sectors is subdivided into 10 steps, 0 to 10, where 5 correspond to the most representative colour of the sector (indicated by solid lines). For instance, 5R means pure red and 10R (= 0YR) means the hue at the border between R and YR. Value Munsell varies from 0 (absolute black) to 10 (absolute white), indicating the degree of lightness of a colour in terms of a neutral gray scale. Chroma Munsell is also described numerically beginning at 0 for neutral greys (the achromatic point) without tangible upper limit.

Furthermore, seventeen small samples of paint were extracted from the woodwork of these buildings to analyse their micromorphology and pigment composition in the laboratory. The samples were embedded in an epoxy resin and, once cured, cut transversally to the paint layers and polished, in order to prepare cross-sections allowing the study in detail of the different paint layers. The cross-sections were observed under an Optical Microscope Nikon Japan 115 with reflected light, and the general features of the sample (such as the number, colour, thickness, degree of adhesion and state of conservation of the different paint layers) were characterized. Afterwards, the cross-sections were studied under Scanning Electronic Microscope EVO-LS15 coupled with Energy Dispersive X-ray Spectroscopy, obtaining data on the micromorphology and elemental composition of the paint layers. Finally, the paint cross-sections were analysed by means of Micro-Raman Spectroscopy for a more accurate characterization, as this technique provides molecular composition. The MRS analysis were performed with a Renishaw InVia Reflex equipment and the experimental conditions were: excitation of 785nm and 514 nm, and power between 0.15 and 3 mV. Raman results were compared with reference spectra libraries of pigments [11, 12].

## 3. Results and Discussion

### 3.1. On site Colour measurements.

Table 1 shows the results of the colourimetric measurements , both in the CIE L*a*b* colour space and in the Munsell notation, expressed as the mean of the five readings taken with replacement, carried out on the thirteen woodwork from the eight buildings selected. Moreover, a colour sample of each woodwork is presented but it must be taken only as an approximate guide as impression devices and computer screens can strongly modify the authentic colours.

The colourimetric measurements on the oldest paint layers show narrow variations among the traditional colours of these architectonic wooden fittings, which were predominately reddish, except number 6 that was green. Thus, the hue parameter of the Munsell notation was YR for every woodwork, except for woodwork number 6. This parameter ranged from 0.2 to 9.7 but the difficulties during the colour measurement of woodwork 12 (hue: 9.7 YR), due to the extremely reduced available area, have to be taken into account and its high value should be attributed to the interference of the adjacent layers. So, ignoring measurements on woodwork number 6 and 12, the hue parameter obtained varies between 0.2 and 4.1 YR, being almost all the cases located in the same sector of the Munsell colour space, from 10R to 5YR (Fig.2).

The variation on the value parameter, leaving out measurements 6 and 12, is narrow as well: between 2.7 and 3.8, which means that colours measured are mainly dark colours. More significant is the variation in the chroma parameter, between 2.7 and 6, that probably reflects the conservation state of the paintings, a higher intensity of the red colour relating to a better state of conservation.

## 3.2. Analysis of the paint cross-sections

The paint samples prepared in cross-sections were observed under optical microscope with reflected light and the general morphology of each sample was studied. In general, a large number of superimposed paint layers were observed: up to 19, with an average of 8 layers. This finding could be explained by the exposition of the wooden fittings to the highly humid environmental conditions in the city of Lugo, which demands a continuous maintenance of the wooden elements that would be painted over frequently.

On samples presenting numerous paint layers there are some features that make possible to differentiate two application periods. More recent layers are better conserved and continuous, with a much finer texture, whereas older paint layers are more deteriorated, often discontinuous, and its texture is coarser. Under optical microscope it is possible to differentiate the limit between both groups of layers, traditional and recent, where a very poor adhesion between the paint layers can be noticed, probably due to their different mechanical behaviour (Fig. 3a). In addition, the analysis by SEM-EDS revealed a difference of chemical composition between more recent paint layers, which contain titanium (Fig. 3c), suggesting the use of titanium white, a pigment that was not regularly manufactured until the 1920´s [13]; and ancient paint layers, where titanium is absent of its composition and lead appears instead (Fig. 3d), probably due to white lead, the most common white pigment used before the 19th century [13]. This limit between both groups of paint layers indicates the chronological change from the use of traditional paintings, based on natural pigments of local provenance and prepared by hand, to the use of industrially manufactured paintings since the 19th century.

Regarding the oldest paint layer, the most interesting for this research, microscopic observation of the cross-sections revealed that in 9 of 17 cases it was red, with variable shades. This finding can be related to the traditional reputation of the quarter, socially degraded until recently, where probably the red doors symbolized the prostitution houses. In 3 cases it was green, in 2 cases it was blue, in other 2 cases it was turquoise and in 1 case it was yellow. The predominance of red as the colour of the traditional paintings on the woodwork observed under OM in the cross-sections supports the on site colourimetric results presented previously, where the hue parameter ranged between 10R and 5YR.

The elemental composition of the oldest paint samples was analysed by SEM-EDS and, in those cases where elemental analysis was not revealing enough information of the pigment employed, samples were analysed by micro Raman spectroscopy that provided structural information, in order to get a more accurate identification of the compound or to confirm SEM-EDS results.

The results showed that the red paints contain the elements constituent of silicates such as Si, Al, Ca, Mg and Na, and iron as chromophore element. In all cases the red pigment identified was red ochre, a natural clay rich in iron oxide haematite ($Fe_2O_3$), which characteristic bands at 224vs, 243w, 290vs, 299s(sh), 408m, 495w, 609w $cm^{-1}$ are shown in the Raman spectrum of sample 8, with the contribution of the 282 $cm^{-1}$ band of calcite,  present as ground layer (Fig. 4a). This red earth pigment may have a local provenance, due to the presence of ores of this mineral in the province of Lugo, for example in the sedimentary basin of Portomarín. In one case lead red or minium ($PbO_3$), a red lead oxide, was also added to the red ochre, probably to give an orange shade to the paint. The EDS spectrum of the red paint layer of sample 17 shows the peaks of the elements that constitute red ochre (Fe, Si, Al, O), red lead (Pb,O), calcite (Ca, C, O) and barite (Ba, S, O) (Fig. 4b). The appearance of Barite in most of the paint layers analysed constitutes evidence that we are dealing with pigment mixtures from 1800 onwards as this compound started to be regularly added as an extender for the pigments in the early 19$^{th}$ century.

The blue pigments used in the oldest paint layers were identified as ultramarine blue and Prussian blue. In sample 9 the characteristic band of lazurite at 548vs $cm^{-1}$ appears in the Raman spectrum of a blue particle (Fig. 5a). Spectra of lazurite from natural lapis lazuli and synthetic ultramarine blue are extremely difficult to differentiate as the synthetic ultramarine blue duplicates the crystalline structure of lazurite ($3Na_2O\cdot3Al_2O_3\cdot6SiO_2\cdot2Na_2S$). Ultramarine blue was first synthesised at 1828 and since then it substituted in Europe the highly expensive lapis lazuli. Thus, in the present case it can be presume that the band at 548vs cm-1 corresponds to an early occurrence of ultramarine blue. Prussian blue ($Fe_4[Fe(CN)_6]_3$), a synthetic blue pigment used during the end of 18th and the 19th century [13], was identified in sample 13, as its bands appear in the Raman spectra: 282vw, 538vw, 2102m, 2154vs $cm^{-1}$ (Fig. 5b).

The yellow pigment used is generally the yellow monoxide of lead (PbO), named massicot, which is made by the gentle roasting of white lead [13]. The EDS spectrum of the yellow layer of sample 4 shows the presence of the following elements: Pb, O, Ca, C, Ba and S; that may constitute massicot (PbO), calcite ($CaCO_3$) and barite ($BaSO_4$). An analysis of elemental distribution for the lead, calcium and barium has been done as well and they can be located on the mappings: calcium forms the ground layers, lead seems to concentrate at the thin yellow paint layer and barite is is found in all paint layers as a charge for the pigments (Fig 6a). To confirm these results, a micro Raman analysis has been done and the spectrum obtained from the yellow paint layer shows the main bands of lead monoxide massicot at 289s and 542w $cm^{-1}$ (Fig. 6b).

In the old green paint layers, data from SEM-EDS and Raman permitted to identify a mixture of Prussian blue ($Fe_4[Fe(CN)_6]_3 \cdot 14\text{-}16\ H_2O$) and a lead yellow pigment, probably massicot (PbO), which bands can be seen on the Raman spectrum of the oldest green paint layer of sample 5: 282vw, 538vw, 2102m, 2154vs $cm^{-1}$ (Prussian blue), 143vs, 289s, 385w, 542w $cm^{-1}$ (yellow lead monoxide) and 453m, 461w(sh), 616w, 647w, 988vs $cm^{-1}$ (barite, as a charge) (Fig. 7a). Moreover, in the case of sample 14 the SEM-EDS analysis revealed the presence of Ca, O, Pb, Si, Al, Mg and Cu in the oldest green paint layer. The identification of copper, suggests the use of a copper based green pigment, but MRS analysis was not helpful to identify the pigment this time (Fig. 7b), which might possibly be Scheele´s green, a copper arsenide ($Cu(AsO_2)_2$) or verdigris, a copper hydroxyacetate ($Cu_3(C_2H_3O_2)_2(AsO_2)_6$).

The samples that have a turquoise paint layer as the oldest one, contain phtalocyanine green, an organic compound with Cl and Cu that presents bands at 680vw, 741vw, 773vw, 1208w, 1283w, 1336w,1537m $cm^{-1}$ in the Raman spectrum of sample 16 (Fig. 8a). The EDS spectrum of the same sample, shows the elements that constitute titanium white (Ti, O), barite (Ba, S) and silicates (Si, Al, Mg Na, Ca) (Fig. 8b). Both phtalocyanine green and titanium white ($TiO_2$), were synthesised industrially as pigments in the 20$^{th}$ century, which means that these paintings are recent and hence not representative of the traditional colours of the quarter.

**4. Conclusions**

From the results here obtained, it can be concluded that red was the predominant colour of the cityscape in the old quarter of *A Tinería* (Lugo, NW Spain), being the local red ochre the main pigment, sometimes mixed with minium, to obtain an orange shade.

Other colours and pigments used were: green, obtained from a copper-based compound or a mixture of Prussian blue and massicot; blue, obtained from ultramarine blue or Prussian blue; and yellow, obtained from a yellow lead monoxide.

The combination of the different techniques used was very efficient to identify the pigments and orientate its dating. Thus, optical microscopy (OM) and scanning electronic microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS) were helpful in the recognition of paint from two different application periods, which were well defined by the presence-absence of titanium (indicating the transition from handmade to industrially manufactured paintings), as well as by the morphology and state of conservation of the paint layers. In the same way, micro Raman spectroscopy (MRS) results in a very useful complement to SEM-EDS for a more accurate identification of the pigments.

These results have been taken into consideration during the rehabilitation of this medieval quarter in the city of Lugo, *A Tinería*, which has been awarded with the United Nations´ International Dubai awards 2008, recognizing good practices and local leadership.

## 5. Acknowledgements

The present study was financed by the Xunta de Galicia (09TMT014203PR and 09SEC003203PR). P. Sanmartín and L. Pereira-Pardo would like to thank the Spanish Ministry of Science and Innovation and the Spanish Ministry of Education for their PhD grants.

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Table 1: Results of the colour measurements on the thirteen painted wooden elements, expressed both in the CIEL*a*b* system and in the Munsell notation, and a colour sample.

| Woodwork | L*a*b* | Munsell | Colour sample |
|---|---|---|---|
| 1 | L*: 36.07<br>a*: 16.63<br>b*: 12.87 | 0.2YR 3.5/3.7 | |
| 2 | L*: 34.96<br>a*: 14.13<br>b*: 10.70 | 0.2YR 3.4/3.0 | |
| 3 | L*: 31.09<br>a*: 14.54<br>b*: 12.87 | 1.6YR 3.0/3.3 | |
| 4 | L*: 27.41<br>a*: 10.60<br>b*: 12.03 | 4.1YR 2.7/2.7 | |
| 5 | L*: 36.56<br>a*: 13.43<br>b*: 16.35 | 3.8YR 3.6/3.5 | |
| 6 | L*: 41.88<br>a*: -6.64<br>b*: 13.93 | 3.3GY 4.1/2.3 | |
| 7 | L*: 35.21<br>a*: 25.18<br>b*: 21.42 | 0.5YR 3.4/5.9 | |
| 8 | L*: 38.43<br>a*: 20.99<br>b*: 21.96 | 2.1YR 3.7/5.3 | |
| 9 | L*: 38.01<br>a*: 24.24<br>b*: 23.95 | 1.5YR 3.7/6.0 | |
| 10 | L*: 33.74<br>a*: 13.45<br>b*: 11.00 | 0.9YR 3.3/3.0 | |
| 11 | L*: 38.69<br>a*: 14.68<br>b*: 12.70 | 1.0YR 3.8/3.4 | |
| 12 | L*: 40.67<br>a*: 3.39<br>b*: 10.27 | 9.7YR 4.0/1.6 | |
| 13 | L*: 38.97<br>a*: 12.42<br>b*: 12.76 | 2.5YR 3.8/3.0 | |

FIGURE CAPTION:

**Figure 1.**

a) Map of the Lugo historical quarter surrounded by the Roman walls [14]. b) Aerial view of the historical quarter of Lugo nowadays (Google Earth inc.). c) The Roman walls of Lugo near the Cathedral. d) *A Tinería* quarter from the top of the Roman walls e) Example of the painted woodwork studied. f) Detail of the multiple layers of paint marked on a door.

**Figure 2.**

Munsell colour space. The red arrow the shows the sector where all the colour measurements are located (except 6 and 12).

**Figure 3.**

a) Examples of cross-sections with multiple paint layers. The limit between recent and ancient paint applications is indicated by an arrow. Photographs of samples number 9, 12 and 14, from left to right.

b) Optical microscopy (OM) photograph of cross-section of sample 1.

c) X ray energy dispersive spectroscopy (EDS) spectrum of a recent white layer, containing Ti.

d) EDS spectrum of an ancient white layer, where Ti is absent and Pb appears.

**Figure 4.**

Red paint.

a) OM photograph of sample 8 and Raman spectrum of the red paint layer (base line corrected), showing the haematite bands.

b) OM and Back-Scattered Electrons (BSE) photograph of sample 17 and EDS spectrum of the red paint layer showing the elements that constitute red ochre, red lead and barite.

**Figure 5.**

Blue paint.

a) OM photograph of the stratigraphy of sample 9 and Raman spectrum of a blue pigment particle: ultramarine blue.

b) OM photograph of the stratigraphy of sample 13 and Raman spectrum of the blue paint layer: Prussian blue and barite.

**Figure 6.**

Yellow paint.

a) OM and BSE photograph of the stratigraphy of sample 4, EDS spectrum of the yellow paint layer and mapping of distribution of Ca, Pb and Ba.

b) Raman spectrum of the yellow paint layer: lead monoxide.

**Figure 7.**

Green paint.

a) OM photograph of the stratigraphy of sample 5 and Raman spectrum of the oldest green paint layer. (Base line corrected). Prussian blue, yellow lead oxide and barite.

b) OM photograph of the stratigraphy of sample 14, EDS spectrum of the green paint layer, where copper is detected, and Raman spectrum of the oldest green paint layer.

**Figure 8.**

Turquoise paint.

a) OM photograph of the stratigraphy of sample 16 and Raman spectrum of of the turquoise paint layer, containing phtalocyanine green.

b) BSE photograph and EDS spectrum of the same sample, Ti present.

Figure 1

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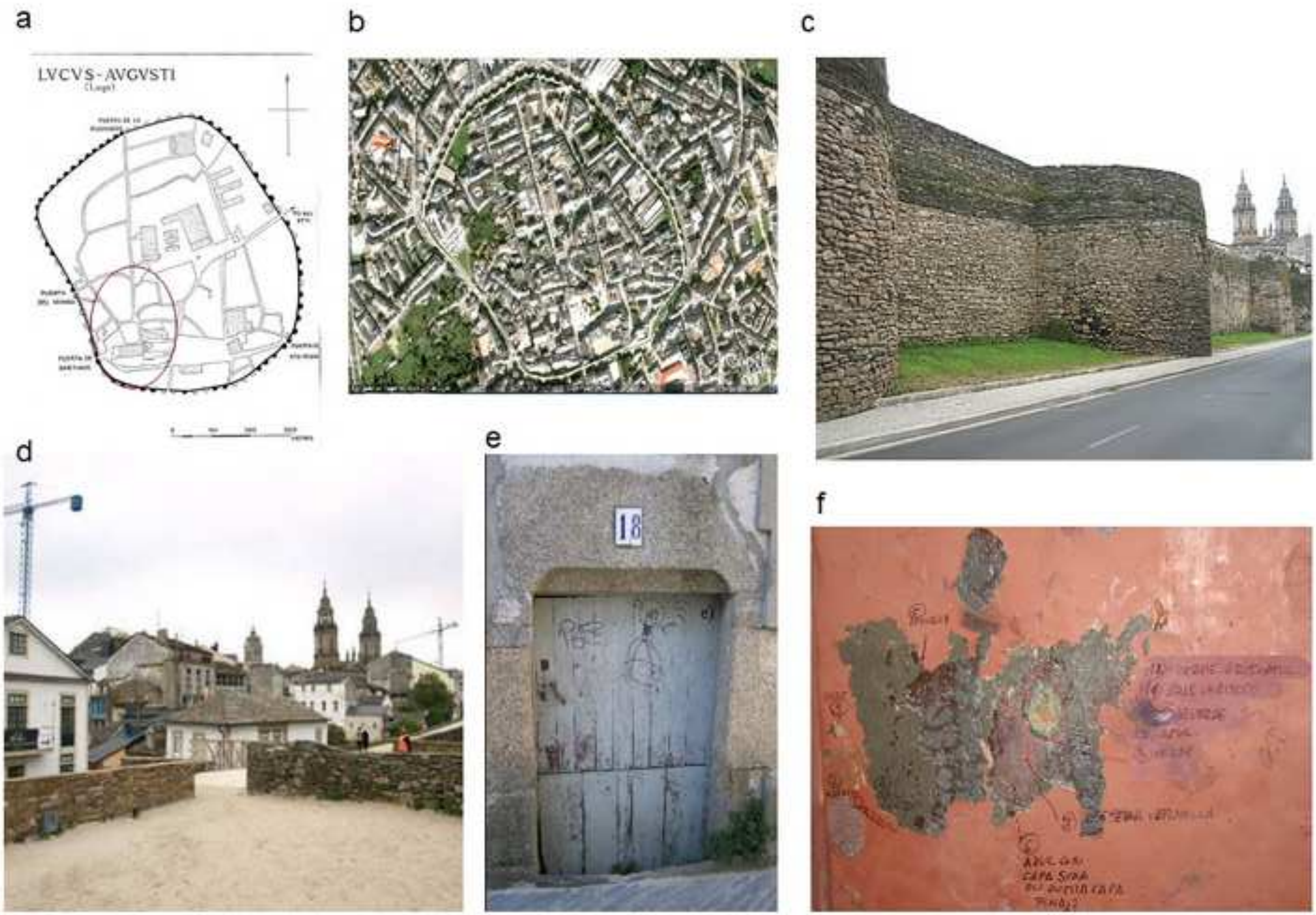

Figure 2

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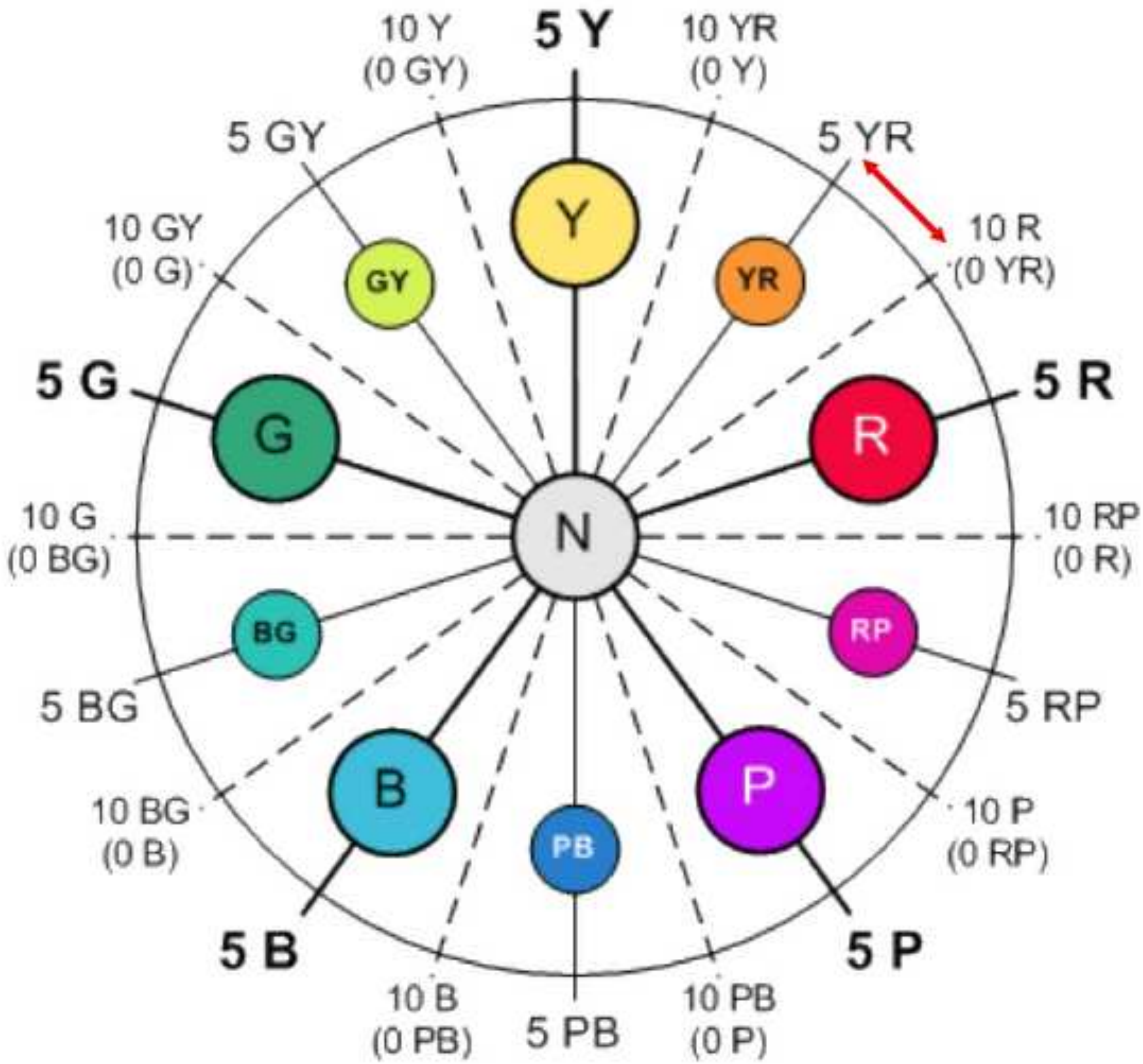

Figure 3
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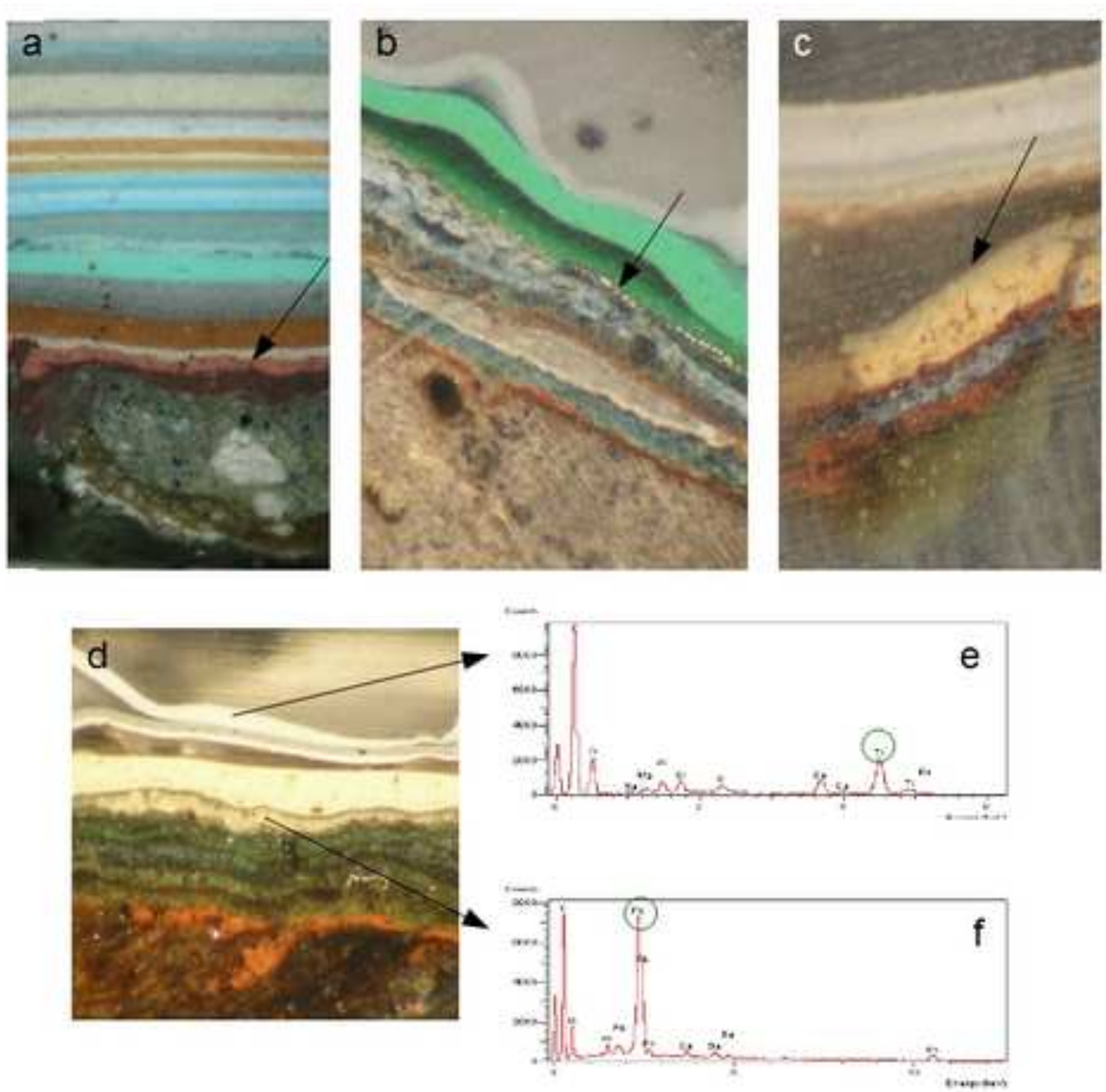

Figure 4

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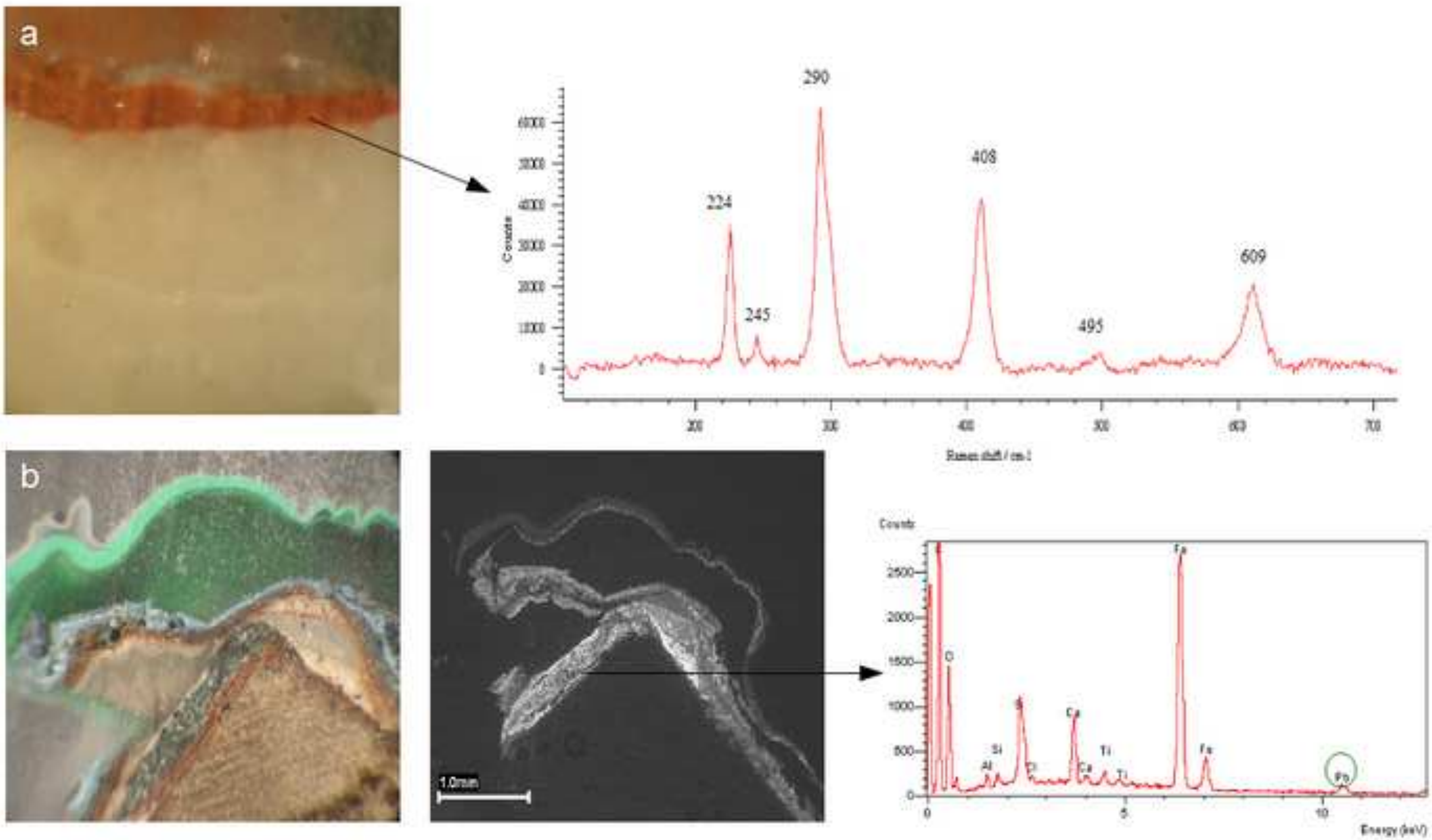

**Figure 5**
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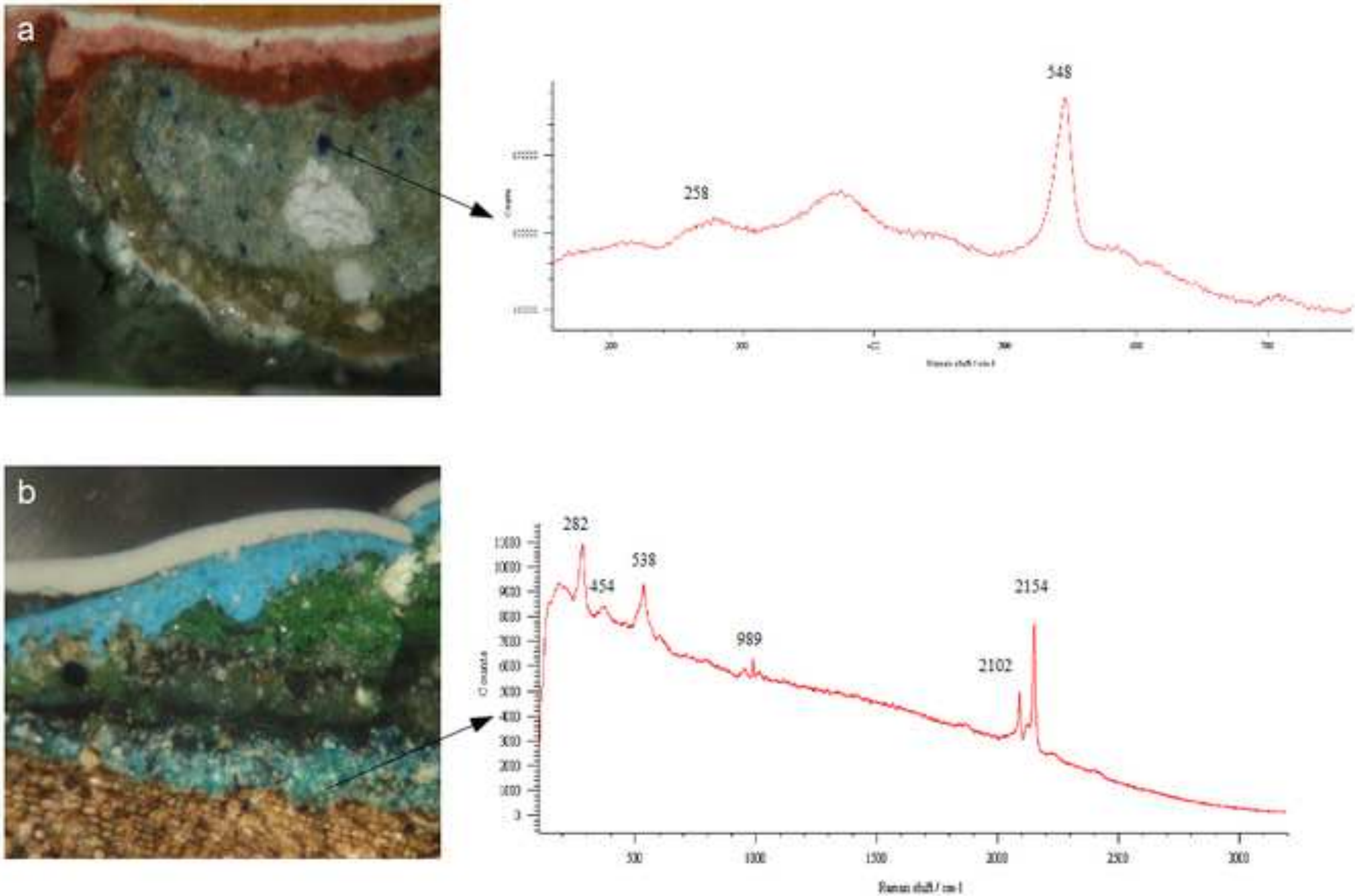

Figure 6
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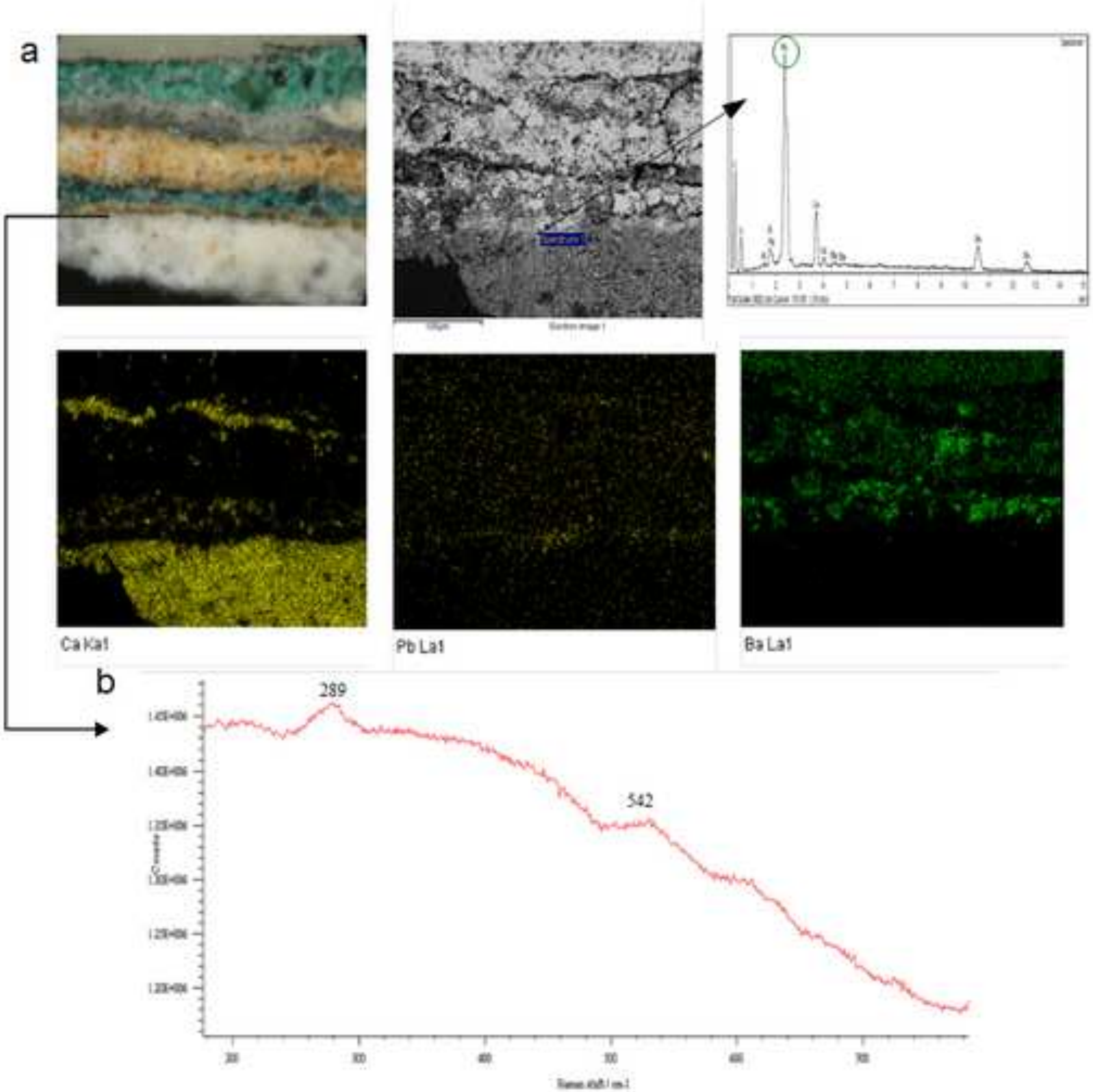

**Figure 7**

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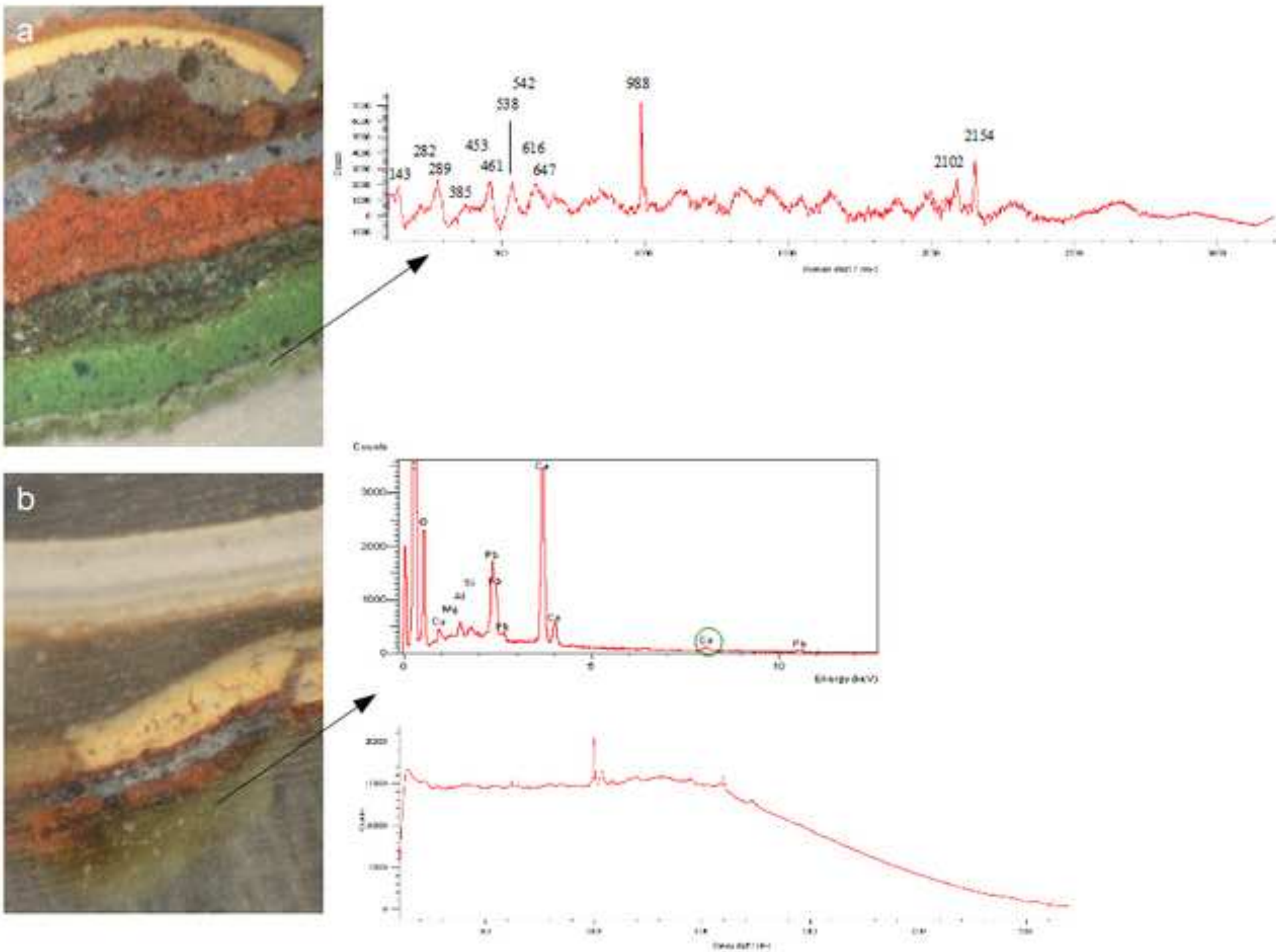

Figure 8

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