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A study of the polychromy of Campana's panels

Estudo da policromia dos painéis de Campana

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Abstract

The study focuses on the colour of architectural earthenwares known as Campana slabs, which often show polychromy remains. We have analysed several fragments of simas, crowning and revetment panels found between 2001 and 2013 on the northeast slopes of the Palatine Hill (Sapienza Università di Roma), in the excavation pit of the Arch of Constantine and in the House of Augustus. In this work, we have reported the results obtained on 21 samples by means of Optical Microscopy (OM), X-ray fluorescence spectroscopy (XRF) and Raman Spectroscopy. The analytical approach used has enabled to understand the palette and techniques used by ancient artists.

KEYWORDS
Earthenware
Campana reliefs
Non-destructive analysis
Polychromy of Roman architecture
X-rays

Resumo

O estudo incide sobre a cor das louças arquitectónicas conhecidas como lajes Campana, que apresentam frequentemente vestígios de policromia. Analisámos vários fragmentos de simas, coroamentos e painéis de revestimento encontrados entre 2001 e 2013 nas encostas nordeste do Monte Palatino (Sapienza Università di Roma), no fosso de escavação do Arco de Constantino e na Casa de Augusto. Neste trabalho, descrevemos os resultados obtidos em 21 amostras por meio de microscopia ótica (MO), espetroscopia de fluorescência de raios X (XRF) e espetroscopia Raman. A abordagem analítica utilizada permitiu compreender a paleta e as técnicas utilizadas pelos artistas desse tempo.

PALAVRAS-CHAVE
Faiança
Relevos de Campana
Análise não destrutiva
Policromia da arquitetura romana
Raios X

The Campana's slabs: a short introduction

The architectural earthenwares commonly known as "Campana slabs" include various types of clay-based revetments produced between the late Republican age and the first half of the second century CE. So called from the name of the collector and first publisher the Marquis Campana, a leading figure of nineteenth-century collecting [1], whose changing fortunes led to the dispersion of the collection in the largest museums in Europe. In his publication, the slabs are represented graphically, sometimes with colors. The slabs in his collection were sometimes integrated and colored, so that the archeologists often have doubts about their authenticity. We must thank Rohden-Winnefeld for the first complete edition of the Campana slabs, a large catalog with black and white photos [2]. Much later, Siebert's edition of the Kestner Museum of Hannover (2011) finally shows a complete collection in color [3]. Today, the number of editions, especially on excavations, showing slabs with polychromy has grown considerably.

Campana slabs are a serial product linked to brick manufacturing that combines easy reproducibility with high-quality artisanship, but the mechanisms of dissemination of moulds or models still elude us.

The use of these earthenwares represents an elitist phenomenon, essentially linked to the great aristocratic residences and the non-sacred spaces of sanctuaries and develops from earthenware decoration attested in central Italy during the third and second BCE combined with the Etruscan-italic decorative tradition.

In some way, the contexts where they express the highest level of modelling and workmanship, are always linked to the imperial family or families close to it, either directly, or in restructuring programs where the imperial will occupy a prominent place [4].

A peculiar figurative heritage is reflected in the Campana slabs, largely inspired by Greek mythology, which is often associated in an iconological key with a meaning alluding to the historical and political realities of the time.

Other slabs have a narrative flavor and depict aspects of Roman life, such as chariot races, hunts, theatrical scenes and Nilotic landscapes, found mainly in secondary contexts, such as tombs, thermal baths, and rustic parts of villas.

The decorative schemes show compositional principles typical of marble reliefs, toreutics, ceramics, and plaster, while stylistically they are largely inspired by Neo-Attic classicism, but also by the Hellenistic style and, to a lesser extent, by traditional italic characters [5].

There are five types of terracotta among the Campana slabs categorized by their position in the roof or by their supposed function, all of which were colored. Although the position of the two simae on the roofs of the buildings is certain, it remains more difficult to define the placement of the crowning and revetment slabs. In general, the crowns and bases were added to the decorated slab, so we can have the same decoration on different types of earthenware (Figure 1).

The raking simas were modeled in one piece with the tile, often with a groove on the top, for the cimasa, or provided with drip noses when attached to the eaves. The revetment slabs had a crown usually in the form of an ionic kyma, and a base in the form of a pattern of palm leaves and calyxes. These slabs were usually fixed on the wooden structure with nails, at the head of the beam or on the architrave as a frieze, with the primary function of protecting the wood.

Less clear is the function of the crowning slabs, which should be fixed to the wall with mortar and thanks to the listel at the base, as a single relief, in pairs, in repeating series forming an ionic frieze, at different heights of the wall, from the base of the wall to the top [5].

None of these reliefs were ever found *in situ*.

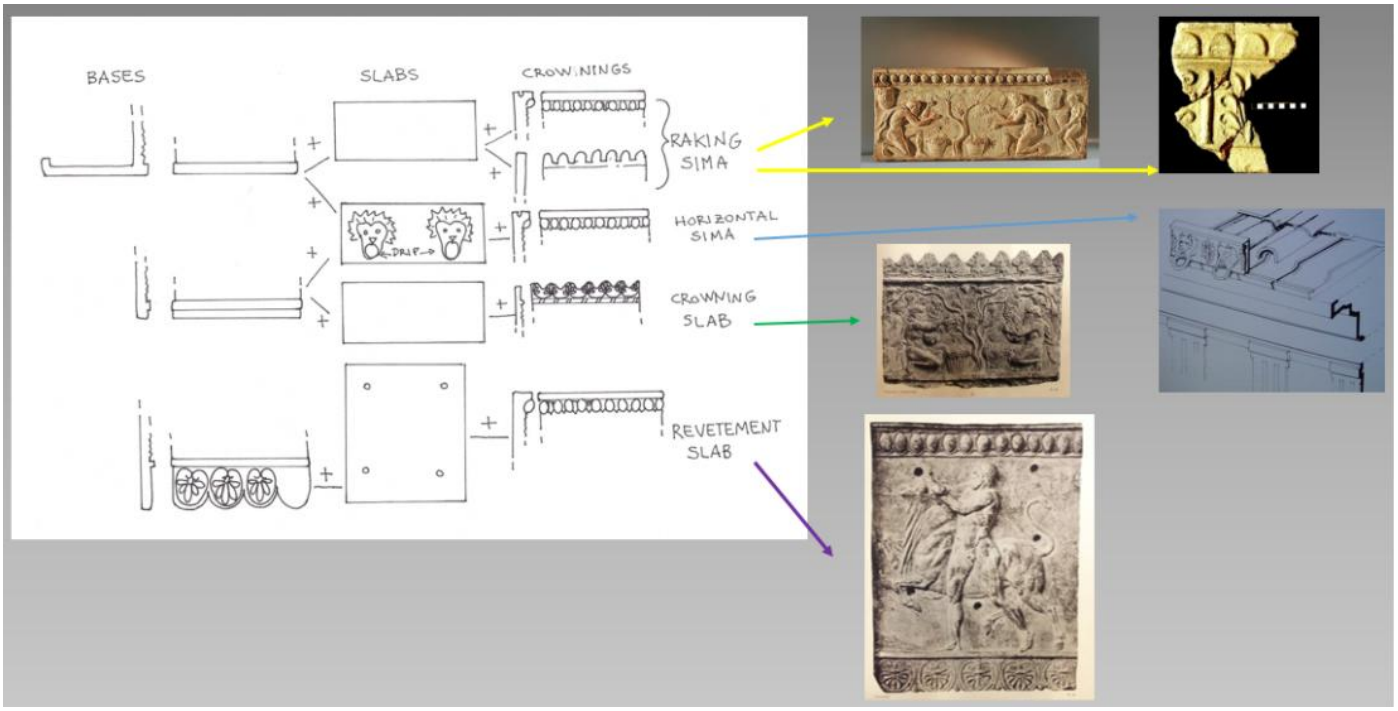

Figure 1. Campana's slabs typology. The scheme shows the different types of slabs resulting by the combination of different bases or crowns with different kind of decorated slabs.

The technical point of view

For the study, due to the doubts we already expressed about the authenticity of the colour on the Campana's collection slabs, we chose to analyse only slabs coming from recent excavations: the north-eastern slopes of the Palatine hill (Sapienza Università di Roma, Prof. C. Panella), the foundation pit of the Constantin's arch (SSBA Roma) and the House of Augustus (Parco del Colosseo). All of the contexts are in some way related to the first emperor. The slabs from the north-eastern slopes come from different contexts, even chronologically very far from their first use, but were probably connected to the birthplace of Augustus, *ad capita bubula*, and the restoration of the house held in first imperial age. The slab form the Constantin's arch pit is a single object of uncertain place of origin, but not far or from the previous one, anyway connected by the theme to the Apollo's cult. The last ones come from the first phase of the Augustus house, dated 36-28 BCE; they were dismantled from the *peristilium* of the house and reused to close the first and previous entrance to the Apollo's temple, along the corridor of the fallen vaults.

On the technical side, the slab is mould modelled but, as we can see observing the section, the tempers abundantly present in the matrix are never visible on the surface of the relief. Thus, we must think that, at first, a thin layer of dense and fine clay was spread in the mould and just after that the usual mix with tempers.

Starting from the technique of paint application, it has been proven by many studies the application of compounds of pigments, solvents (water) and organic binders (difficult to identify, but probably egg) on a surface, often but not always, prepared with lime wash, which improves pigment adhesion [6-7]. This background, when abundant, is often the only trace that has survived. Figure 2 shows two slabs: in the first the lime wash is visible under and around the blue of the background, the only surviving color (Figure 2a), in the other, the blue background has completely disappeared, but the other colors have survived (Figure 2b).

Figure 2. Lime wash on slab's surface: *a*) lime wash under blue pigment; *b*) pigment disappeared, lime wash lasting.

Figure 3. Slab with scene of grape harvest. Red color overtaking the edges, it will be covered by the blue of the background when the slab is completed.

The application probably follows an order of convenience: first the light colors, then the dark ones, with little attention to respecting the edges (Figure 3), and lastly the background, which would correct any error.

The polychromy

The palette used is that of architectural decorations, based on the primary colors of yellow, red, and blue, joined by orange, green, pink and white. The fact that this palette is related to the three-dimensional nature of the support, the tile or slab, and not to the motifs depicted on it, can be seen in the transfer of the same to a two-dimensional pictorial surface. The backgrounds

of the paintings often become black or dark red. From this point of view, the slabs are much closer to the plaster, so that the three-dimensionality is the distinguishing element. Due to the neo-attic style of most of the slabs, we can imagine that they also followed the color rules and the sobriety of classical Attic architecture, especially the Parthenon [8].

The choice of colors for the individual elements of the figuration is based, as far as possible, on a naturalistic principle, but above all on the differentiation of the figures and the levels of the relief.

Figure 4 shows two different crowning slabs, both with a symmetrical decoration and probably to be displayed together. Figure 4a shows a Nike facing a missing central object. We can recognise the light pink of the skin, the white dress of the Nike, but at the same time, the wings of the Nike have a different color, yellow and reddish brown to distinguish them. The other slab (Figure 4b) shows the central object, a shield, held by light pink arms.

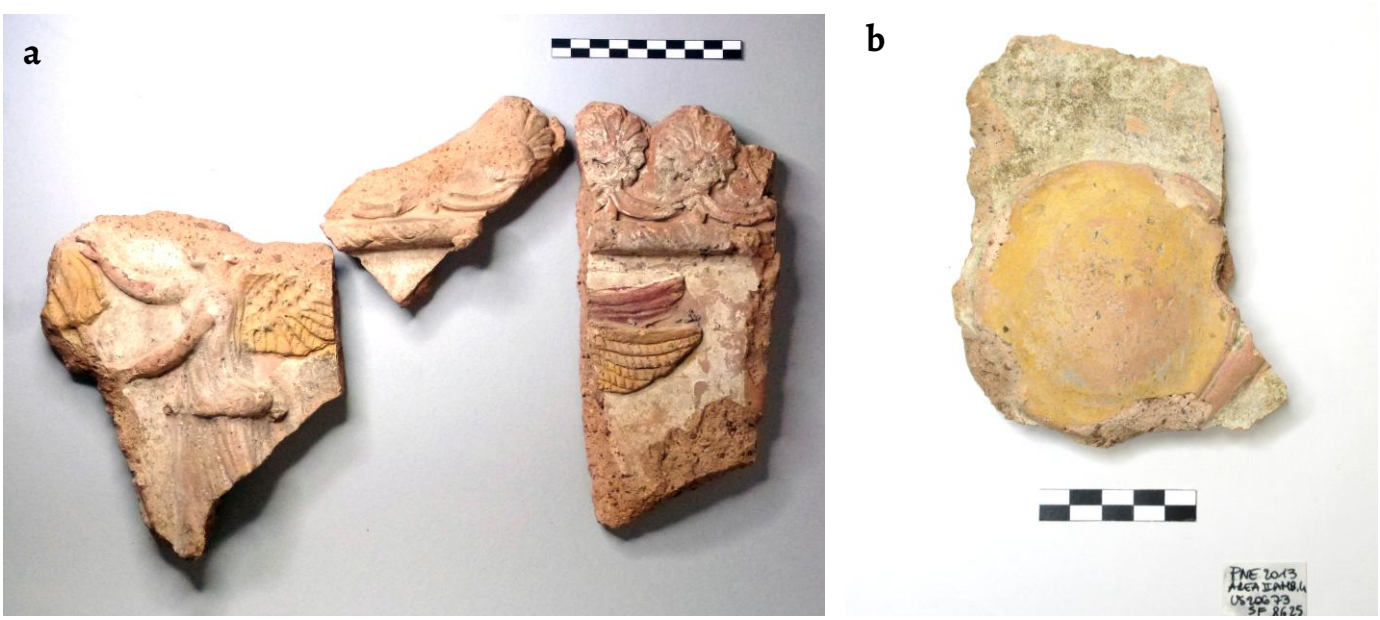

Figure 4. Polychromy on crowning slabs: a) Nike with wings of different colour; b) naturalistic colouring of the skin.

Figure 5. Shields of different colour in a crowning slab with triumph scene (unpublished).

In Figure 5, a slab with prisoners and soldiers shows a panoply with shields of different color (yellow and red), to make them all visible and distinguishable.

The freedom of the painter in the composition of the colours is shown also in slabs with the same theme but coming from different contexts. An example of this is the panel with the theme "The Tripod Dispute between Apollo and Heracles". On the panels displayed in the Antiquario Palatino, the colour of the space under the basin of the tripod is blue, while on other fragments it is orange. Another example is the coloration of the Ionic kyma. One is completely white and made with white lead, another with white ovoli and an orange and pink frame and a red pin.

We have no elements that indicate a usual detailed coloring of the figures (eyes, eyebrows, and lips): the silhouette and thickness of the relief probably being sufficient to make the figures recognizable, as on the plasters or, as seen, on pictorial surfaces with the same motifs.

Examination of the available bibliography with color photos has so far revealed a detailed overpainting in only one case, namely in a small fragment of a slab from the Palatine Hill with a horse in strong relief [9], in which the bridle is highlighted with a dark red color, probably red ochre. The slabs from the House of Augustus show the highest level of workmanship and painting so far and they are exceptional: together with a larger variety of colors, the eyes of the Gorgon are painted, the edge of Hermes' cloak shows a red strip at the edge, and the faces of the gods are naturalistically rendered (Figure 6).

The usual state of preservation of the panels in general does not allow to assess the presence of nuances that, for the same reasons as the physiognomic details, perhaps had no reason to exist.

As far as we have been able to analyze, the backgrounds of the panels are usually blue and occasionally orange; the situation is different for the slabs with the doric frieze, where the red background is typical of the metopes and follows the decorative canon of the metopes of the Parthenon [8].

Figure 6. Physiognomic details on slabs from the House of Augustus.

A long tradition of architectural studies has tried to investigate the meanings of the colours used, reaching the conclusion of the "non-significance" of red or blue or even absent backgrounds, highlighting however that the transition from red to blue backgrounds took place in ancient Greece at the end of archaic age, simultaneously with the transition from black-figure to red-figure pottery [10]. The metalinguistic value of the blue backgrounds in late-republican roman art has been well investigated by P. Liverani in multiple occasions [11]. The colours used in the creation of the figures in the marble friezes do not follow naturalistic principles, but are a narrative and compositional sign, capable of distinguishing the figures placed high on the architraves; instead, in Campana's slabs we have seen a mix of naturalistic and compositional sign.

Experimental

We began with direct observation of the slabs with the naked eye and optical microscopy, then we performed elemental and molecular point-by-point analyses directly *in situ*, such as X-ray fluorescence and Raman spectroscopies. Other analyses involving also micro-destructive techniques were published in a previous work [12].

Optical microscopy (OM)
The surfaces of plaques were viewed using a Bresser optical microscope with 40× zoom and a movable light guide system. The photos were taken with a professional Nikon camera.

X-ray fluorescence spectroscopy (XRF)
XRF is a very popular technique in the field of cultural heritage because it is non-invasive, and we can perform the analysis directly on the surface of the objects. We identify the elements present on the examined point and can indirectly trace them back to the pigment used. The elemental analysis was performed using a portable device with a Pd-anode X-ray generator (EISS srl) and a Peltier-cooled silicon pin (Si-PIN) detector (Amptek, mod. XR-1000CR). The XRF spectra were obtained at a voltage of 40 kV and a tube current of 350 mA with a data acquisition time of 200 s. The sample area had a diameter of about 2 mm.

Raman spectroscopy (Raman)
A Raman system (AvaRaman-532TEC), with a spectrometer (AvaSpec-2048TEC) was used. It is composed by a 25 μ slit, an NC grating that covers the spectral range 535-750 nm (corresponding to a shift from the 532 nm laser line of 100 to 5400 cm^{-1}), a DCL-UV/VIS filter, and a CCD detector with 2048 pixels. The excitation laser is a TE-controlled diode laser, emitting at 532 nm, with adjustable output power from 0 to 250 mW. The spectra processing was performed using the AvaSoft-Raman Software, with which the intensity values of the peaks related to the elements were obtained. The Origin software was used for the spectra processing, which allowed us to average the multiple spectra for individual points to obtain an average spectrum from which the intensity values of the peaks were derived.

Results and discussion

Based on OM observation we could prove that pigments were applied in two ways: directly the ceramic matrix surface or on a ground of lime wash. The ground probably was used to smooth the surface, to improve the adhesion of the pigment, and to make the colour lighter. In Figure 7 some examples are reported.

The XRF analysis shows that iron is the main element for the yellow and dark red colour suggesting the use of ochres. For the dark red hues, Raman spectra show the following peaks: 210, 297, 407 and 600 cm^{-1} attributable to red ochre [12-13].

For yellow hues, Raman peaks at 297 and 395 cm^{-1} are recorded suggesting the use of goethite [12].

Among the red hues, in some cases we observe traces of an orange pigment that contains high counts of lead (Table 1). Raman spectra show that the most intense peak is at 543 cm^{-1} ascribable to minium [13].

The blue pigment is characterised by the presence of copper (Table 2), however XRF reveal also high counts of calcium and iron (relative percentage major or equal to 30 %). Raman spectra show the presence of the following peaks: 429, 607 and 1083 cm^{-1} (Figure 8a). The peaks at 430 and 1084 cm^{-1} are attributed to Egyptian blue and calcium carbonate [13], whereas 607 cm^{-1} could be related to the presence of hematite. This hypothesis is confirmed for some fragments that present a blue-violet hue by a previous work [12].

Figure 7. Application of pigments: *a-b)* blue and orange pigment applied directly on the ceramic surface; *c)* white pigment applied on the ground (OM).

Table 1. Significant examples of XRF results for the identification of pigments with high counts of lead, in bold are the main detected element (chromophore).

Sample	Colour	Detected elements (%)										
		K	Ca	Ti	V	Mn	Fe	Cu	Zn	Sr	Zr	Pb
Museo 03	Dark red	0.9	18.9	0.6	0.3	0.9	**72.2**	0.4	0.9	0.8	0.3	3.8
Museo 06		0.6	10.4	0.6	0.1	0.7	**83.8**	0.1	0.9	0.4	0.2	2.2
Museo 07		0.4	8.6	0.6	n.d.	1.1	**85.8**	0.2	0.8	0.6	0.2	1.8
Museo 22		0.5	7.5	0.5	0.4	1.0	**86.8**	0.3	0.3	0.5	0.2	2.0
Museo24		0.5	11.3	0.5	2.4	0.7	**59.9**	0.4	0.8	0.7	n.d.	22.8
Museo 25		0.5	6.9	0.5	0.2	0.7	**85.3**	0.5	0.9	0.3	n.d.	4.2
Cer_07	Yellow	1.7	33.6	0.5	n.d.	1.0	**57.8**	0.6	0.3	0.8	n.d.	3.7
Museo 27		1.5	28.5	1.4	0.2	1.2	**63.8**	0.3	0.4	1.5	0.4	0.8
Museo 28		0.4	6.7	0.4	0.1	0.8	**89.7**	0.1	0.4	0.5	0.2	0.7
Museo 32		1.4	11.7	1.1	0.1	1.1	**81.7**	0.1	0.5	0.9	0.2	1.2
Museo 34		1.0	12.7	0.8	n.d.	1.1	**81.7**	0.3	0.6	0.8	0.2	0.8
Museo 31		0.9	10.0	1.0	5.9	0.9	**46.9**	0.2	0.6	0.9	0.2	32.6
Museo 37		0.4	9.4	0.7	7.7	0.9	**42.5**	0.2	0.5	0.7	0.2	36.8
Cer_4	Orange	1.5	25.3	1.0	0.4	1.1	**37.2**	0.2	0.4	1.4	n.d.	**31.5**
Museo 19		n.d.	4.1	0.3	0.6	0.4	16.2	0.5	0.2	0.2	n.d.	**77.5**
Museo 36		0.2	7.6	0.2	1.6	0.2	8.1	0.4	0.2	n.d.	n.d.	**81.5**

Table 2. Significant examples of XRF results for the identification of pigments on blue colours, in bold is the chromophore element. The results are reported as relative percentages (%).

Sample	Detected elements (%)										
	K	Ca	Ti	V	Mn	Fe	Cu	Zn	Sr	Zr	Pb
Cer_3	0.8	18.3	0.2	n.d.	0.5	17.5	**59.9**	0.3	0.7	n.d.	1.8
Museo02	0.4	8.8	0.2	0.1	0.2	10.2	**77.9**	0.3	0.5	0.2	1.2
Museo23	1.2	20.4	0.8	n.d.	1.1	**43.4**	**30.1**	0.4	1.4	0.5	0.7
Museo35	0.8	23.2	0.5	0.2	0.7	**27.0**	**44.8**	0.4	0.9	0.2	1.3
Museo38	1.2	19.4	1.0	0.2	0.9	**41.8**	**35.1**	0.4	n.d.	n.d.	n.d.
Museo08	1.7	**30.5**	0.9	0.2	1.4	**47.6**	**15.5**	0.3	1.1	0.3	0.5
Museo14	1.4	**20.6**	1.3	0.3	1.2	**42.7**	**30.0**	0.4	1.1	0.4	0.6

Table 3. Significant examples of XRF results for the identification of pigments on white and grey colours, in bold is the chromophore element. The results are reported as relative percentages (%).

Sample	Colour	Detected elements (%)										
		K	Ca	Ti	V	Mn	Fe	Cu	Zn	Sr	Zr	Pb
Cer_5	White	1.8	**57.1**	n.d.	0.9	n.d.	7.2	0.2	0.3	0.7	n.d.	**31.8**
Cer_6		1.6	**56.4**	n.d.	1.2	n.d.	5.6	0.4	0.6	0.8	n.d.	**33.4**
Museo20		1.6	**65.7**	n.d.	1.6	0.4	14.2	0.3	0.8	3.8	0.3	11.3
Museo05	Grey	0.4	4.3	0.4	0.2	0.8	33.3	0.4	0.3	0.5	n.d.	**59.4**
Museo12		0.7	12.7	0.9	6.0	1.0	43.1	0.4	0.4	1.0	n.d.	33.8
Museo33		0.3	7.6	0.5	0.4	0.5	24.0	0.3	0.5	0.5	n.d.	**65.4**
Museo16	White-yellow	1.3	16.2	1.2	1.9	1.4	**60.3**	0.4	0.5	1.1	0.4	15.3
Museo17	White-red	0.8	11.3	1.0	1.8	1.4	**72.8**	0.9	0.5	1.0	0.3	8.2

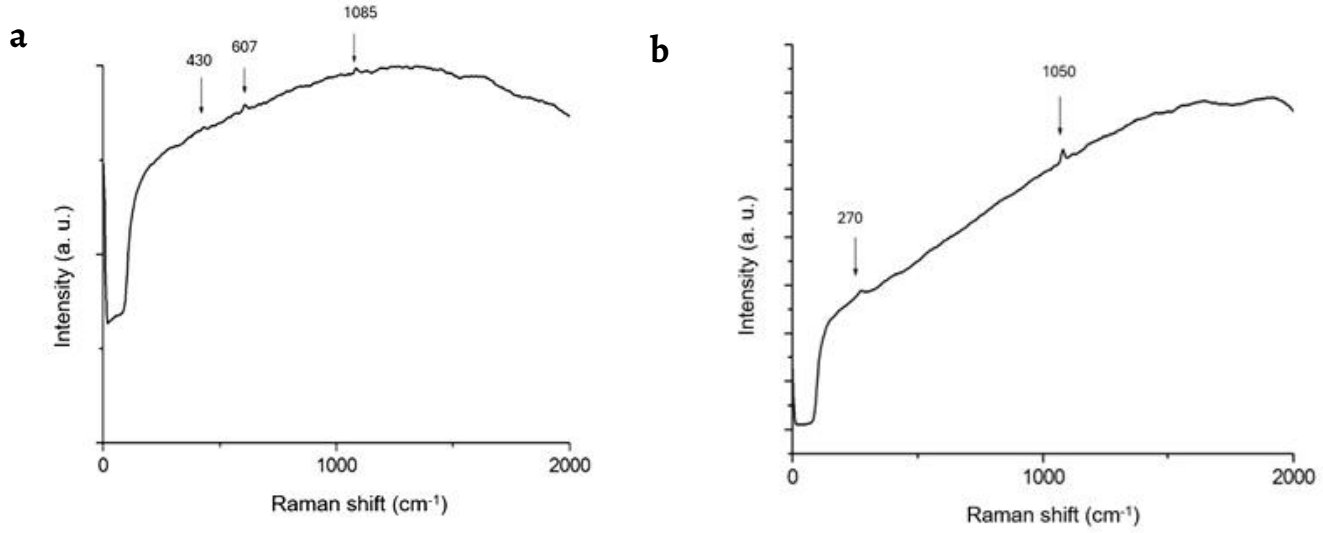

Figure 8. Raman spectrum of the: *a)* blue layer; *b)* white layer.

Finally, XRF analysis revealed that calcium is the main elements for the pure white layers, while the grey hues are enriched in lead. For the white-yellow and red, iron was detected suggesting the use or a contamination from ochres (Table 3). Raman spectroscopy reveals mainly the peaks at 271 and 1080 cm^{-1} (Figure 8b) related to calcium carbonate [13]. This aspect could indicate that the lead white may have been used as preparatory layer.

The white-grey colour is the result of the darkening of an originally white surface due to the burial environment or the degradation of Pb layers. XRD examination performed in a previous work [12] confirmed the presence of PbS (galena) according to the chemical reaction: $PbCO_3{\cdot}Pb(OH)_2 + H_2S \rightarrow PbS + CO_2 + H_2$ and calcite ($CaCO_3$) due to the surface preparation [15].

Conclusion

Over the years, we have studied some Campana plaques, mainly in fragments, using non-invasive techniques such as X-ray fluorescence analysis and Raman spectroscopy. The number of examples, the repetition of the analysis and the consistency of the results reinforce some of our points.

The slabs are decorated with natural and synthetic pigments typical of the colour palette of Roman architecture; the red and yellow colours are characterised by ochre, the white pigments are calcium-based compounds and lead white, the orange is minium, the blue is Egyptian blue, and the grey hues are the darkening of lead white.

Figure 9. Virtual restoration examples of Palatine plates: *a)* canefore on the sides of a *tymiaterion*; *b)* girls decorating a betilo; *c)* the tripod dispute (1- real plate, 2 - integrative virtual restoration, 3 - coloured virtual restoration).

The painting technique used on the panels is similar to mural painting, in both cases using calcium compounds or organic compounds as binders. We can confirm that all the panels were painted by looking at the traces of Egyptian blue found on fragments with no visible traces of paint [12].

Less certain is the distribution of colour on the various elements of the decoration: as seen in the discussion, we cannot assumed today that a paint without traces is present, despite the general rules

To advance the study, we have attempted a virtual restoration of the images of the Palatine panels available to us (made by ourselves or found online). We first restored all or part of the plate with the missing parts and then applied the colours based on the traces of pigment left on the plates or fragments of the same theme. Where no traces of pigment are visible, we did not apply any paint in view of the limitations just pointed out in our reconstruction. Figure 9 shows our results.

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REFERENCES

1. Gaultier, F.; Haumesser, L.; Trofimova, A. A., *Un rêve d'Italie: la collection du marquis Campana*,exibition catalogue, Louvre éditons, Parigi (2018).
2. Rohden, H. von; Winnefeld, H., *Architektonische Römische tonreliefs der Kaiserzeit*, W. Spemann, Berlin (1911).
3. Siebert, A.V., *Geschichte(n) in ton, Römische Arkitekturterrakotten*, Schnell und Steiner, Regensburg (2011).
4. Strazzulla, M. J., 'Le lastre Campana: considerazioni conclusive', in *Museo e territorio*, atti del V convegno, eds. M.Angle & A. Germano, Bonsignori, Roma (2007) 155-161.
5. Tortorella, S., 'Introduzione', in *Museo e territorio*, atti del V convegno, eds. M. Angle & A. Germano, Bonsignori, Roma (2007) 13-19.
6. Michałowska, K., 'A digital reconstruction of Roman terracotta reliefs: recreating the ancient technique', *Światowit: rocznik poświęcony archeologii przeddziejowej i badaniom pierwotnej kultury polskiej i słowiańskiej* **12**(53)/A (2014) 39-52.
7. Rescigno, C.; Sampaolo, V., 'Appunti sull'impiego del colore sulle terrecotte architettoniche capuane', *Meditterranea* **II** (2005) 133-163.
8. Brinkmann, V., 'La sobria policromia delle sculture del Partenone', in *I colori del bianco, policromia nella scultura antica*, ed. P. Liverani, Musei Vaticani, Roma (2005) 151-156.
9. Pensabene, P., *Scavi del Palatino II: culti, architettura e decorazioni*, L'erma di Bretschneider, Roma (2017).
10. Walter-Karydi, E., 'Il colore nello sfondo nei rilievi nella scultura arcaica e classica', in *I colori del bianco, policromia nella scultura antica*, ed. P. Liverani, Musei Vaticani, Roma (2005) 225-234).
11. Liverani, P., 'Per una «Storia del colore». La scultura policroma romana, un bilancio e qualche prospettiva', in *Diversamente bianco, la policromia della scultura romana*, eds. P. Liverani & U. Santamaria, Edizioni Quasar, Roma (2014) 9-32.
12. Tarquini, O.; Pronti, L.; Lorenzetti, E. G.; Felici, A. C., 'Pigment identification on Campana reliefs from the Palatine Hill and Colosseum Valley in Rome', *Journal of Cultural Heritage* **43** (2020) 294-302, https://doi.org/10.1016/j.culher.2019.07.026.
13. Caggiani, M. C.; Cosentino, A.; Mangone, A., 'Pigments Checker version 3.0, a handy set for conservation scientists: a free online Raman spectra database', *Microchemical Journal* **126** (2016) 123-132, http://doi.org/10.1016/j.microc.2016.06.020.
14. Caggiani, M. C.; Colombana, P., 'Testing of Raman spectroscopy as a non-invasive tool for the investigation of glass-protected pastels', *Journal of Raman Spectroscopy* **42**(4) (2011) 790-798, https://doi.org/10.1002/jrs.2740.
15. Goltz, D.; McClelland, J.; Schellenberg, A.; Attas, M.; Cloutis, E.; Collins, C., 'Spectroscopic studies on the darkening of lead white', *Applied Spectroscopy* **57**(11) (2003) 1393-1398, http://dx.doi.org/10.1366/000370203322554563.

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