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IMAGING-BASED RESEARCH ON 20TH-CENTURY PORTUGUESE MURAL PAINTING: MATERIALS, TRANSFER TECHNIQUES AND PICTORIAL EXECUTION IN ALMADA NEGREIROS'S 1945 AND 1949 MURALS

Milene GIL[1,2*], Luís DIAS[1], Mafalda COSTA[1], Sara VALADAS[1], Inês CARDOSO[3], Peter VANDENABEELE[4], Ana MANHITA[1], Marcus ANDRADE[5], Cristina DIAS[1]

[1]HERCULES Laboratory and IN2PAST Associate Laboratory, Institute for Advanced Studies and Research, University of Évora, Palácio do Vimioso, Largo Marquês de Marialva, 7000-809 Évora, Portugal;
[2] City University of Macau Chair in Sustainable Heritage and Institute for Advanced Studies and Research, University of Évora, 7000-809 Évora, Portugal
[3] Museus e Monumentos de Portugal E.P.E.-Laboratório José de Figueiredo, R. das Janelas Verdes, 1249-018 Lisboa, Portugal
[4] Raman Spectroscopy Research Group, Department of Chemistry, Ghent University, Campus Stere, Ghent, Belgium
[5] Universidade Federal de Minas Gerais, Brasil

Abstract

This paper presents the first imaging-based comparative study of the mural paintings created by Almada Negreiros in 1945 and 1949 for Lisbon's Maritime Stations, two major ensembles of twentieth-century mural painting. Although both cycles are officially documented as fresco paintings, their visual appearance differs. The central question was whether the differences are merely stylistic or whether they also correspond to distinct technical and material choices. The research was centred on an on-site imaging and analytical protocol integrating technical photography (Vis, Vis-Rak, and UVF), colorimetry, handheld optical microscopy (h-OM), and handheld energy-dispersive X-ray fluorescence (h-EDXRF). Targeted laboratory analysis of selected micro-samples from mortars and paint layers was carried out using 3D and 2D OM, VP-SEM-EDS, XRD, µ-Raman, and Py-GC/MS, allowing more in-depth stratigraphic, colorant, and binder analysis. The results suggest that the differences between the two mural ensembles are not primarily related to the materials used by Almada Negreiros in the plasters and paint layers. Rather, they appear to concern technical procedures, color distribution, and the differentiated working of the painted surface during execution. This is particularly evident in the transfer of the full-scale drawings to the wall, involving variations between traditional and innovative pouncing techniques. The pigment range appears broadly similar in both cycles, combining traditional earth pigments and modern synthetic colors, but their use and chromatic impact differ significantly. Visible raking light imaging was particularly useful for revealing differences in the paint surface appearance, from the pressed ground-colour surface in the 1945 murals to the more textured surfaces with visible brushwork in the 1949 cycle.

Keywords*: Modern Mural Paintings; Almada Negreiros, Technical photography, h-OM, h-EDXRF, VP-SEM-EDS, µ-Raman, Py-GC/MS*

Introduction

Historical Context and Research Question

Almada Negreiros' mural paintings at the Lisbon maritime stations form part of a broader body of mural work produced in Portugal between 1938 and 1956 by one of the leading figures

* Corresponding author: milenegil@uevora.pt

of Portuguese modernism [1], [2]. These works have been studied within the project *ALMADA: Unveiling the Mural Painting Art of Almada Negreiros (1938–1956)*, a four-year transdisciplinary academic research project devoted to the systematic study of the five mural painting ensembles created by the artist in Lisbon during this period [3].

Within this corpus, the paintings at the two maritime stations on Lisbon's riverfront occupy a particularly significant position owing to their number, scale, and artistic and cultural relevance (Fig. 1). The Alcântara murals were painted in 1945, while those at Rocha do Conde de Óbidos were completed in 1949. Together, they comprise fourteen monumental mural paintings referred to as frescoes in the official documentation [4], [5]. Despite their chronological proximity, their shared architectural and port context, and their common technical classification, the two ensembles differ markedly not only in style but also in visual appearance, particularly when examined at close range from scaffolding. These differences, observed during the 2021 and 2022 fieldwork campaigns, raised the central question of the present study: whether the visible distinctions between the Alcântara and Rocha murals are solely stylistic, or whether they also correspond to differences in the materials used, the pictorial techniques employed, and the ways in which these elements were combined and handled in the painting process.

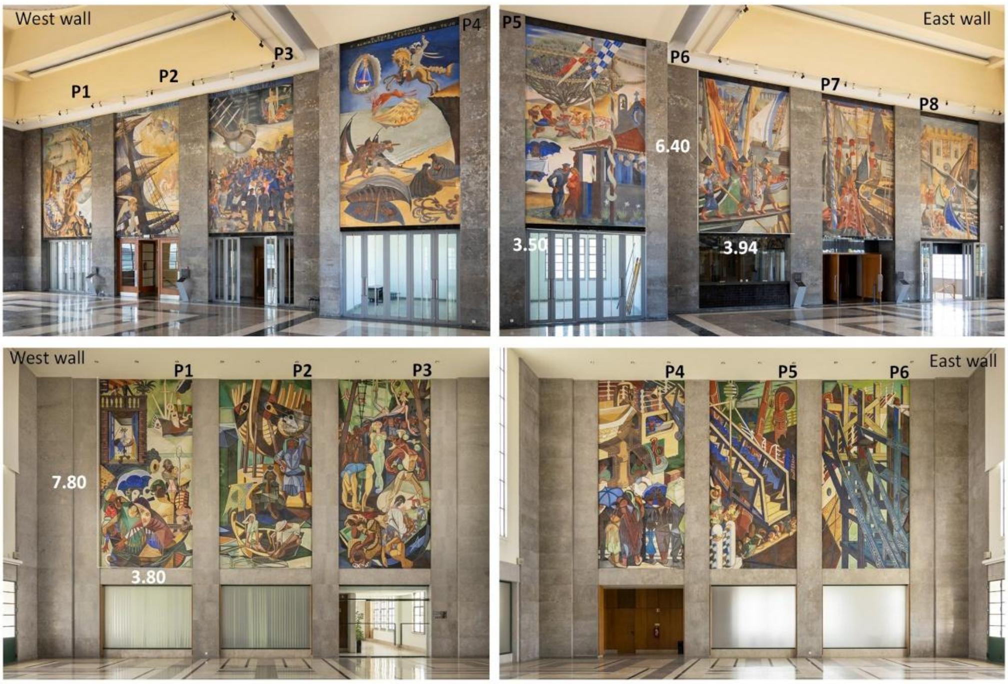

Fig. 1. Overview of the two ensembles painted on the west and east walls of the Lisbon maritime stations: Alcântara, above, and Rocha do Conde de Óbidos, below, with an indication of the dimensions of the murals in metres. The numbering of the paintings follows the official leaflets of Lisbon Port Administration and was adopted here for identification purposes [25]. Photographs by Manuel Ribeiro, 2021 and 2022.

This question is particularly relevant to the field of technical art history because Almada Negreiros was a self-taught artist who worked largely alone, occasionally with a single assistant on site (Fig. 2). He left no pupils through whom his technical knowledge could be transmitted, and no known written records by the artist explain his training, artistic sources, choice of materials, or procedures when painting on walls. In the absence of such direct technical evidence, the present research relied on photographic and documentary sources [4]-[13], on-site observation, technical imaging, material analysis, and painting materials identified in Almada's studio and in other almada painting sets by the artist [3], [14], [15], [16].

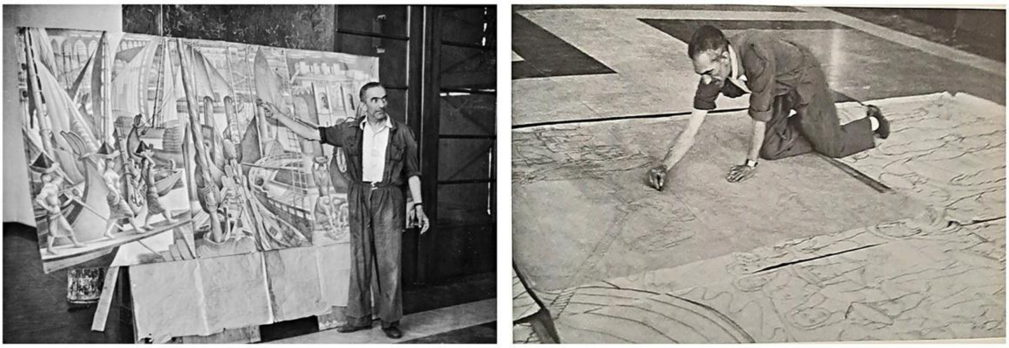

Fig. 2. Historical photographs showing two moments in the execution of the mural paintings at Alcântara maritime station in 1945: left, Almada Negreiros presenting the final color sketches for murals P6 to P8; right, the artist tracing the composition from the full-scale drawings onto tracing paper. Image sources: ANSA-F-247, CEDANSA - NOVA FCSH / © Estate of José de Almada Negreiros and reference [10]

The research was also informed by earlier conservation documentation. The first warnings concerning the state of conservation of the Alcântara murals date from 1956, while those relating to the Rocha do Conde de Óbidos murals date from 1964, eleven and fifteen years after their completion [2]. Reports drawn up in the 1970s by teams from the former Instituto José de Figueiredo (now the Laboratorio José de Figueiredo) identified vulnerabilities in the materials and techniques used in Almada's mural painting, noting variations in pigment quality, an imbalance in the pigment-to-binder ratio, and the use of organic water-soluble binders [17], [18]. Written in the context of the first restoration campaigns carried out at both stations, these reports documented deterioration features such as flaking and powdering paint layers, as well as salt-related deterioration, which were also identified in 2021 and 2022 and studied within the framework of project ALMADA [19]-[22].

In 1971, technical reports from the former Instituto José de Figueiredo (IJF) also recorded adhesion tests on-site using acrylic- and polyvinyl alcohol-based adhesives (Paraloid, Mowiol B80, and Gelvatol) [17], [18], [23]. Both maritime station ensembles underwent two conservation and restoration interventions during the 1970s. The first and most extensive intervention took place between May and June 1971, one year after the artist's death, and has encompassed the painted surfaces as a whole. Its primary aim was the consolidation of unstable paint layers. In 1979, more localized restoration campaigns were carried out to address the recurrence of similar deterioration phenomena. The treatment methodology appears to have been broadly similar in both campaigns, involving the application of the synthetic adhesives Mowiol B80 and Gelvatol by nebulization to powdering paint layers, followed by the setting down of flaking areas with Melinex paper. Casein tempera and oils were also used as retouching materials. Although oils were not mentioned in oral testimony, they were identified at Rocha do Conde de Óbidos in retouched paint layers in 2023 [24]. Understanding the conservation history of these murals was essential to the present study, since the materials used in later restoration treatments increased the complexity of interpreting technical and material evidence. In the absence of past mapping documentation, distinguishing between original materials and later additions constituted a key challenge in the technical study of Almada's mural paintings.

Some notes on the paintings and their commissions

Both painting ensembles were state commissions produced during the Portuguese dictatorial regime, at a time when public art was actively promoted as part of the regime's cultural and ideological programme [2], [26]. Although Almada Negreiros worked within this institutional framework, he remained a critical and highly individual artistic figure whose work did not always conform to the representational conventions favored by official culture. The murals at the Lisbon Maritime Stations are particularly revealing in this respect. Rather than adopting the heroic nationalist imagery found in other Portuguese public buildings of the period, such as the mural programs of the Assembly of the Republic and the National Library [26m], [27], Almada developed compositions centred on popular narratives, everyday labor, and human experience [28].

In both maritime stations, the paintings were executed on the east and west walls of the boarding hall on the first floor. At Alcântara, the iconographic programme includes the legend of the *Nau Catrineta* and scenes of everyday life involving ordinary people in village and riverside settings. At Rocha do Conde de Óbidos, Almada extended this engagement with life along the riverfront, introducing a broader reflection on migration and the human condition (Fig. 1).

The two ensembles also differ markedly in formal terms. In the Alcântara murals, the representation remains broadly figurative and is characterized by a dense decorative quality, with figures whose stylisation recalls, in certain respects, Portinari's social figuration, particulary in the rendering of hands and feet [29]. In the Rocha murals, by contrast, Almada adopted a more stylized visual language, informed by Cubist principles, in which forms and colours are simplified and no longer treated naturalistically [30].

The commissioning of both mural ensembles extended over several years. The Alcântara commission unfolded between 1943 and 1945, whereas that of Rocha do Conde de Óbidos developed between 1946 and 1949, as recorded in the dates inscribed at the base of the paintings. In both cases, the murals were executed only after the maritime stations had already been inaugurated and opened to the public. To date, only the contract relating to the Rocha commission has been located, in the archival holdings of the Forte de Sacavém, which preserves documentation from the former Direção-Geral dos Edifícios e Monumentos Nacionais (DGEMN; Directorate-General for National Buildings and Monuments), the former state body responsible for public buildings and national monuments from 1929 onwards. Comprising approximately eighty typed and handwritten pages, these documents records the complex and, at times, contentious history of the painting commission and its artistic programme [4]-[9]. Together with information gathered from other documentary sources, including contemporary newspapers [10], [11], [13] and the published testimony of the artist's wife, Sarah Affonso [12], it provides a broader understanding of the progress of the work, its constraints, and Almada's working timetable. These sources indicate that, in both commissions, the artist spent more than two years in his studio developing the preparatory sketches and producing the final full-scale drawings, which were subsequently traced and transferred to the walls, as shown in Figure 2.

According to these documents, the on-site painting of the murals was considerably faster. At Alcântara, Almada took approximately sixty-four days to complete the eight mural paintings, beginning in mid-April and finishing in July 1945 [10], [12]. According to Sarah Affonso, he spent eight days on each painting and rested for one week between murals, a rhythm she associated with the physical demands of the work, which could require the fifty-two-year-old artist to paint for up to sixteen hours a day [11], [12]. At Rocha do Conde de Óbidos, according to an interview given by the artist in 1950, the six paintings were executed in twenty-nine days [13], while archival documentation records an extension of the deadline for completion until the end of November 1949 [8]. Documentary references to the materials used are scarce. In the Rocha contract, the only explicit references concern the gouache, temperas, and glues to be used in the studio and, for the on-site execution, lime, sand, and earth pigments [9]. For the Alcântara murals, the preparation of the plaster supports appears to have been the artist's financial responsibility. At Rocha do Conde de Óbidos, following some discussion, the cost of preparing the plasters was assumed by the DGEMN, with Almada supervising the work carried out by the masons [7].

Experimental methodology

The present research followed a three-phase workflow combining documentary analysis (Phase 1), on-site visual examination and non-invasive analysis (Phase 2), and laboratory-based microanalytical study of selected micro-samples (Phase 3). This approach enabled the two mural ensembles to be compared in terms of execution procedures, colour, the handling of the painted surface, and material composition. The equipment and experimental conditions used in phases 2 and 3 followed those reported in previous studies [14], [15], [16], [19]-[24] and are detailed in Table 1.

Table 1. Equipment and experimental conditions used in Phases 2 and 3 of the methodological workflow.

Method	Equipment and experimental conditions
Phase 2	**In situ examination and non-invasive analysis**
Preliminary general and macro photography	Samsung Galaxy A52 and Canon EOS 800D with Sigma DC 17–70 mm f/2.8–4 Macro HSM lens; natural daylight from nearby windows
Visible photography (Vis)	Nikon D3200 24 MP DSLR camera with Nikkor 18–55 mm f/3.5–5.6 GII ED lens; halogen lamps, 1000 W–230 V D58525 (OSRAM GmbH, Augsburg, Germany).
Visible raking light photography (Vis-Rak)	Nikon D3200 24 MP DSLR camera, raking light at 15–20° from the painted surface, from eight different directions.
Ultraviolet-induced visible fluorescence (UVF)	Nikon D3200 24 MP DSLR camera with Nikkor 18–55 mm f/3.5–5.6 GII ED lens; Labino RMPXL UV PS135 light source, 35 W PS135UV midlight, 230 V (Labino AB, Vallentuna, Sweden); UV filter, 310–400 nm, peak at 365 nm; midlight distribution angle of 20°; and start-up time of 5–15 s to reach full power.
Image acquisition and calibration	Images were acquired in JPEG and RAW formats; the QPCard 101 target was used for white balance, and the AIC PhD color chart was used for UVF calibration.
Handheld optical microscopy (h-OM)	Dino-Lite Premier AD3713TB and PRO AM413T-FVW digital microscopes (AnMo Electronics Corporation, New Taipei City, Taiwan); 20× and 430× magnifications.
Colorimetry	Datacolor CheckPlusII spectrophotometer (Lawrenceville, NJ), equipped with integrating sphere, diffuse illumination/8° viewing geometry according to CIE Publication No. 15.2; SCE mode; D65/10° standard illuminant/observer; USAV aperture Ø 5 mm and UXAV aperture Ø 2.5 mm; three measurements per point
Handheld energy-dispersive X-ray fluorescence (h-EDXRF)	Bruker Tracer III SD handheld XRF spectrometer (Bruker, Germany); Rh target; polychromatic X-ray beam of 3 × 3 mm; XFlash silicon drift detector; 40 kV, 30 µA; real acquisition time of 30 s; spectra recorded with S1PXRF and processed with Artax software; net areas of fluorescence lines normalized to the Rh Kα lines.
Phase 3	**Laboratory-based microanalytical study**
Cross-section preparation	Cross-sections embedded in epoxy resin, Epofix (Struers, Ballerup, Denmark), and polished with Micro-Mesh sanding sheets (GC Abrasives Ltd., Darlington, UK).
3D and 2D optical microscopy (2D and 3D-OM)	HRX-01 HIROX digital microscope equipped with a 5 MP sensor suitable for 4K resolution and motorised HR lenses; HR-5000E lens; microfragments observed as collected at 140×, 200×, 400×, 800×, and 2000× magnifications; Leica DM2500M reflected-light optical microscope; dark-field illumination mode; 100×, 200×, and 500× magnifications; images acquired in visible and ultraviolet modes with a Leica MC 170HD digital camera; UV imaging with a high-pressure 103 W/2 UV lamp, BP 340–380 excitation filter, 400 dichroic mirror, and LP425 suppression filter
X-ray diffraction (XRD)	Bruker D8 Discover diffractometer; Cu Kα radiation; plaster samples from the inner layer (arriccio) and finishing layer (intonaco); 3°–75° 2θ; 1 s per step; 40 kV and 40 mA.
Variable-pressure electronic microscopy (VP-SEM-EDS)	Hitachi S-3700N SEM coupled with Bruker XFlash 5010 silicon drift detector; detector resolution of 123 eV at Mn Kα; BSE mode; 20 kV; 40 Pa chamber pressure; uncoated samples; point/area analyses, elemental maps, and semi-quantification processed with Bruker ESPRIT compact software, version 2.3.1.1019.
Micro-Raman spectroscopy (µ-Raman)	The Senterra R200-L confocal Raman spectrometer at HERCULES Laboratory, with 785 nm diode and 532 nm Nd:YAG lasers, an Olympus microscope, and a thermoelectrically cooled CCD detector. Complementary analyses at Ghent University with a Senterra dispersive Raman spectrometer (Bruker, Ettlingen, Germany), 785 nm and 532 nm lasers, an Olympus microscope with 5×, 20×, 50×, and 100× objectives, and an XYZ motorized stage. Laser intensity is controlled by neutral-density filters and typically set at 0.5 mW for the green laser and 1.8 mW for the red laser; the CCD detector is cooled to -65°C; spectral resolution is 3–5 cm^{-1}; the system is controlled with OPUS software; offline processing is done in-house with RamSpec software written in Matlab.
Pyrolysis–gas chromatography–mass spectrometry (Py-GC/MS)	Frontier Lab PY-3030D double-shot pyrolyzer coupled to a Shimadzu GC-2010 gas chromatograph and Shimadzu GCMS-QP2010 Plus mass spectrometer; pyrolysis interface at 280°C; Phenomenex Zebron ZB-5HT capillary column; helium carrier gas at 1.5 mL min^{-1}; acquisition between m/z 40 and 1090; samples <200 µg derivatized with 3 µL tetramethylammonium hydroxide, 2.5% in methanol v/v, in a 50 µL Eco-cup capsule and pyrolyzed at 500°C; compounds identified using AMDIS software integrated with the NIST-Wiley database.

Documentary Research (Phase 1)

Documentary research focused on family archival sources, contracts relating to the artistic commissions, conservation and restoration reports from the former Instituto José de Figueiredo (IJF), photographic records, and contemporary newspaper references published between 1945 and 1950 [4]-[13], [17], [18]. Particular attention was given to a mural painting manual found in the artist's studio, Costin Petresco's *L'art de la Fresque*, which provided technical references for comparison with the material and procedural evidence observed in the murals [31]. Together, these sources established the historical and technical framework of the study.

In situ examination and non-invasive analysis (Phase 2)

All fourteen murals were first visually examined and photographed in the visible range, including general and detailed photographs, with complementary raking light photography where necessary. Given the scale of the corpus and the project timetable, this preliminary survey enabled the selection of six murals, three from each station, for detailed on-site and laboratory-based analytical study: P3, P5, and P8 from Alcântara; and P1, P3, and P6 from Rocha do Conde de Óbidos. These paintings were considered representative of the range and variation of the color palette used in the two ensembles, as well as of the specific technical features observed on their painted surfaces (Fig. 1).

The on-site protocol discussed in this paper combined technical photography in visible light (Vis), visible raking light (Vis-Rak), ultraviolet-induced visible fluorescence (UVF), handheld optical microscopy (h-OM), colorimetry, and handheld energy-dispersive X-ray fluorescence (h-EDXRF). These methods enabled the comparative study of surface morphology, chromatic variation, drawing-transfer evidence, texture, gloss, and elemental composition markers. They also supported the distinction between original materials and those related to past interventions.

Visible raking light (Vis-Rak) was central to the documentation of plaster patches, incisions, pouncing marks, smoothing and polishing marks, texture variations, and brushwork. In total, more than 800 images were acquired across the six selected panels and additional areas of interest in the remaining murals. Colorimetry was used to characterise the current chromatic range of the murals through the CIE L*a*b* color space. In total, 663 color measurements were carried out on light, mid-tone, and dark hues across the paint layers from 12 areas found representative of the color palette used by the artist. Handheld EDXRF was used in the same location to identify elements associated with specific pigments, including Fe, Cd, Cr, Cu, and As. The spectra were processed semi-quantitatively, with the net areas of the fluorescence lines normalized to the Rh $K\alpha$ line.

Based on the on-site results, selected micro-samples were collected from plasters and paint layers to address stratigraphic, technical, and material research questions that could not be resolved through the on-site analytical protocol alone. Figures 3, 4, and 10 show the locations of the twelve micro samples discussed in this paper. Most of them, with less than 0.5 mm in size, were collected near deterioration features, such as lacunae and fissures, from the edges of the paintings and from imprinted holes left by one of the drawing-transfer methods. The paint micro-samples were taken from the six murals selected from an in-depth stratigraphic and composition analysis. Additional samples were also collected from the remaining murals to complement the results (P4arr/int and P2_8).

Laboratory-based microanalytical study (Phase 3)

In Phase 3, the micro-samples were analyzed as microfragments and as cross-sections. Cross-sections were prepared by embedding the samples in epoxy resin and polishing them with Micro-Mesh sanding sheets. The analytical setup included 3D and 2D optical microscopy in the visible and ultraviolet, VP-SEM-EDS, XRD, μ-Raman, and Py-GC/MS. These techniques provided stratigraphic, mineralogical, elemental, and molecular data from selected areas, complementing the on-site evidence.

Results and discussion

This section presents the most representative results from the comparison between the two painting ensembles. The findings are organized into four subsections, reflecting the different stages in the execution of the paintings.

Plaster composition

The analytical study of the plasters used as pictorial supports in the two maritime stations revealed a comparable stratigraphic structure and material composition (Figs. 3 and 4). In both ensembles, the support consists of a two-layer plaster system composed of lime-based mortars with mineral aggregates, a construction sequence commonly associated with fresco painting. These layers are generally referred to by the Italian terms arriccio and intonaco: the former corresponds to the inner mortar layer used to level the masonry surface, while the latter forms the upper finishing layer and the direct support for the painting.

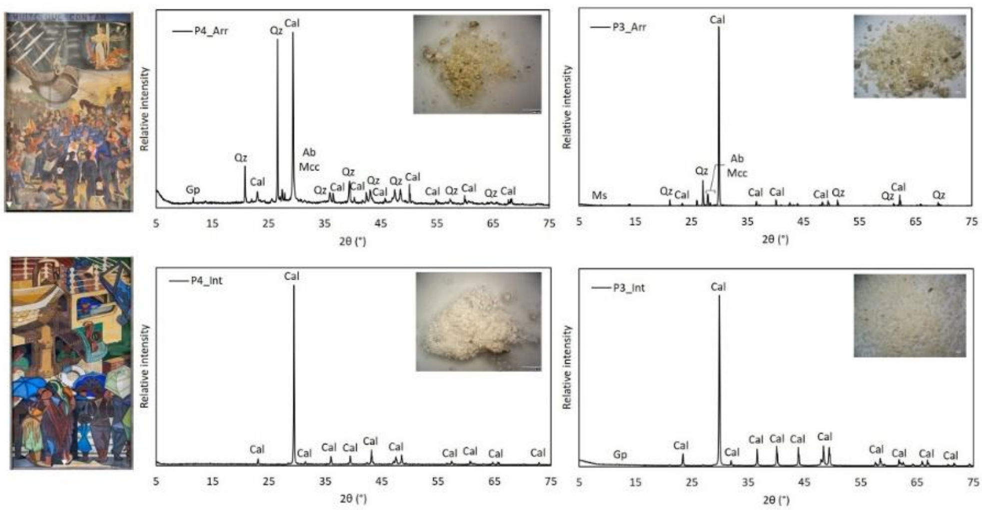

Fig. 3. From left to right: sampling areas for P4_Int and P4_Arr from the Rocha do Conde de Óbidos and for P3_Int and P3_Arr from the Alcântara maritime stations. The samples were collected from lacunae, approximately 1.5–3 cm long, located at the base of the corresponding murals. Representative XRD patterns of the four powdered plaster samples are shown. Abbreviations: Gp, gypsum; Qz, quartz; Cal, calcite; Ab, albite; Mcc, microcline

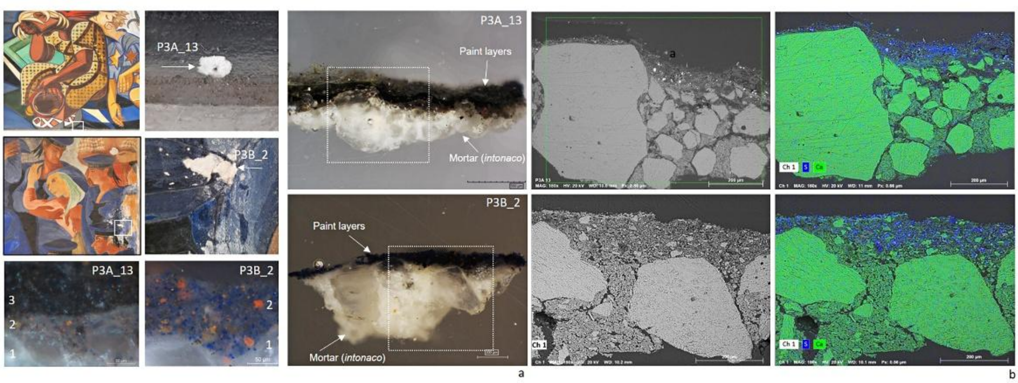

Fig. 4. From left to right: (a) sampling areas and optical microscopy images of cross-sections P3A_13 and P3B_2, collected respectively from a well-preserved paint layer and from a deteriorated area affected by salt formations, with indication of the visible layers: 1, intonaco; 2 and 3, paint layers; (b) areas analyzed by VP-SEM-EDS. VP-SEM and EDS elemental distribution maps of calcium (Ca) and sulfur (S), showing the presence of calcium in the intonaco, both in the binder and aggregate, and of sulfur only in the paint layers. The absence of a Ca crust in the interface intonaco-paint layer supports a fresco execution. EDS results are presented in Table 2.

The stratigraphy of this plaster system could be observed in lacunae located near the edges of the paintings, from which the four powdered samples shown in Figure 3 were collected for mineralogical analysis. In both stations, the inner layer appears brownish and more heterogeneous, corresponding to the arriccio samples P3_Arr and P4_Arr, whereas the upper layer is white and homogeneous, corresponding to the intonaco samples P3_Int and P4_Int. The small size and limited depth of the lacunae did not allow the thickness of the inner layer to be measured. The intonaco, however, ranges from 0.5 to 0.8-1.0 cm in thickness.

XRD analysis showed that the two arriccio samples contain calcite together with silica-rich sands and potassium- and sodium-bearing feldspars used as aggregates, namely microcline and albite (Fig. 3). Gypsum was detected only as a minor phase in sample P4_Arr, attributed to rainwater infiltration. The abundance of calcite indicates the use of calcitic air lime as a binder.

The intonaco samples consist almost exclusively of calcite, indicating a more carbonate-rich finishing mortar. This interpretation was further supported by VP-SEM-EDS analysis of the intonaco in cross-sections P3A_13 and P3B_2, which revealed fragments of crushed calcium carbonate, ranging from approximately 50 to 400 μm, embedded in a calcium-rich matrix (Fig. 4, Table 2). The size and distribution of these carbonate particles contributed to a degree of surface roughness, in contrast to the smoother intonaco finishes often sought through the use of finely crushed carbonate materials, such as marble powder, in both earlier fresco and 20th-century mural painting practices [33], [34].

The predominance of carbonate phases in both the binder and aggregate accounts for the white colour of these layers. No gypsum was identified in the intonaco samples. Sulphur was detected only in the paint layers, where it may be associated either with salt-related alteration products [19], [20] or with the sulphur-containing pigments, such as the ultramarine blue identified in P3B_2 and shown in Figure 4.

Transfer of the drawings to the walls

One of the most immediate technical differences observed between the two maritime station ensembles during close-range examination from scaffolding concerns the methods used by Almada Negreiros to transfer the full-scale drawings onto the wall surfaces (Figs. 2, 5 and 6).

At the Alcântara maritime station, the transfer marks preserved on the painted surfaces suggest the use of a traditional pounced drawing, combined with direct incisions, as the main method for transferring the composition to the wall. With the pouncing technique, the drawings are pricked on tracing paper and transferred to the wall by dabbing a gauze sachet filled with powdered pigment over the perforations, thereby recreating the outlines on the surface of the fresh intonaco. In some areas of the murals P6 and P8, the pouncing marks remain clearly visible on the painted surface (Fig. 5). Particularly noteworthy is the unusual presence of three closely spaced dots, rather than the single dot more commonly expected in pouncing, as well as the use of both black and red transfer pigments.

In the paint layers where the pouncing marks are still visible, the dotted outlines can also be seen to have been subsequently reinforced by incisions made directly into the plaster (Fig. 5). These incisions are clearly distinguishable on the painted surface under visible raking light. Variations in their morphology and depth appear to be related to the hydration state of the mortar at the time of execution, as well as to the specific tool used by the artist (probably the handle of a brush). This combined transfer method, already noted in Almada's earlier mural painting production of 1939 [16], is also supported by the testimony of his wife, Sarah Affonso, who assisted him in the preparatory stages of the work [12].

At the Rocha do Conde de Óbidos maritime station, the evidence preserved on the painted surfaces points to a different approach (Fig. 6). In this painting ensemble, the way in which Almada Negreiros transferred most of the full-scale drawings to the walls, as previously reported, appears particularly innovative [24]. Mural P1 is especially relevant in this respect, since it was in this painting that the artist changed his working method halfway through the work. Under visible raking light, the upper part of the mural reveals incised lines comparable to those observed at the Alcântara maritime station. From approximately the lower half onwards, however, Almada adopted a modified form of the pounced drawing technique.

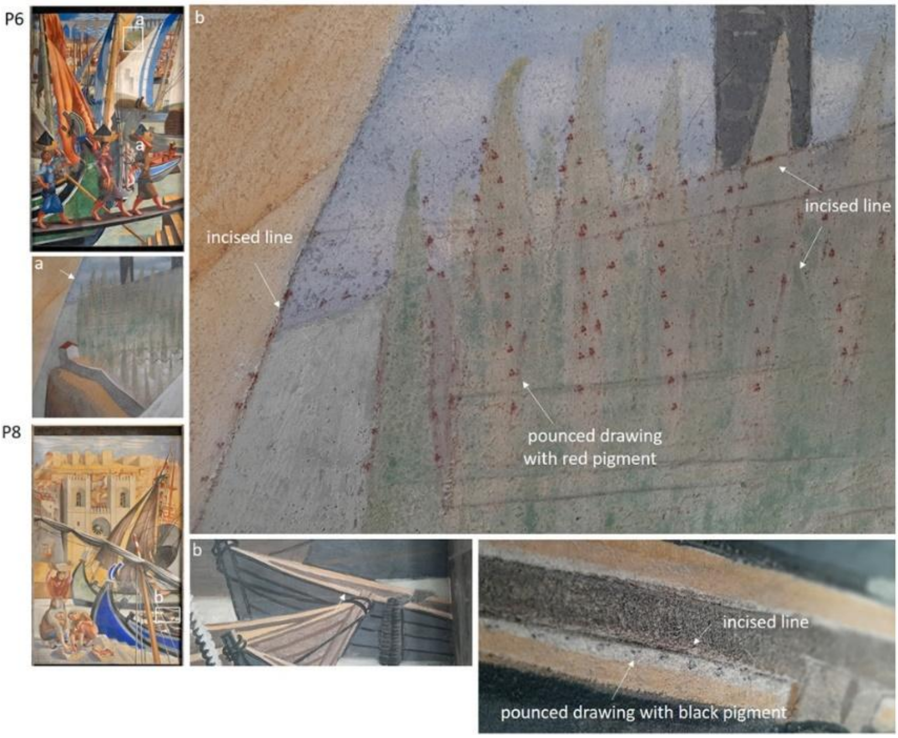

Fig. 5. Location and visible-light details of the pounced drawing technique combined with direct incisions, identified in murals P6 and P8 at the Alcântara maritime station. Photographs by Milene Gil, 2021.

Fig. 6. Location and visible-light detail of the incised pounced drawing in P1 at Rocha do Conde de Óbidos maritime station. Photographs by Milene Gil, 2022.

Rather than transferring the outlines of a previous pricked drawing by dabbing powdered pigment through the perforations, at Rocha do conde de Óbidos, the tracing paper was placed against the plaster, and the full-scale drawings were pricked directly through it onto the wet surface. The regularity of the resulting imprints, approximately 3 mm apart and 1 mm in diameter, strongly suggests that Almada used a tracing wheel (Fig. 6). This method left both imprinted holes and slight rounded grooves linking them, caused by the pressure exerted through the tracing paper by the round-type instrument used for the purpose. To date, no comparable examples of incised pouncing have been identified in Portuguese mural painting. Internationally, and to the best of the authors' knowledge, a similar procedure has only been reported in *The Massacre in the Main Temple*, painted in fresco by Jean Charlot in Mexico City in 1923 [32].

Colour palette and pigments

Colorimetric analysis provided the first objective assessment of the colour palette of both mural ensembles. Figure 7 shows the two-dimensional projections of the colorimetric coordinates in the CIE a*b*, CIE L*a*, and CIE L*b* color spaces for the paint layers analysed in P3, P5, and P8 from Alcântara and in P1, P3, and P6 from Rocha do Conde de Óbidos. Overall, the 663 measurements made extend from approximately −35 to +45 on the green-red a* axis, from about −65 to +35 on the blue-yellow b* axis, and from roughly 30 to 85 on the L* axis. These values show that Almada explored a broad range of hues and lightness levels, with marked tonal variation within the main chromatic domains.

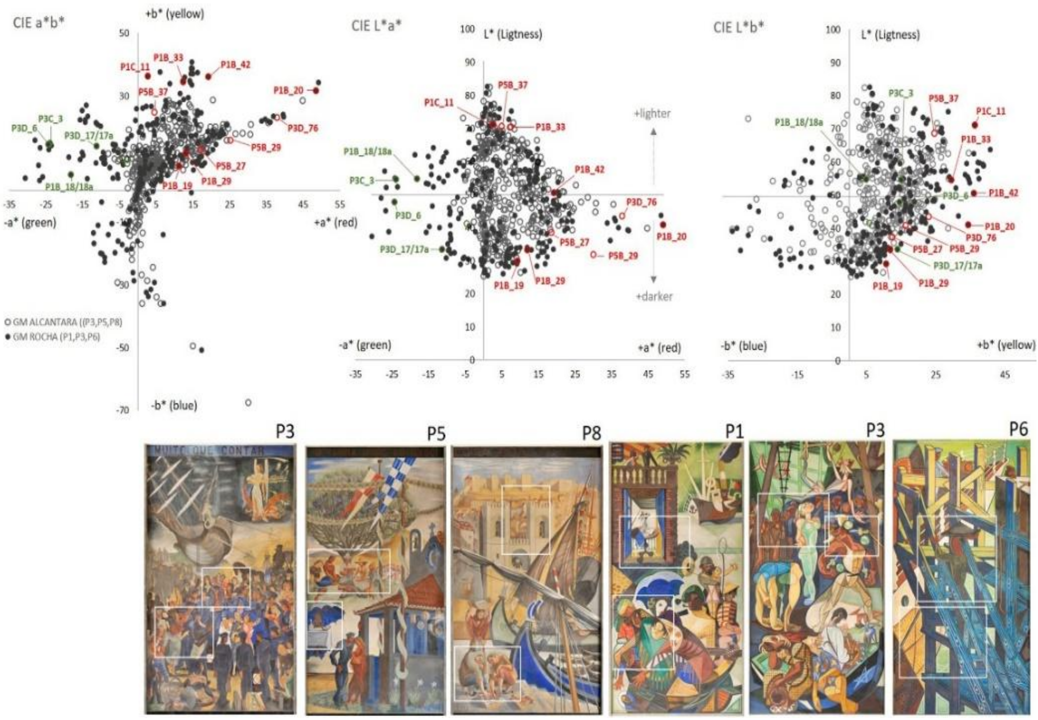

Fig. 7. 2D projections of colorimetric coordinates in the CIE a*b*, CIE L*a*, and CIE L*b* colour spaces of analysed paint layers in P3, P5, and P8 from Alcântara (empty circles) and P1, P3, and P6 from Rocha do Conde de Óbidos (black circles). The white squares indicate the areas selected for analysis as representative of the colour palette used by Almada. Red numbers refer to h-EDXRF analyses carried out in the yellow-red domains, shown in Figures 8 and 9, and the green numbers refer to micro-samples collected in green paint layers and analysed by Raman spectroscopy in Figure 10.

In the CIE a*b* projection, the two ensembles partly overlap but show different chromatic emphases. At Alcântara, the greatest hue variation is concentrated in the warmer region of the diagram, mainly in the +a*/+b* quadrant, extending from yellow to red through a wide range of orange and brownish tonalities. Most measurements fall between approximately +5 and +25 on the a* axis and between + 2 and +30 on the b* axis, although some red paint layers reach a* values close to +45, corresponding to bright red details such as the little girl's garment in P3D_76 (Figs. 7 and 8).

While the paintings at Alcântara are chromatically richer along the warm yellow-red axis, those from Rocha do Conde de Óbidos show greater dispersion towards negative a* values, with several green paint layers positioned between approximately −10 and −35. This distribution reveals a richer use and modulation of green hues in the 1949 painting ensemble, ranging from cooler green and blue-green tones to more yellowish greens. Measurements with negative b* values also indicate a higher contribution of blue-green tones. These results are consistent with previous observations on this ensemble, which highlighted the role of greens, blues and blue-greens across backgrounds and structural elements of the composition, contributing to the more vivid, less naturalistic colour scheme [30].

A first indication of differences in pigment composition was provided by UVF imaging (Fig. 8). As previously established in Almada's working palettes for the 1939 DN building murals, UVF proved particularly useful for distinguishing fluorescence responses in yellow, orange and red paint layers, some of which were subsequently associated with Cd-based pigments [15]. In the two mural ensembles, comparable fluorescence responses were observed in warm-coloured paint layers within the yellow-red range defined in the CIE a*b* projection in Figure 7, providing an initial indication of Cd-containing materials. This interpretation was supported by the h-EDXRF analyses carried out on the spots marked in Figure 8 and presented in Figure 9a-d.

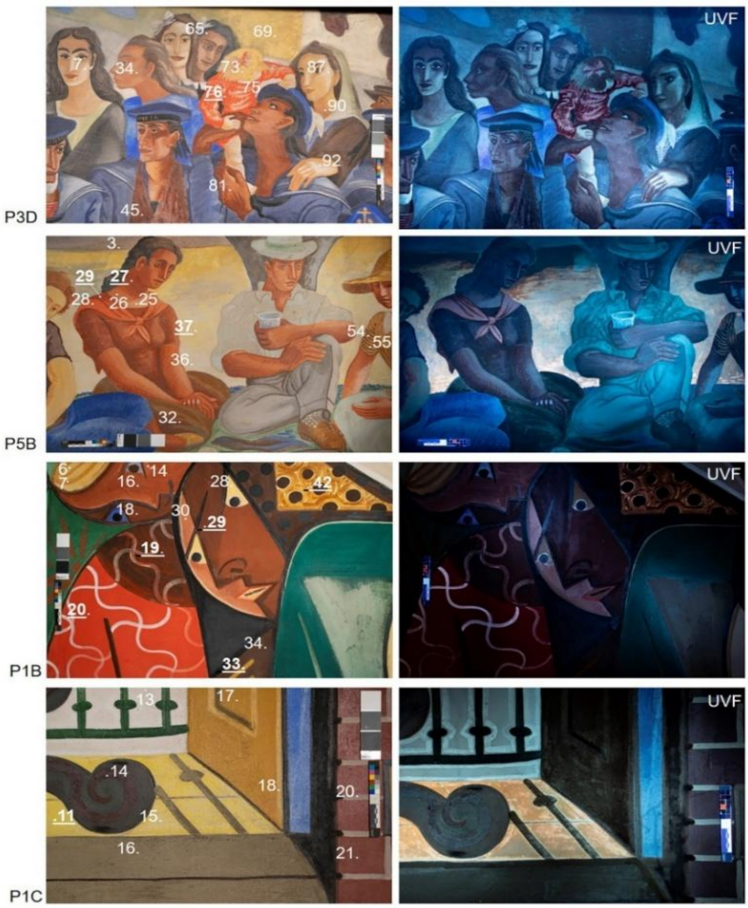

Fig. 8. Visible-light and UVF images of selected painted areas from Alcântara murals P3 and P5 and Rocha do Conde de Óbidos mural P1. The numbers indicate selected paint layers analysed by colorimetry and h-EDXRF; underlined numbers identify the layers highlighted in Figures 7 and 9. Photographs by Manuel Ribeiro, 2021 and 2022.

The Fe–Cd plot shows the predominance of Fe signals in most of the analysed paint layers within this chromatic range, confirming the recurrent use of Fe-rich pigments in both painting ensembles. The highest Fe signal intensities were recorded in the brownish layers P1B_33, P1B_29 and P1B_19 from Rocha do Conde de Óbidos, and in P5B_27 from Alcântara. The attribution of several of these Fe-rich layers to earth pigments is supported by their association with terrigenous elements, such as Si, Al, K and Mg, identified in the h-EDXRF spectra shown in Figure 9b–d.

Cd-based pigments were identified in selected layers within the same yellow-red colorimetric range. This is particularly evident in the bright red layer P1B_20 from Rocha do Conde de Óbidos, which shows the highest Cd contribution. Cd was also detected in other red and yellow layers from both mural ensembles, including P3D_76, P5B_29 and P5B_37 from Alcântara, and P1C_11 and P1B_42 from Rocha do Conde de Óbidos (Figs. 8 and 9a-d). Cadmium was identified either alone or in association with Se, supporting the use of cadmium sulphide and cadmium sulfoselenide pigments. The spectra further indicate that Cd-based pigments were used either as the main chromophore or in association with Fe-rich pigments, whether in mixtures or in superimposed paint layers.

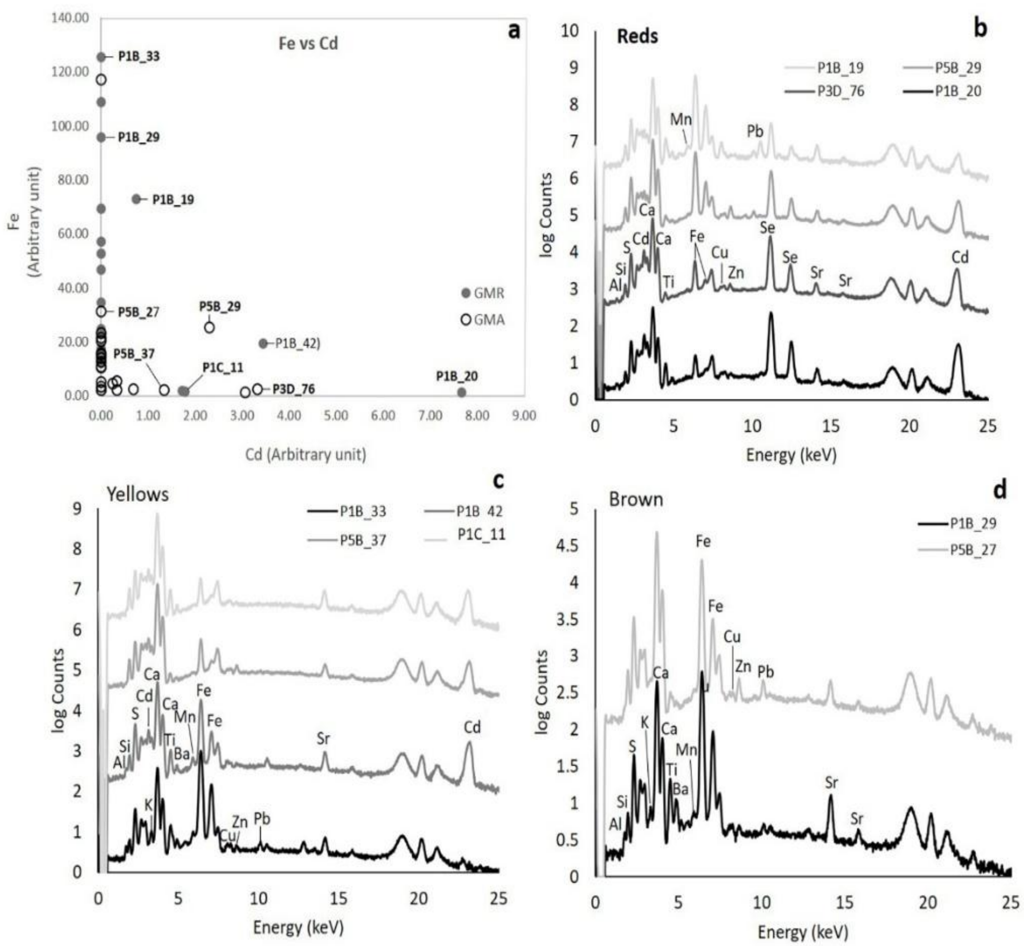

Fig. 9. h-EDXRF results for the numbered paint layers marked in Fig. 8. (a) Fe–Cd scatter plot of the analysed paint layers; (b–d) representative h-EDXRF spectra collected from red, yellow and brown paint layers.

Table 2 further confirms the recurrence, in both stations, of the same main pigment groups in the eight analysed cross-sections shown in Figures 4 and 10: Fe-rich pigments, Cd-based yellows and reds, ultramarine blue, carbon- or animal-black pigments, and calcium carbonate. The presence of modern synthetic pigments, particularly Cd-based pigments, is significant since the use of these materials in fresco painting was controversial, as previously reported [14], [15], [24]. A similar issue is raised by emerald green, first found in Alcântara and extensively used in Rocha do Conde de Óbidos together with Cr-based pigments. The analysis of the green paint layers was particularly challenging, both because of their material fragility and because elemental data alone were often insufficient for secure pigment discrimination. Raman spectroscopy was therefore decisive for their molecular identification, as demonstrated in 2024 for the Rocha murals [35]. Figure 11 presents four representative Raman spectra from that study, obtained from micro-samples collected from the four different green paint layers indicated in the CIE plots in Figure 7.

Table 2. Summary of OM-Vis and VP-SEM-EDS analyses of eight cross-sections from the Alcântara and Rocha do Conde de Óbidos murals, including sampling location, elemental composition of the mortars and paint layers, pigment attribution, and hypotheses on painting technique.

Location	Ref. Sample	Colour at the surface	Stratigraphy (number of layers and thickness)	VP-VP-SEM-EDS Mortar (at%)	VP-VP-SEM-EDS Paint layer (at%)	Pigment attribution (hypothesis)	Painting technique (based on Ca elemental map and EDS analysis)
Alcântara Maritime station							
sailer beret/costume	P3B_2	Dark blue	**Fig. 4** **2:** blue layer (≈ 39-104 µm) **1:** white mortar (intonaco)	Matrix: (*2): Ca (93.46), Na (2.01), Cl(1.40), Mg(0.83), S (0.79), Si(0.78), Al (0.73); (*3): Ca (100) Agrgegate (1*): Ca (100)	**2**: Ca (45.13), Si (15.89), Al (12.81), Na (12.04) S (8.85), Fe (2.21), K (1.84), Cl (1.22)	**2**: ultramarine blue (synthetic) + Fe based pigment (earth pigments)	Lime fresco
Background (edge of the painting)	P2_10	Dark purple	**Fig. 4** **2**: purple layer (≈ 231-307 µm) **1**: white mortar (intonaco)	Matrice: Ca (100) Aggregate (1*): Ca (100)	**2**: Ca (58.31), P (31.62), Na (3.97), Fe (1.67), Cl(1.15), S (1.62), Si (0.62), Mg (0.59), Al (0.44); Fe (94.61), Ca (2.85), S(0.94), Si (0.63), Al (0.55), Cl (0.43); Ca (21.08), Na (19.89), S (12.85), Si (11.72), Fe (11.84), Al (8.73), Cl (7.19), Mg (n 3.51), Zn (1.49), K (1.21)	**2**: Animal black + Fe based pigment (earths pigments) + synthetic ultramarine blue	Lime fresco
Children costume	P3D_5	Bright red	**Fig. 10** 3: bright red layer (≈ 5-12 m) 2: light red layer (≈ 30-	Matrice: Ca (92.35), P (3.80), S (2.71), Si	**3**: Ca (66.15), S (16.96), Cd (9.18), Se (4.76), Si	**3**: Cadmium red + Fe based pigment (mars colour?)	**3**: Fresco **2**: Lime fresco/lime painting?

			50 µm) 1: white mortar (intonaco)	(1.13) Agregate (1*): Ca (100)	(1.61), Fe (1.37) **2**: Ca (49.38), S (33.03), Si (5.33), Al (4.51), Fe (4.30), Mg (2.08), K (1.38)	**2**: Fe based pigment (earth pigments)	
Captain costume	P3D_13	Blue	**Fig. 10** 2: blue layer (≈ 5-13 µm) 1: white mortar (intonaco)	Matrice: Ca (95.12), S (4.88) Agregate (1*): Ca (100)	**2**: Ca (31.14), Na (20.01), S (16.51), Si (15.75), Al (14.92), K (1.67)	**2**: synthetic ultramarine blue	Fresco
Background (edge of the painting)	P2_8	Light brown	**Fig. 10** **3**: brown layerr (≈ 43-224 µm) **2**: light brown layer (≈ 40-125 µm) **1**: white mortar (intonaco)	Matrice: Ca (94.33), Cl (2.19), Na (2.09), Mg (0.96), Si (0.43) Agregates: Ca (100); one particle of Si (93.87), Ca (5.60, Al (0.53)	**3**: Ca (73.08), Si (7.73), Al (7.58), Na (3.37), Mg (2.59), Cl (1.97), Fe (2.03), S (1.66) **2**: CE (44.08), Si (26.42), Al (10.79), Fe (8.46), Mg (3.99), Na	**3**: Fe based pigment (earth pigments) **2**: Fe based pigment (earth pigments)	**3**: Lime fresco **2**: Fresco
Rocha do conde de Óbidos Maritime Station							
Background (edge of the painting)	P3A_13	Grey/black	**Fig. 10** **3**: black layer (≈ 43-224 µm) **2**: brown layer (≈27-195 µm) **1**: white mortar (intonaco)	Matrice: (*2): Ca (90.91), Si (3.46], Al (2.88), Na 81.40), K (0.35), Fe (0.99); (*3): Ca (96.88), Cl (1.42), S (1.70) Agregate (1*): Ca (100)	**3**: Ca (55.8), P (22.2), S (5.7),Na (4.0), Si (3.9), Al (3.0), Mg (2.1), Cl (1.4), Fe (1.2), K (0.8) **2**: Ca (69.8), S (24.2), Si (2.4), Al (1.2), K(1.1), Fe(1.3); C	3: animal black, Fe based pigment (earth pigments) 2: Fe based pigment (ochres) + C black	**2** and **3**: Lime fresco
Background (geometric motif)	P3D_8	white	**Fig. 10** 3: white layer (≈4-40 µm) **2**: brownish red layer (≈6-31 µm) **1**: white mortar (intonaco)	Matrice: Ca (97.58), S (1.79), Cl (0.63) Agregate (1*): Ca (100)	3: Ca (95.99), S(2.28), Cl (0.69), Na (1.04) **2**: Fe (82.74), Ca (14.39), Si (1.23), S (1.16), Cl (0.48)	**3**: calcium carbonate **2**: Fe based pigment (mars colour?)	**3**: Lime Fresco **2**: Fresco
Stars on the costume	P3A_2	Dark green	**Fig. 10** **3**: dark green layer (≈ 98-155 µm) **2**: yellow layer (≈51-128 µm) **1**: white mortar (intonaco)	Matrice: Ca (93.46) Agregate (1*): Ca (100)	**3**: Ca (56.2), S (18.3), Ba (16.3), Na (6.1), Fe (1.9), Si (0.9),Al (0.4) **2**: Ca (51.6), Fe (17.5), Si (12.2), Al (11.5), K (2.5), Mg (0.3), S (1.5), Cl (1.6), Ba(1.4)	3: PG8 **2**: Fe based pigment (earth pigments)	**3**: Fresco? Secco? **2**: Lime fresco

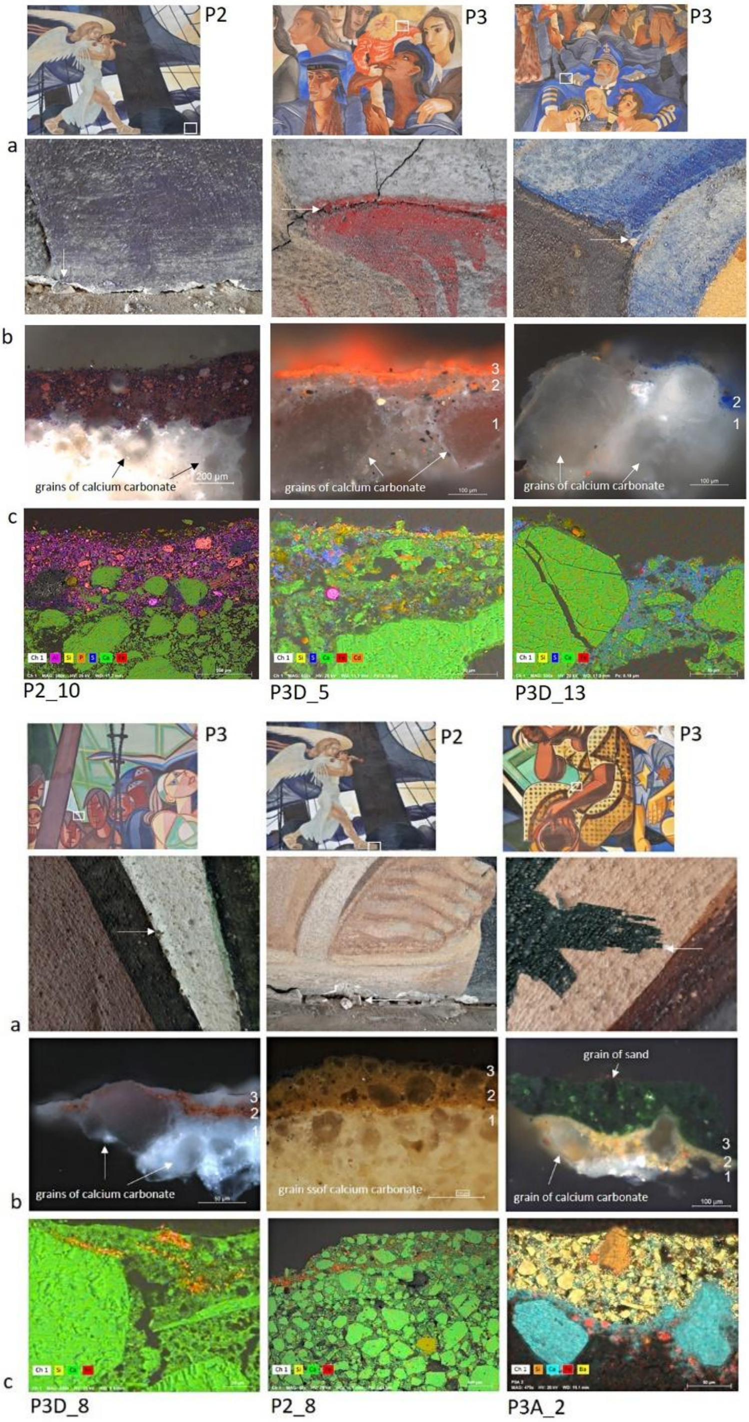

Fig. 10. Sampling areas, cross-sections, and VP-SEM-EDS elemental maps of paint layers from the Alcântara and Rocha do Conde de Óbidos mural paintings. (a) Sampling locations; (b) OM-Vis images of the corresponding cross-sections, showing the stratigraphic sequence and the number of layers identified; (c) VP-SEM-EDS elemental maps showing the distribution of the main elements associated with the plaster and with the chromophore particles present in the paint layers. The EDS results are presented in Table 2.

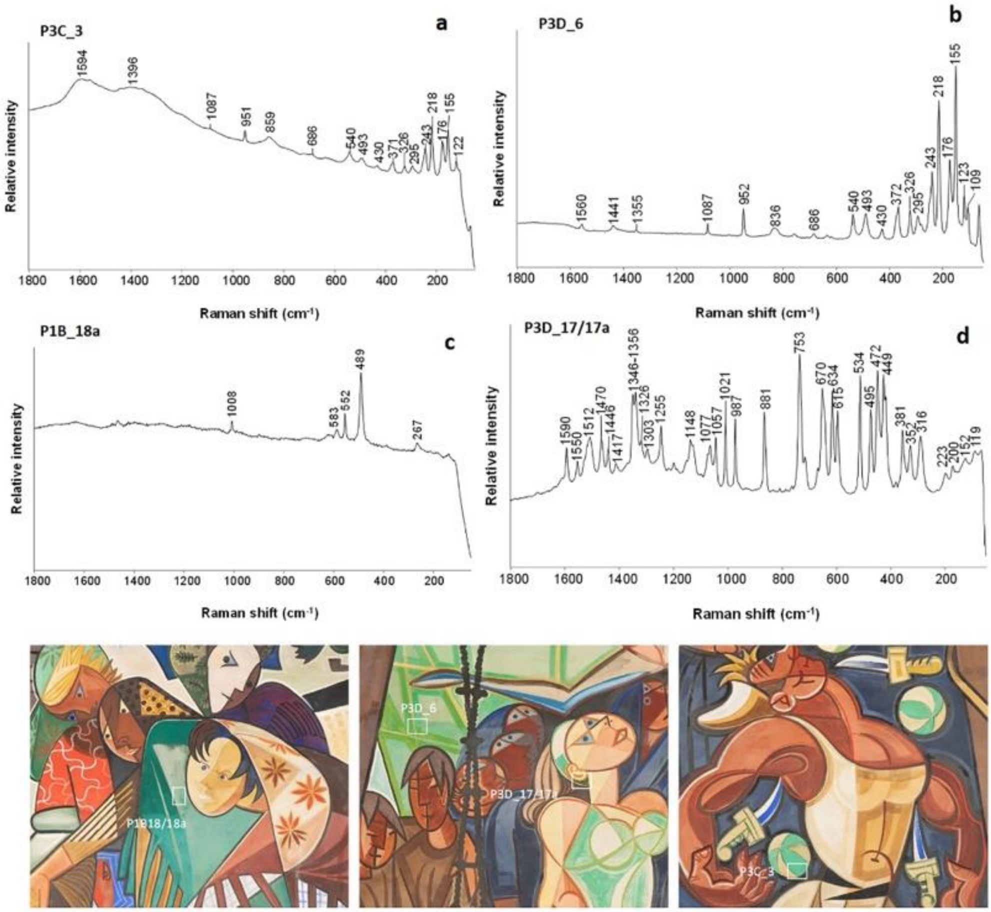

Fig. 11. From top to bottom: a) Raman spectrum of emerald green (122, 155, 176, 218, 243, 295, 326, 371, 430, 493, 540, 689, 951 cm^{-1}) found in sample P3C3. The band at 859 cm^{-1} has been attributed to the symmetric vibration of the arsenate anion. Bands at 1396 and 1594 cm^{-1} can be attributed to humic earths such as Van Dyck brown and might explain the darker hue, while the band at 1089 cm^{-1} can be attributed to calcite and is likely associated with the preparation layer. b) Raman spectrum of emerald green (109, 123, 155, 176, 218, 243, 295, 326, 372, 430, 493, 540, 689, 836, 952, 1355, 1441, 1560 cm^{-1}) found in sample P3D 6. The band at 1089 cm^{-1} can be attributed to calcite and is likely associated with the preparation layer. c) Raman spectrum of viridian (267, 489, 552, 583 cm^{-1} in sample P1B18a). The band at 1008 cm^{-1} can be attributed to gypsum. d) Raman spectrum of synthetic pigment PG8 (119, 152, 200, 223, 316, 352, 381, 449, 472, 495, 534, 615, 634, 670, 753, 881, 1021, 1057, 1077, 1148, 1255, 1303, 1326, 1346-1356, 1417, 1446, 1470, 1512, 1550, 1590 cm^{-1}). The band at 987 cm-1 is attributed to barite.

Pictorial execution

Regarding the painting sequence, both stations show a similar procedure: Almada first laid down opaque and rather thick ground colours, over which he applied diluted and more opaque brushstrokes to build up form and shadow, as shown in Figure 12 and in the six cross-sections illustrated in Figure 10. This sequence had already been recorded in 2024 in a technical study of the Rocha do Conde de Óbidos murals [24] and is also clearly visible at Alcântara, particularly in mural P3, in the modelling of the garments within the dense figurative group represented. In both ensembles, diluted paint was used with an aquarelle-like effect both in broad colour washes and in finer hatched strokes, whose width, direction, and density vary according to the motif depicted.

Fig. 12. Details from the Alcântara and Rocha do Conde de Óbidos mural paintings showing diluted paint with an aquarelle-like effect applied over more opaque ground colours, both in broad colour washes and in finer brushstrokes. Photographs by Milene Gil, 2021 and 2022.

As summarised in Table 2, VP-SEM-EDS analysis shows Ca-rich matrices in the eight paint-layer cross-sections from both maritime stations, illustrated in Figures 4 and 10. These matrices are observed in both the more diluted paint layers and the thicker, more opaque layers, where pigment particles appear to have been mixed with slaked lime and laid down on fresh plaster, consistent with lime fresco. In both painting ensembles, Almada also appears to have occasionally added calcium carbonate and sand to the paints, as confirmed by the stratigraphic and VP-SEM-EDS analysis of P2_8 and P3A_2 (Fig. 10; Table 2). The intonaco itself contains coarse aggregate particles, some of which become visible at the paint surface, as shown in P3D_13 and P3D_8 in Fig. 10. However, these may not be the only factors contributing to the differences in surface texture observed on site, which may also relate to varying degrees of pressure applied during plaster laying and, most probably, during paint execution.

The appearance of the painted surface is, in fact, one of the main distinguishing features of the two painting ensembles, as supported by the analysis of more than 800 images acquired on-site under visible light and visible raking light. As stated in the introduction, both ensembles are classified as frescoes in the official documentation. Almada Negreiros' admiration for this technique is also attested by the interview he gave to a newspaper [Diario de Lisboa] in 1950, in which he briefly referred to his three-year apprenticeship in fresco painting, without providing further details [13].

In technical terms, fresco entails the application of pigments onto a still-wet lime-based intonaco, in which calcium hydroxide gradually carbonates into calcium carbonate, fixing the pigment particles at the surface. One of its defining operational features is therefore the application of fresh plaster in daily patches. The size, number, and shape of these plaster patches depend on the complexity of the composition, the number of artists involved, and the environmental conditions in situ. Their identification, usually through the observation of plaster joints under visible raking light, remains one of the main material indicators of fresco practice.

In both maritime stations, evidence of these features was documented in the six murals under study, although their visibility varies according to the care taken to disguise them during plaster and paint execution (Fig. 13). Their assessment at Alcântara was particularly difficult in this respect.

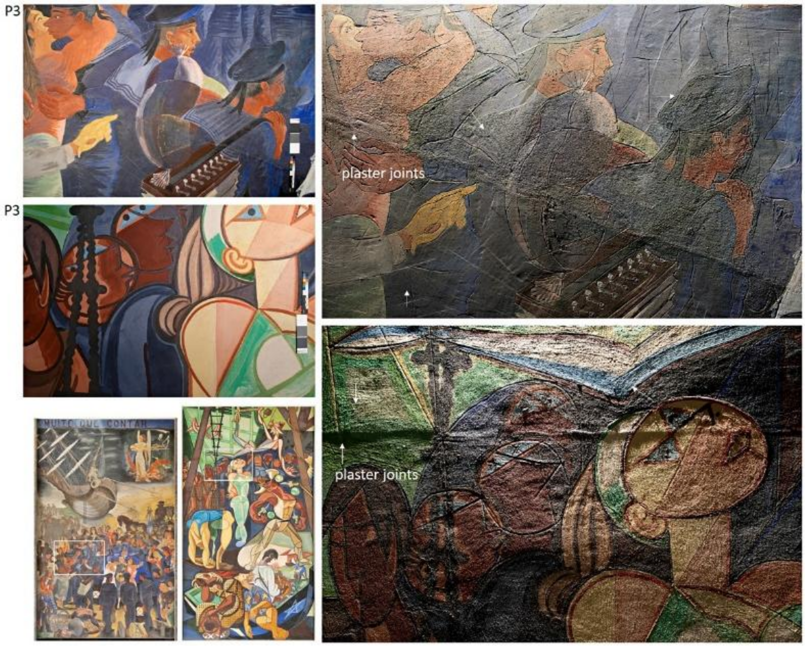

Fig. 13. Details of murals P3 from the Alcântara and Rocha do Conde de Óbidos maritime stations, recorded under visible light and visible raking light. The Vis-Rak images highlight plaster joints between adjacent plaster patches, as well as differences in the paint-surface appearance. Photographs by Manuel Ribeiro, 2021 and 2022.

For this reason, Figure 14 is especially relevant: it shows Almada adding the final painted touches to the first plaster section laid down in P3. Below the painted surface, an area of arriccio is visible, ready to receive the final intonaco layer. This detail is technically significant because painting a secco would require only a dry support to paint on.

The evidence of plaster patches supports the hypothesis that fresco painting was indeed an intended and important technique in both ensembles. However, it is not possible to ascertain precisely how much of the painted surface may have been effectively executed in this technique. This uncertainty results not only from the large dimensions of the plaster patches identified, which easily exceed two metres in length or height, but also from the poor condition of several analysed paint layers [20], [21], [22]. Although Almada was an experienced artist and may have used strategies to extend the working time of fresco, the execution of such large-scale daily patches would have been technically demanding, considering that he painted alone, with only the aid of one assistant on-site.

As mentioned above, Almada Negreiros was a self-taught artist, but he had access to technical literature on fresco painting. Three fresco manuals were found in his studio [31], [36], [37]. Particularly relevant to the present discussion is the manual by Costin Petresco, published in 1931 by Lefranc–Paris. Petresco, the son of one of the last Romanian mural painters working within the Byzantine tradition, described in *L'art de la fresque* the full sequence of fresco execution, from the preparation of the plaster layers to the final retouching, while also providing recommendations intended to ensure the durability of the paintings [31].

One of these recommendations concerns a stage that Petresco considered crucial to the success of fresco painting: the intense smoothing, or polishing, of the painted surface after the ground colours of the composition had been laid down. The pressure applied would not only promote a stronger bond between the paint layer and the plaster and help to even out the colour but also favoured the further migration of calcium hydroxide within the intonaco towards the surface, thereby extending the time available for fresco execution. This was not a minor detail, especially when large plaster patches were involved.

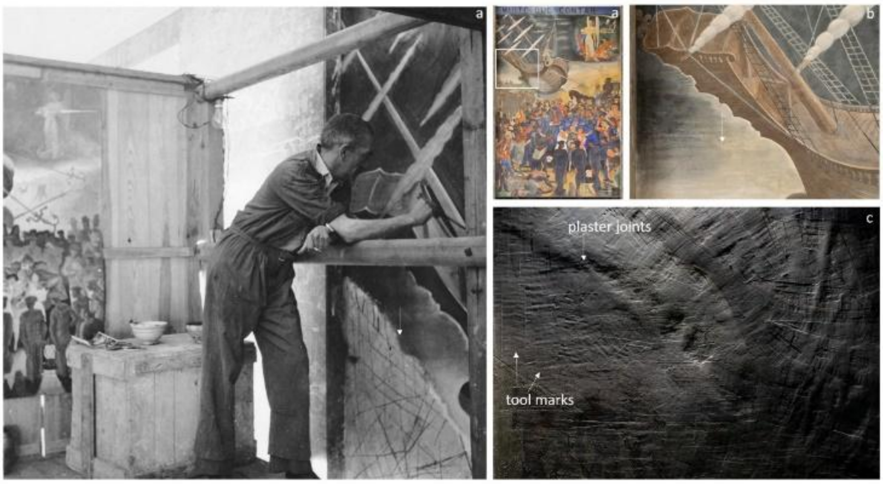

Fig. 14. Mural P3 at Alcântara: (a) historical photograph taken during its pictorial execution in 1945; (b) corresponding detail recorded in 2021 under visible light; (c) the same area recorded under visible raking light, highlighting plaster joints, surface irregularities, and tool marks, Image sources: ANSA-F-246, CEDANSA - NOVA FCSH / © Estate of José de Almada Negreiros and Manuel Ribeiro, 2021.

Such pressure, applied with tools also used to lay and compact the intonaco before painting, would leave marks on the plaster and soften the relief of brushstrokes in the thicker paint layers. This is precisely what is observed in the Vis-Rak images from Alcântara station, where the extensive presence of trowel marks in P3, P5, and P8 suggests the pressing and smoothing of the ground colours. These features are particularly evident in the paint surface of the sailor's blue garments in Figure 13.

The painted surfaces at Rocha do Conde de Óbidos present a different appearance (Fig. 13). As already noted, with the exception of the upper part of mural P1, where extensive tool marks are also visible, the remaining murals mainly show depressions that may have been caused by irregularities in the underlying masonry and by the pressure exerted on the damp surface when the full-scale drawings were transferred to the walls [24]. The paint surface is more textured, and the relief of the brushstrokes forming the opaque coloured grounds remains visible (Fig. 13). This contrast points to a different approach to the handling of the painted surface in the two ensembles. One hypothesis currently under consideration is that the use of incised pounced drawings may have accelerated the transfer of the composition to the wall and allowed painting to begin sooner. Since the composition at Rocha do Conde de Óbidos is stylistically simpler than that at Alcântara, Almada may have been able to advance more rapidly and may therefore no longer have considered it necessary to press the ground colour layers, allowing him to explore the texture of the brushwork more freely.

A final distinction between the two painting ensembles concerns the coexistence of matt and glossy surfaces. At Rocha do Conde de Óbidos, both surface finishes were observed across the six panels examined, as illustrated by representative details from P1, P4, P5, and P6 in Figure 15. At Alcântara, by contrast, glossy areas were much more restricted, occurring only locally and mainly in black and brown paint layers with poor adhesion. This distinction is technically relevant because lime-based painting has a matt appearance. Glossy surfaces therefore indicate the presence of organic material, which may have been originally used by Almada, later added during conservation treatments, or resulted from the superposition of both phases.

Fig. 15. Details of murals P1, P4, P5 and P6 from Rocha do Conde de Óbidos, showing the coexistence of matt and glossy areas on the painted surface, visible as differences in surface reflectance under oblique viewing conditions. Photographs by Milene Gil, 2021 and 2022.

At Rocha, the interpretation of these glossy areas is complex because of their extent, location, and state of conservation. In several paint layers examined by h-OM on-site and in cross-sections by OM-UV and SEM-EDS, the organic material appeared to be confined to the paint surface rather than distributed throughout the full thickness of the paint layer, as illustrated by P3A_13 in Figure 16. This supports the presence of surface-applied materials. The much greater extent of glossy surfaces at Rocha, when compared with Alcântara, suggests that intervention materials alone may not fully explain this appearance. Since broadly similar conservation procedures were used in both stations, including the nebulisation of polyvinyl alcohol (PVA) on the painted surfaces, other factors should also be considered, namely the original paint formulation of some final brushstrokes or Almada's the possible use of a surface coating or varnish to obtain specific optical effects.

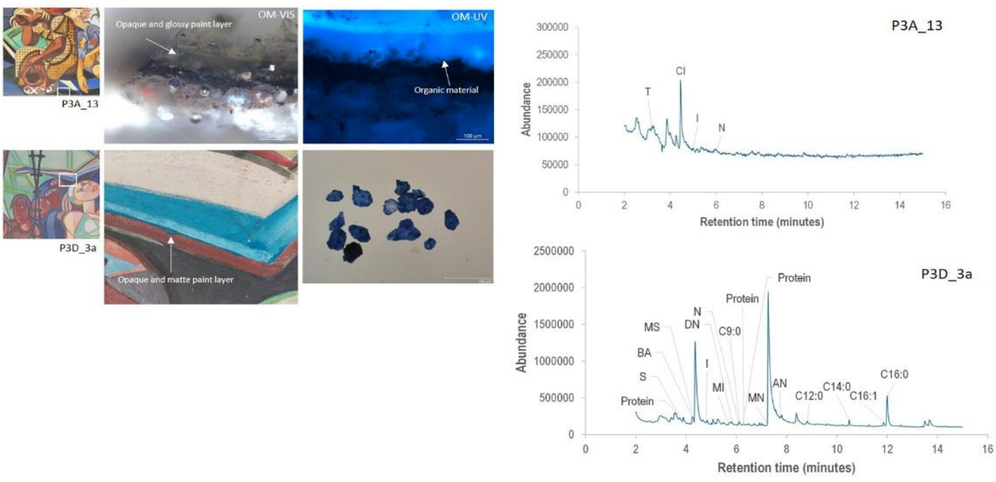

Fig. 16. From left to right: sampling locations of P3A_13 and P3D_3a, OM-Vis and OM-UV observations, and corresponding Py-GC/MS chromatograms. In P3A_13, OM-UV highlights fluorescent organic material located at the paint surface, while Py-GC/MS detected poly(vinyl acetate). In P3D_3a, Py-GC/MS revealed markers compatible with proteinaceous material in the blue matt brushstroke.

Previous μ-FTIR studies on both maritime stations had identified vinyl polymers in glossy paint surfaces. At Alcântara, PVA was identified in most of the greenish paint layers analysed, which showed severe flaking [19], [21]. At Rocha do Conde de Óbidos, this product was also assigned to black, yellow, and green paint layers in good condition, together with traces of unidentified organic material, lipidic compounds, and oxalates [20], [24]. Although these results suggested the presence of organic compounds, their origin could not be fully established.

Recent Py-GC/MS analyses provided further evidence for the complexity of the organic fraction (Fig. 16). In P3D_3a, collected from an original paint layer with no evidence of later intervention, markers compatible with proteinaceous material were detected, although the results were not sufficient to identify a specific binder. In P3A_13, PVAc was the only compound identified. In this sample, PVA had already been identified by μ-FTIR and was initially attributed to past intervention, since the sample was collected near paint layers fixed and retouched in the 1970s. However, the detection of PVAc adds complexity to this interpretation, as PVAc was already commercially available for paint and conservation industries in 1949. Further chromatographic studies on selected samples from both stations will allow this question to be refined.

Conclusions

The present study offers the first imaging-based comparative technical and material assessment of Almada Negreiros' mural paintings at the Alcântara and Rocha do Conde de Óbidos maritime stations. This comparison is particularly relevant because the two ensembles were painted only four years apart, within the same architectural and functional context, and were both referred to as frescoes in the official documentation. Contrary to initial expectations, the results show that the differences between them are not primarily related to the materials used by Almada Negreiros in the plasters and paint layers, which are broadly comparable in both stations. Rather, they concern the way in which these materials and techniques were combined during mural execution, including the transfer of the drawings, the colour, distribution, the handling of the painted surface, and the possible articulation between fresco and *a secco* applications.

The results also show that Almada was still experimenting on-site. The change in the drawing-transfer procedure observed at Rocha do Conde de Óbidos is particularly significant in this respect, since it points to his adaptive approach during execution. Working largely alone and within a demanding timetable, the artist appears to have sought practical solutions that could simplify and accelerate both the transfer of the composition to the wall and the beginning of the painting process. This capacity to adapt the pictorial process on-site is further suggested by the different appearance of the painted surfaces in the two painting ensembles.

Overall, the evidence gathered indicates that Almada's mural technique may have been more complex than the general classification of these paintings as frescoes would suggest. The presence of plaster patches in both stations, together with Ca-rich paint matrices and pigment particles incorporated into lime-based matrices, confirms that fresco was in fact an intended and important technique in the execution of the two ensembles.

The question that remains is how much of these monumental painted surfaces was effectively completed in fresco. The answer may lie precisely in the differentiated handling of the painted surface after the coloured grounds had been laid down and in the final paintwork and surface finish, as suggested by the raking-light images and by the most recent chromatographic results. The detection of markers compatible with proteinaceous material in a blue matt brushstroke, together with the widespread occurrence of glossy areas at Rocha do Conde de Óbidos, raises the possibility that Almada used organic binders in some final brushstrokes and even a final surface coating or varnish to create specific optical effects.

By combining documentary research, on-site imaging, non-invasive analysis, and laboratory microanalysis, this study provides new evidence for understanding Almada Negreiros' working process and represents an important contribution to the technical art history of modern mural painting. It also provides reference data that may be compared with, and further explored in relation to, other contemporary mural painting ensembles in Portugal and abroad.

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