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# Unveiling the Artistry of Juan Martínez Montañés: Carving and Polychromy in the Santa Clara Church Altarpiece

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**Abstract:** Juan Martínez Montañés was one of the most important sculptors and altarpiece architects of the Spanish Golden Age. The restoration of the Santa Clara church in Seville has presented a unique opportunity to study the main altarpiece, crafted by Montañés between 1621 and 1623. He was also in charge of the polychromy and gilding, believing that delegating these procedures to others would diminish the quality of his work. This conviction led to a well-known lawsuit with the renowned contemporary Spanish painter Francisco Pacheco. Ultimately, the painter and sculptor Baltasar Quintero performed the polychromy of this altarpiece, but under the strict conditions of Montañés. Various non-invasive analytical techniques, such as CT, UVF, XRF, and digital microscopy, were employed to study wood treatment and polychromy. Additionally, three samples were prepared as cross-sections and analysed by SEM-EDX. The results revealed Montañés' meticulous woodwork, anticipating its long-term preservation. Consistent with Montañés' commitment to maintaining the superior quality of his work, the analysis showed an absence of a ground layer in the flesh areas, while the gilding was executed with high-quality gold. The pigment palette corresponds to the treaties and documents of his time, and the extensive areas of later retouches were accurately located. These new data provide a deeper understanding of both the technique and the high standards of one of the most important and globally recognised sculptors.

**Keywords:** polychromy; sculpture; woodwork; pigments; Montañés; altarpiece; XRF; SEM-EDX; computed tomography

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## 1. Introduction

The sculptor Juan Martínez Montañés (1568–1649) [1–3] is recognised as the foremost exponent of the so-called Sevillian School of Imagery. In his time, he was considered the "Andalusian Lysippos" and "the God of Wood" due to his mastery of working with this material.

As the son of an embroiderer artist, Juan Martínez, he moved with his family from his hometown, Alcalá la Real (Jaén), to Granada in 1579. There, at the age of 12, he apprenticed under the sculptor Pablo de Rojas and collaborated with other artists, exploring various artistic styles. This experimentation undoubtedly played a role in shaping his distinctive

sculptural style. He later settled in Seville around 1581. On 1 December 1588, at the age of 21, he successfully passed the examination as a sculptor, master carver, and architect, overseen by artist–examiners Gaspar de Águila and Miguel Adán. Montañés established his own workshop in Seville, where he had as his favoured disciple the Cordovan Juan de Mesa. Evidence suggests a sojourn in Madrid in 1635 to sculpt the bust of Felipe IV, commissioned by painter Diego Velázquez for the monarch's equestrian portrait in Plaza de Oriente. Tragically, Montañés succumbed to the plague epidemic that devastated Seville on 18 June 1649.

As a master sculptor and assembler, he had the right to undertake works in architecture, design, and the crafting of altarpieces. Today, we primarily value him as a sculptor of altarpieces, for which he conceived a significant number of sculptures. His works exhibit elements of classicism and mannerism, reflecting the spirituality and emotional realism characteristic of the Counter-Reformation influenced by the rising importance of the Catholic Church. Montañés played a crucial role in the transition from the Renaissance to the Baroque, as his technical prowess and ability to imbue his works with profound emotion helped the establishment of the Baroque aesthetic in Spain.

This work focuses on studying the main altarpiece that presides over the church of Santa Clara in Seville (Spain), see Figure 1. For its creation, Martínez Montañés was commissioned in 1621, who took charge of its design and carving. However, in 1722, the altarpiece underwent a renovation, during which a relief depicting Saint Clare (*Santa Clara*) among the nuns of her community was removed and replaced by a shrine, altering the original composition of the work. This mannerist-style altarpiece adapts to the polygonal apse of the church and is structured into two bodies and an attic. The first body features two reliefs depicting scenes from the life of Saint Clare: "The imposition of the habit on Saint Clare by Saint Francis" and "The miraculous blessing of bread". These reliefs flank the central shrine housing the image of "Saint Clare", between which are the sculptures of "Saint Bonaventure" and "Saint Anthony of Padua with the Child in his hands". At the ends of the second body, two reliefs portray scenes of the "Nativity of the Lord" and the "Annunciation", while the central aisle is presided over by the image of the "Virgin of the Rosary", attributed to Francisco de Ocampo and dated around 1633. Flanking this central image are the sculptures of "Saint Agnes" and "Saint Mary Magdalene". The attic is occupied by a representation of the "Holy Trinity", following the post-Tridentine iconography of the Throne of Grace. Finally, on the altarpiece's predella, on the sides of the tabernacle, are two small sculptures of "Saint Peter", possibly crafted by Alonso Cano, and "Saint Paul".

In the assembly contract for the altarpiece of 6 November 1621, Montañés committed himself to undertaking the architecture, carving, and sculpting, boldly venturing to include among the contract conditions the execution of gilding, *estofado* (a decorative technique that imitates the appearance of gold brocade by scratching through a paint layer to reveal another layer of contrasting colour or material—generally gold—below), and flesh tones [4]. These latter conditions, which persisted in the subsequent contract, sparked the well-known lawsuit of 1623 with the renowned Sevillian painter Francisco Pacheco. The sculptor had breached the rigid guild regulations of the time, encroaching into the realm of painting by subcontracting competencies outside the trade for which he was examined. Additionally, Montañés made an economic estimate of the polychromy, which accounted for one-third of the financial estimate for the assembly and sculpture, leading to the Painters' Guild feeling disgraced during a period when they sought to elevate their art and having it regarded as a more intellectual discipline than manual labour, in order to avoid paying sale taxes.

Francisco Pacheco had already countered the sculptor's actions by dedicating the famous dissertation "On the Antiquity and Honors of the Art of Painting and Its Comparison with Sculpture, Against Juan Martínez Montañés" published in 1622 [5]. In his discourse, the painter emphasised that only those who were examined would use the craft of painting, warning that the master sculptor risked a penalty ranging from 600 to 900 maravedis and up to nine days in jail with his attitude. Thus, it was not the first instance in which Montañés

had contracted the carving and painting of entire works, overcoming tasks that did not fall within his purview.

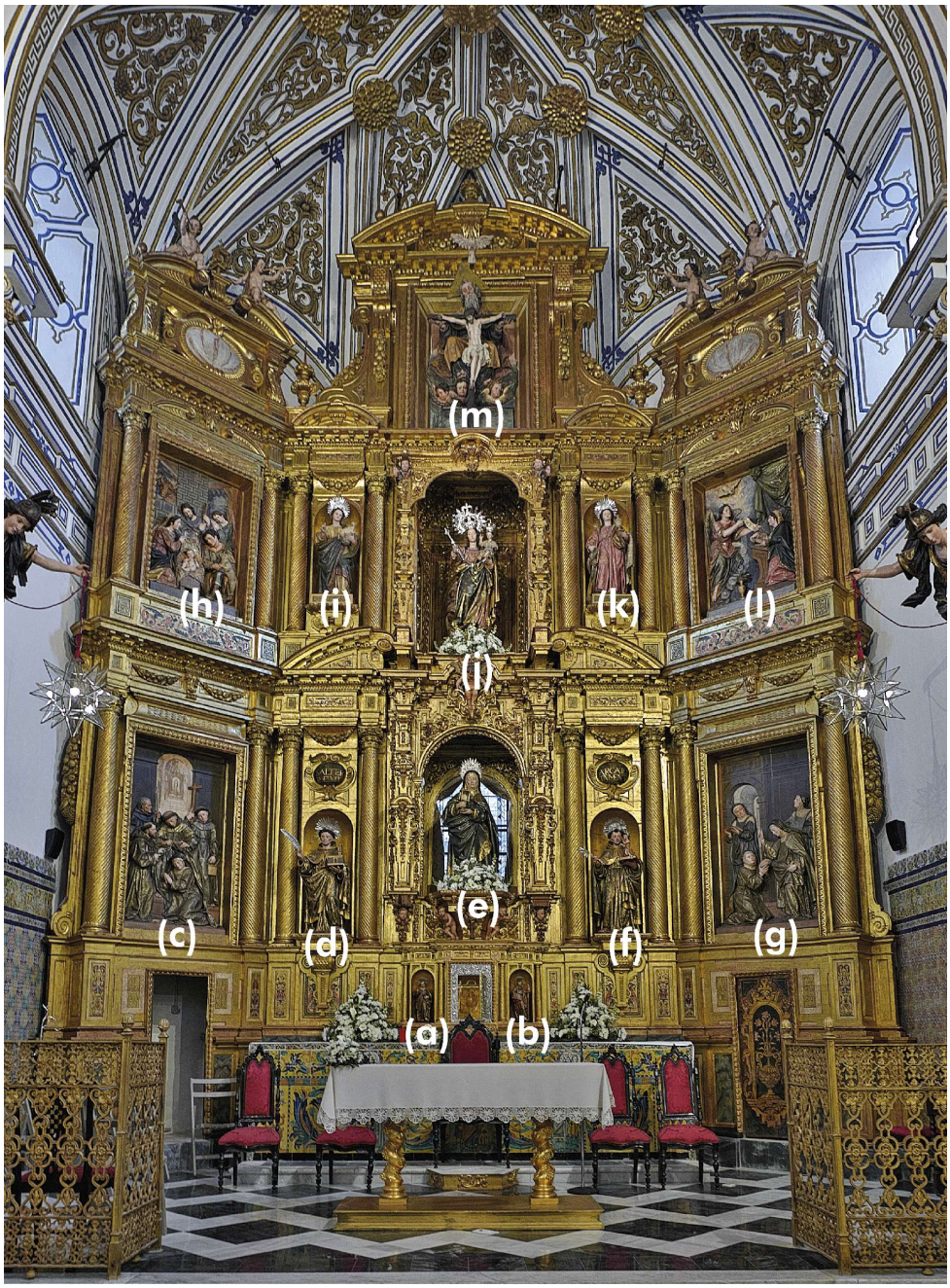


**Figure 1.** Main altarpiece of the church of Santa Clara: (a) Saint Peter; (b) Saint Paul; (c) The imposition of the habit on Saint Clare by San Francisco; (d) Saint Bonaventure; (e) Saint Clare; (f) Saint Anthony of Padua; (g) The miraculous blessing of bread; (h) Nativity of the Lord; (i) Saint Agnes; (j) Virgin of the Rosary; (k) Saint Mary Magdalene; (l) Annunciation; (m) Holy Trinity.

The terms outlined in Montañés' contract [4] for the polychromy reflect the prevailing characteristics of the time, in line with the style and preferences of the early 17th century: a matte finish for the flesh, burnished gold, engravings, and application of estofado using a brush tip. Alongside these technical specifications, the contract also addresses more subjective conditions, highlighting the sculptor's concern about entrusting his work to the painter and the potential impact this might have on his artwork. Specifically, it demanded

that the ground layers meticulously respect the volumes of the carving and preserve all the details of the sculptor's craftsmanship.

Montañés' motivation for hiring polychromy stemmed from his desire to preserve the integrity of his remarkable works, unwilling to risk shattering them with deficient polychromies. As a celebrated artist of his time, estimated by clients ranging from religious orders and churches to individuals who trusted him for the execution of private devotions, Montañés held his artistic reputation in high regard. On the other hand, he contended that gilding and polychromy were not part of the realm of painting, considering them less intricate tasks than painting or drawing [6,7]. These assertions only served to outrage the demanding guild further and demonstrate the master sculptor's pride in retaining sole control over his work. Finally, Montañés faced defeat in the lawsuit and delegated the task of polychromy to the esteemed painter Baltasar Quintero [8], recognised as one of the preeminent polychromists of the Sevillian School and admired even among his peers in the guild. Baltasar Quintero had previously collaborated with Montañés, and no new conditions were established in the contract, maintaining those initially set by Montañés.

The Church of Santa Clara, which belongs to the Archdiocese of Seville, was completely restored, and the works were finished in February 2023. This restoration provided a unique opportunity for the study of the main altarpiece. The sculptures were taken to the restoration workshop of the Archbishop's Palace of Seville and to the Centro Nacional de Aceleradores (CNA) for their study and conservation. Various analytical procedures as computed tomography (CT) [9,10], ultraviolet light (UV) [11–15], X-ray fluorescence (XRF) [14,16–19], optical microscopy (OM), and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) [19–21], were employed to gain insight into the artistic technique of one of the world's most eminent sculptors, Martínez Montañés, from wood treatment and sculpting to the polychromy executed by Baltasar Quintero. The analysis of the altarpiece's polychromy, entangled in a conflict between guilds, also allows for us to verify the significant demands of the polychrome technique within the Sevillian School during this period. These demands are evident in the signed conditions, which dictate the meticulous preservation of the sculptor's carving and details, the client's insistence on gold quality, and the painter's precise technical execution and material selection. All these results were of great utility and support in the restoration process. It should be noted that there are currently no known studies on the material and technical aspects of Quintero's polychromy and consequently, on the collaboration between both artists. There are several shorter art historical studies on Quintero [8,22] and very few publications regarding the art of polychromy in Spain during this period [22–24]. Given the absence of direct comparative analyses or previous scientific studies, our discussion draws upon broader art historical context and general principles of polychromy practices.

## 2. Materials and Methods

The altarpiece was studied using various techniques aiming to understand the treatment of wood and its assemblies for the carving of the sculptures and to identify the support and pigments applied in the original polychromy as well as in later interventions. All these data offer a greater understanding of Montañés' technique and the conditions he imposed in the polychromy process. Most of the techniques used were non-invasive. The application of CT [9,10] produces detailed images of the internal structure of a sculpture, which is crucial for understanding the carving technique and material distribution. Additionally, CT can reveal internal cavities or reinforcements, identify and characterise the materials used, and locate possible internal damages, such as cracks or deformations, that are not visible externally. The CT system belongs to the Centro Nacional de Aceleradores (CNA). It is a Siemens Biograph mCT device with multislice UFCTM (Ultra-Fast Ceramic) detectors, capable of producing images of up to 64 slices. The device's aperture is 78 cm; therefore, most of the sculptures could be analysed except for the reliefs and the Christ Crucified.

For the study of the polychromy, first, UV [11–15] fluorescence was applied to localise interventions, which significantly facilitated the cleaning of the sculpture and helped in

choosing original areas for subsequent material analysis. The UV images were captured using a Nikon D3X camera set at 400 ISO with an exposure time of 20 s. The painting was uniformly illuminated with four wooden lamps, with a wavelength of 254 nm, on both sides of a sculpture in a fully darkened room.

The last applied non-invasive technique was XRF [14,16–19]. This technique is used to determine the elemental composition of materials based on their representative chemical elements by measuring the characteristic X-rays emitted when a sample is irradiated with X-rays. Thus, we can obtain a general idea of the material used for the ground layer, priming, original pigments, and those applied in later interventions. The portable XRF equipment used for this study included an EIS RX38 X-ray generator with a tungsten (W) anode and a silicon drift detector (SDD) with an energy resolution of 140 eV at the Mn-K$\alpha$ line. A 1 mm Al filter was applied to the X-ray generator window to eliminate characteristic W peaks from the anode, and the beam spot diameter was 3 mm. Both instruments were fixed to a metal framework to allow for precise forward and backward movements for accurate proximity to the sculpture, minimising the risk of accidents. Additionally, the system incorporates the intersection of two lasers to maintain a consistent measuring distance of 1 cm. All measurements were conducted under identical conditions for direct spectral comparison: 34 kV of energy and 80 μA of current for 200 s acquisition time. The areas of the XRF peaks identified in the acquired spectra were used for a semi-quantitative examination of the colours to estimate whether a specific element is part of the painting's surface layer or resides within an inner layer. A total of 76 points of different colours and shades were chosen to analyse the ground layer and pigments and their combinations to achieve various textures and volumes.

Although the XRF technique is valuable for identifying chemical elements in pigments, it has some specific limitations in this context. XRF has difficulty detecting lighter elements, $Z < 14$ (Si), which may affect the ability to identify some lighter organic or inorganic pigments. On the other hand, it does not distinguish between compounds with the same elemental composition. Therefore, multiple pigments with the same combination of elements, such as copper or lead, may make it challenging to identify specific pigments. A common problem, also observed in the present study, is the inability to differentiate different Cu-based greens among them and from blue azurite (also identified by Cu) in pigment mixtures, where there is no specific green or blue colour. Also, lead white, yellow (massicot or litharge), and red (minium) cannot be differentiated in mixtures.

Finally, three samples of different areas of the relief of the Nativity were prepared as cross-sections and analysed by OM and SEM-EDX [19–21]. These methods provide data about the arrangement and thickness of the colour layers, their composition, and the granulometry of the pigment. However, the valuable information of these three samples is not assumed to be wholly representative of the entire altarpiece, but when combined with XRF measurements they contribute to a more comprehensive understanding of the polychromy and ground layers used. OM analysis was performed with an OLYMPUS BX41 optical microscope equipped with a UV light to distinguish interventions and certain pigments, while SEM-EDX used a FEI Quanta 200 scanning electron microscope. The measurements were carried out in a low vacuum with a pressure of 30 Pa with an acceleration voltage of 22 kV.

## 3. Results

### *3.1. Wood Treatment*

The remarkable state of preservation of the sculptures' supports in all images of the Santa Clara altarpiece was the key factor that prompted their examination using CT. Contrasting Montañés' work with that of contemporary or even more recent sculptors, a notable absence of the typical damage that wood usually presents due to its inherent natural characteristics or the ageing process is observed. On the contrary, the works of other sculptors clearly exhibit evident signs of deterioration, such as natural cracks, openings at the joints and fissures, among others.

Wood, being an organic material, undergoes a pattern of movement throughout its lifecycle, from its origin as part of a tree to its final state as inert timber. During its growth, the tree is essentially composed of three parts: the heartwood, the sapwood, and the bark, arranged from the inside out. This internal structure is crucial when crafting a sculpture. Additionally, the presence of knots in the wood, which results from branches and forms radial marks on the trunk, must be considered. Depending on the cutting method, these knots can manifest as longitudinal marks in radial cuts or circular patterns in a longitudinal cut. Combining these pieces accurately requires a deep understanding of wood behaviour, acquired through experience and careful observation of its characteristics during drying. This behaviour is influenced by the physiognomy of each piece, the proportion of heartwood and sapwood, and the arrangement of growth rings.

Sculptures can suffer two types of deterioration due to the twisting and warping movements of wood, driven by its capacity to absorb and expel water. Firstly, there are natural fissures known as cracks, which arise during the drying process as the wood fibres contract, leading to wood fractures that typically radiate from the centre outward, forming a visible radial pattern in cross-sections. Secondly, these movements can cause longitudinal cracks at the joints between wooden pieces, which environmental conditions and human factors can trigger during manufacturing.

Montañés was knowledgeable about all these issues regarding the behaviour of wood, which allowed for him to apply preventive measures and different compositions in the joint to prevent future damage to his sculptures. Figure 2 shows different cross-sections of several sculptures: Saint Mary Magdalene (a), Saint Anthony of Padua (b), Saint Bonaventure (c), and Saint Agnes (d). In the images corresponding to the heads, it can be clearly observed how the artist identifies areas affected by natural checks and replaces them with other pieces of wood devoid of such problems. In this way, Montañés mitigates the risk of cracks expanding outward over time due to the natural movements of this material. Moreover, the inserted pieces of wood were skilfully fashioned into dovetail (trapezoid) shapes to prevent the expulsion of these grafts under pressure.

For the structure of the bodies, it becomes evident how essential the hollowing out of the pieces is for the stability of the sculptures. Montañés was acutely aware that wood is a living material that continues to move even after being cut due to variations in humidity and temperature, which, over time, could jeopardise the integrity of his works. Thus, he meticulously hollowed out the sculptures, leaving an almost regular thickness throughout each piece (similar to shaping clay sculptures). Sometimes, as seen in the torsos of Mary Magdalene and Saint Bonaventure, he hollowed them out so much that he perforated them, subsequently requiring repair by the polychromist. This hollowing operation reduces the likelihood of wood movements and, consequently, the emergence of cracks since these originate from the core or oldest part of the tree, which is less hygroscopic and more rigid.

In the last image of the sculpture of Saint Bonaventure, Figure 2c, it can be observed that the joint is primarily formed by three-quarters of a tree trunk, to which other pieces were joined, leaving a space. Many sculptors construct joints in this manner, leaving only the spaces the material provides according to the shape the artist bestows. However, Montañés takes this further by enlarging this cavity by removing additional material, which reduces the wood's capacity for movement by removing the core and part of the heartwood. This concept will be further elaborated in Section 4. Finally, in the first image of Figure 2c, it can be seen that the centre of the trunk has been removed to place a new piece that serves two functions. The first is to eliminate the wood's core, and the second is to house the piece where the head is carved. The master was aware that carving the head in the heartwood leads to future deterioration and complicates the carving. Therefore, he incorporated a new piece from a section of sapwood, which is softer for carving and free of long-term issues.

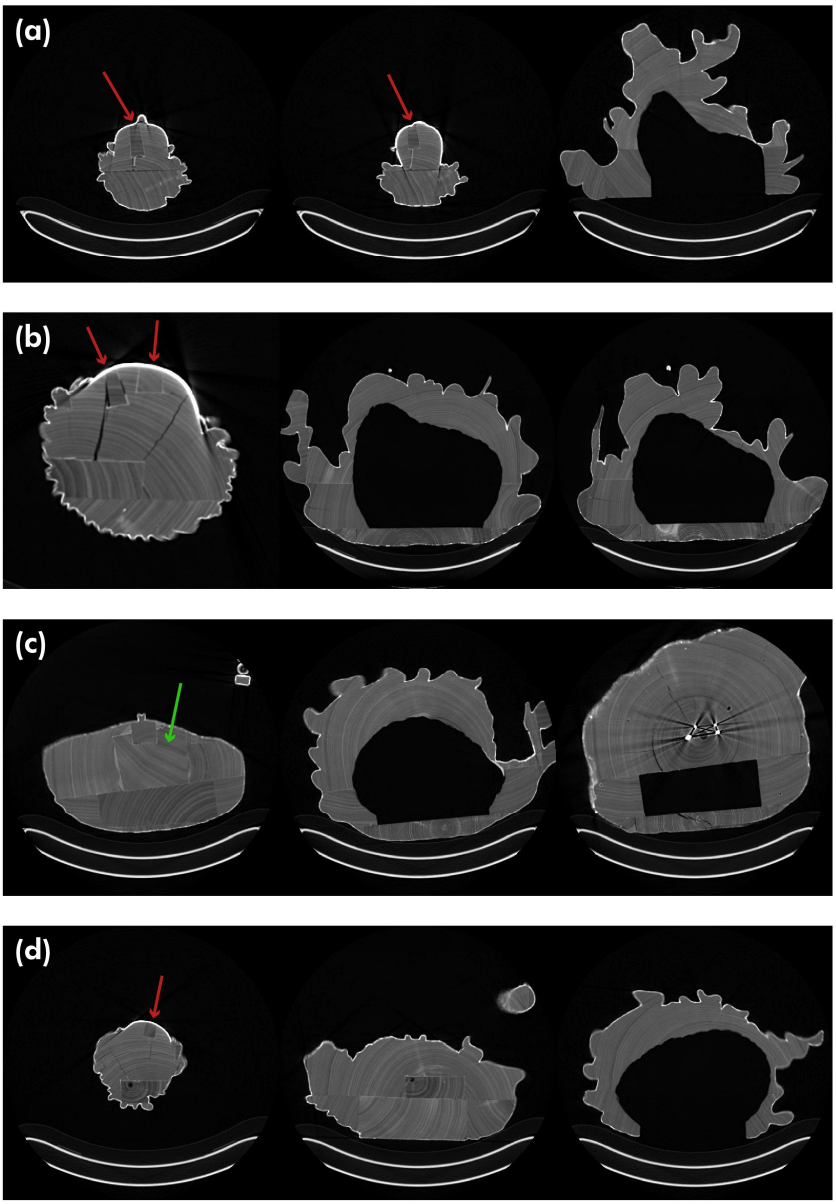


**Figure 2.** Cross-sections of the sculptures: (**a**) Saint Mary Magdalene, (**b**) Saint Anthony of Padua, (**c**) Saint Bonaventure, and (**d**) Saint Agnes. From left to right, the cuts are made from the head to the feet of the sculpture. The red arrows indicate the inserted pieces of wood and the green arrow the piece where the head is carved.

### *3.2. Examination under UV Light*

The sculptures were first studied under UV light. Ultraviolet fluorescence (Figure 3) revealed many interventions, each employing different materials, which is evident from the wide variety of shades observed. These ranged from dark, brown stains, indicative of retouching with earth pigments, to bright whites, characteristic of zinc white. It should be noted that the presence of a fluorescent area in an artwork is mainly informative rather than conclusive evidence, as only certain pigments produce fluorescence of considerable intensity. Other pigments may exhibit enhanced fluorescence due to the presence of added binders. Therefore, interpretation must consider both pigments and binders.




**Figure 3.** Photograph and UV images: (**a**) Nativity of the Lord; (**b**) Christ Crucified; (**c**) Saint Paul; (**d**) Saint Peter.

The most significant interventions are found in the flesh areas in the sculptures studied. Particularly striking was the intense purple hue observed in the body and some areas of the hair and face of the Child in the Nativity. This hue is more likely due to an organic material rather than a pigment, indicating the presence of a binder or varnish used in this retouching. It could be a protein-based repaint applied with egg tempera or animal glue.

### *3.3. Study of Polychromy*

Once the intervention areas were located, the original materials of the polychromy could be analysed. Due to time and accessibility limitations, a selection of sculptures was studied by XRF, not the entire altarpiece: Christ Crucified, Nativity of the Lord, and two small sculptures of Saint Peter and Saint Paul. The analysed areas can be seen in Appendix A (Tables A1–A4; Figures A1–A4) together with the elements detected by XRF and the proposed pigments. The results obtained from the analysis of these few sculptures are assumed to be representative of the rest of the altarpiece, as the same procedures and materials were usually employed in the same workshop.

#### 3.3.1. Ground Layer

The analyses by OM and SEM-EDX on the three extracted samples revealed that the ground layer is made with gypsum [25,26], as identified by the peaks of Ca and S (see Figure 4 and Table 1). Measurements obtained by XRF further corroborated the presence of gypsum, which was identified by the peaks of Ca. This primer was applied throughout the surface, except for the flesh areas, adhering to Montañés' specifications in the polychromy contract [4]. Only the faces of the shepherd and Saint Joseph in the Nativity exhibit a

minimal presence of Ca, which could indicate the specific method employed for producing the flesh tones, as explained later in Section 4.

**Table 1.** Results of the SEM-EDX analysis of the samples shown in Figure 4. The thicknesses, elements, and proposed pigments detected in each layer of the cross-sections are indicated.

| Sample | Layer | Thickness (μm) | Elements | Proposed Pigment | | Observations |
|---|---|---|---|---|---|---|
| (A) | 3 | 10–15 | | - | | Varnish |
| | 2 | 80 | Ca, S, Hg, Pb | Lead white, calcium carbonate *, vermilion * | | Paint |
| | 1 | >500 | K, Ca, Si, S, Pb | Gypsum, silicates * | | Ground layer |
| (B) | 2 | 10–35 | Ca, S, Si, Pb | Lead white, gypsum *, silicates * | | Paint |
| | 1 | >500 | Ca, S, Si | Gypsum, silicates * | | Ground layer |
| (C) | 7 | 0.25 | Au, Ag | **Gold (Au)** | **Silver (Ag)** | Gold leaf |
| | | | | 98.10% | 1.90% | |
| | 6 | 100 | K, Ca, Si, Al, Fe, Pb | Earth pigment, calcium carbonate * | | Bol |
| | 5 | 70–120 | Ca, S, Si, Al, Fe, Pb | Calcium carbonate, gypsum, earth pigment * | | Stucco |
| | 4 | 0.20 | Au, Ag | **Gold (Au)** | **Silver (Ag)** | Gold leaf |
| | | | | 91.72% | 8.28% | |
| | 3 | ≈45 | K, Ca, S, Si, Al, Fe, Pb | Earth pigment, calcium carbonate *, gypsum * | | Bol |
| | 2 | 40 | K, Ca, Si, Al, Mn, Fe, Pb | Earth pigment, umber, calcium carbonate * | | paint |
| | 1 | 0–15 | Ca, S, Si, Al, Fe | Gypsum, silicates * | | Ground layer |

* Low proportion.

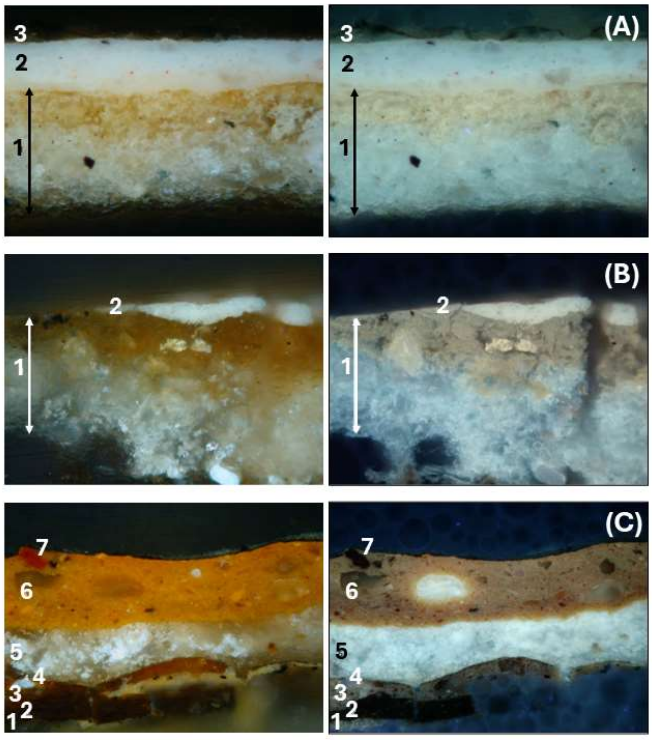


**Figure 4.** Samples cross-sections analysed by OM: (**A**) Virgin's flesh tone near the garment, (**B**) angel's flesh tone near the garment, (**C**) golden area. The right column shows the images obtained under UV illumination and the numbers indicate the different layers.

#### 3.3.2. Pigments

The main chemical elements obtained through XRF analysis of the original pigments in the selected areas are Ca, Mn, Fe, Co, Cu, Hg, Pb, Sn, Ag, and Au. These elements help identify the inorganic pigments used in the polychromy of the analysed sculptures. Based on the results, the palette corresponds to the traditional one for the time [6,7,25,27,28]. Table 2 summarises the results, indicating the colour of each proposed pigment, its chemical formula, and the chemical elements used for its identification. Subsequently, we will explain how these proposed pigments were applied in the different areas of each sculpture.

**Table 2.** Summary of the ground layer and proposed pigments found in the analysed sculptures. The listed pigments are proposed based on our analysis and references, rather than definitively identified due to the limitations of the techniques used. The colour of the proposed pigment and the chemical formula with the characteristic elements detected by XRF, in bold, are also indicated.

| Ground Layer/Colour | Proposed Pigment | Chemical Formula |
|---|---|---|
| Ground layer | Gypsum | **Ca**$SO_4 \cdot 2H_2O$ |
| White | Lead white | **Pb**3(CO3)2(OH)2 |
| Green | Malachite<br>Verdigris<br>Copper resinate | **Cu**$_2CO_3(OH)_2$<br>**Cu**$(CH_3CO_2)_2 \cdot H_2O$<br>**Cu**$(C_{19}H_{29}COO)_2$ |
| Yellow | Lead-tin yellow<br>Yellow earth/ochre | **Pb**$_2$**Sn**$O_4$<br>**Fe**O(OH) |
| Red | Red earth/ochre<br>Vermilion<br>Red lake | **Fe**$_2O_3$<br>**Hg**S<br>unidentified, **Ca** substr |
| Blue | Azurite<br>Smalt | **Cu**$_3(CO_3)_2(OH)_2$<br>not a definite chemical compound containing **Co**, Si, K, As (Ni, Bi. . .) |
| Brown | Umber | **Fe**$_2O_3$ + **Mn**$O_2$ + n$H_2O$ + Si + $Al_2O_3$ |
| Black | Bone black | **Ca**$_3(PO_4)_2$ + $CaCO_3$ + C |

Relief of the Nativity

The XRF analyses identified two types of flesh tones. For the Child, the Virgin, and the angel, a blend of lead white in substantial amounts and vermilion was employed. The Hg content of the vermilion varies between 37.6 $\pm$ 0.5 cps and 61.9 $\pm$ 0.6 cps to achieve diverse shades of pink. These results are confirmed by cross-sections (A) and (B) in Table 1, although vermilion was not found in the stratigraphy of the angel in the selected area, probably because the sample was taken from a part of the skin very close to the clothing. On the other hand, the slightly darker flesh tones of the shepherd and Saint Joseph include some ochre identified by Fe peaks, see Figure 5. Due to the difficulty of positioning the XRF equipment close to the relief, only the mouth and eyes of the angel could be analysed. The predominant presence of Hg and Cu was found in these areas, indicating the most probable use of vermilion and azurite, respectively. Azurite was one of the most used blue pigments in Spain, not only for its beautiful colour and many different hues possible to obtain by finer or coarser grinding, but also due to the location of several copper mines in the Iberian Peninsula; therefore, it was not difficult to obtain [25,29]. This can be also supported by the signed contracts that specifically required the use of the highest quality pigment, which would be azurite.

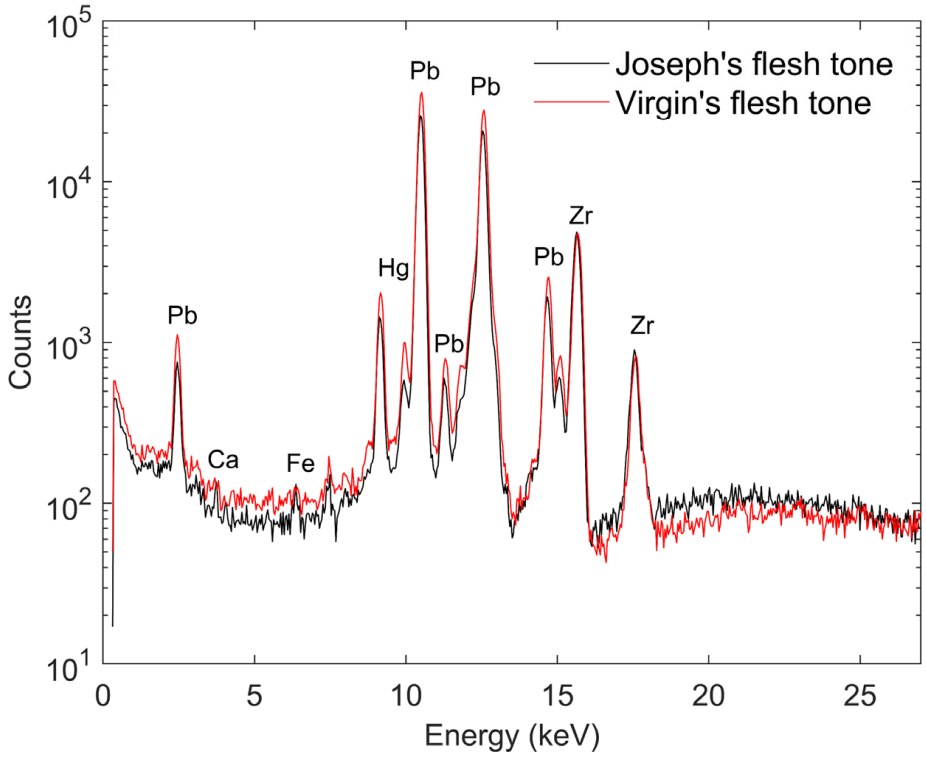


**Figure 5.** XRF spectra of the flesh tones, made with a high amount of lead white (Pb) and vermilion (Hg), with a small amount of ochre for Joseph.

The hair of the figures presents a variety of brown tones achieved through the combination of ochre, umber, vermilion, and quite possibly a copper-based green; green was often added to hair colour mixtures [30]. For the darker hue, there is an increase in the amount of umber (from 2.7 $\pm$ 0.2 cps to 8.7 $\pm$ 0.3 cps of Mn) and ochre (from 42.9 $\pm$ 0.5 cps to 72.7 $\pm$ 0.6 cps of Fe), accompanied by a decrease in vermilion (from 32.6 $\pm$ 0.5 cps to 8.8 $\pm$ 0.3 cps of Hg). However, the quantity of lead white remains relatively stable, likely originating from the primer, as illustrated in Figure 6. Additionally, Zr peaks originate from the detector's collimator and remain consistently present across all measurements, while Sr peaks typically appear alongside high Ca presence, suggesting a calcium-based primer impurity [31]. The intensity of the Sr peaks varies in relation to the intensity of the Ca peaks. In Saint Joseph's hair, which presents the darkest brown tone, the highest peaks of Ca were observed throughout the relief, suggesting the potential use of bone black, which offered more excellent opacity compared to other pigments used at the time [32]. Unfortunately, confirmation of its usage via phosphorus detection is not feasible, as this region of the spectrum is affected by the M-Pb peaks and electronic noise, and no sample could be taken for SEM-EDX analysis.

The vestments show a wide variety of colours: reds, browns, blues, and greens. A blend of vermilion with a small amount of a Cu-based pigment (azurite or a Cu-based green pigment) was predominantly used for the red clothes. Despite the inability to identify the Cu-based pigment by XRF analysis, the colour suggests the probable use of a green pigment; as a complementary colour to red, the artists usually selected it in such mixtures. Combining red with green results in a darker hue, while red with blue would create a purplish tone, which is not present here. A significant amount of ochre and umber was used for the brown attire, with traces of Cu-based green and lead white. This composition extends to other brown-coloured relief areas, such as the crib, architecture walls, and the stable, alongside the ox and the mule, although with varying pigment ratios to achieve different tonalities. The sheet beneath the Child and the sheep received a similar treatment, predominantly lead white and a touch of ochre.

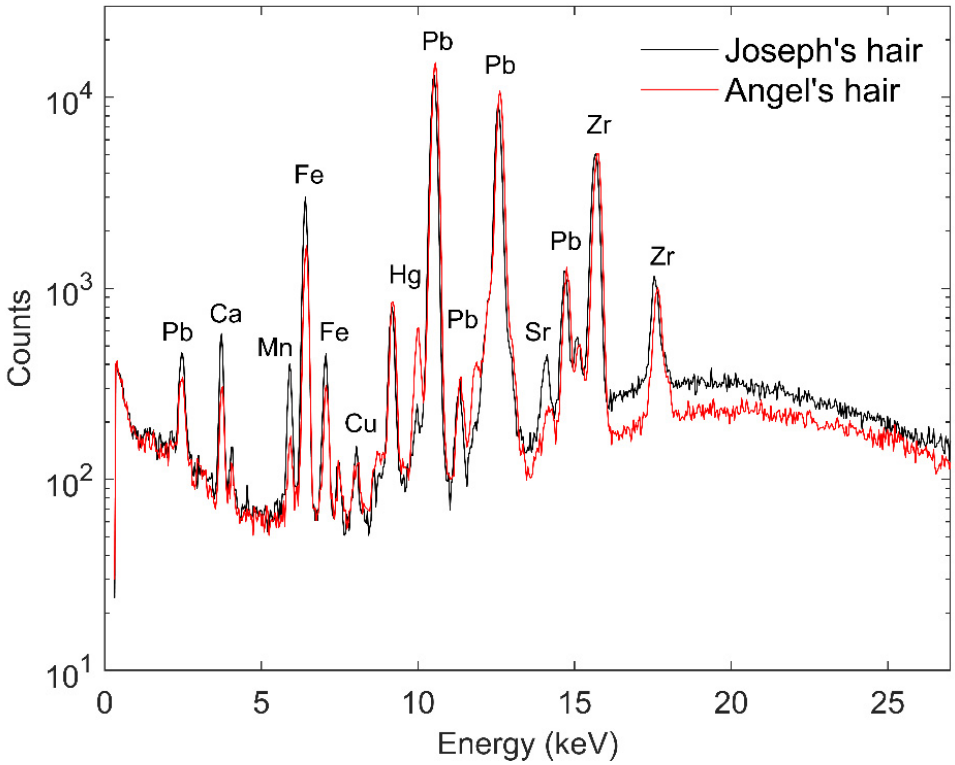


**Figure 6.** XRF spectra of the hair, made with ochre, umber, vermilion, and probably a copper-based green. Joseph's darker hair contains more umber and probably bone black.

Moving on to the blue and green clothing, there are notable peaks of Cu, which most probably identify the azurite and a copper-based green pigment, respectively. As stated above, azurite was a highly appreciated pigment, obtained from a semiprecious mineral, and the mostly used blue one in Spanish polychromy of the time, strongly recommended also by Pacheco [25]. The characterisation of the Cu green pigment is more complicated, since there were several in use (malachite, verdigris, copper resinate, etc.) and cannot be distinguished by XRF alone, as they are all characterised by the same chemical element, Cu. Molecular analysis would offer more precise identification, but such methods were inaccessible during the examination. Furthermore, these pigments could have been applied over a brownish or greyish layer to enhance colour intensity in order to save up the expensive pigment, as well as they could be darkened adding a black or brown (mostly iron oxide) pigment [33,34]. An iron oxide-based pigment must have been used as the underlayer or added to azurite in the studied polychromy, as high peaks of Fe are also detected, see Figure 7. Azurite was most likely used also to paint the sky, as already suggested by Pacheco [25,29] and most probably also for the blue areas of the angel's wings, according to Cu peaks.

Finally, the entire sculpture surface was gilded, except for the flesh and hair areas. Colour layers were applied over the gold and, next, partially removed by sgraffito technique. Sgraffito involves scratching, scoring, or engraving the polychromy with a stylus to reveal the burnished gold underneath the colour, creating brocade textile design [25]. The analysed areas showed Au peaks with varying intensity, depending on the superficial colour layer (ranging from 6.2 $\pm$ 0.4 cps to 128 $\pm$ 1 cps). Moreover, the presence of Fe was observed, indicating the use of red bole (soft clay applied as a base for gold) under the gold leaf. The cross-section prepared from the sample extracted from a golden area (Figure 4 and Table 1) reveals that some parts were intervened and refreshed with a new layer of gold leaf. The original layer, which lies underneath (layer 4 in the stratigraphy), was applied over the bole (layer 3), made of earth pigments, primarily clays, with traces of calcium carbonate and gypsum. Above this layer, two noticeably thick layers are observed: one white layer with a

preparation of calcium carbonate and gypsum (clearly distinguishable from the original ground layer) and another orangy layer, composed of earth pigments and a bit of calcium carbonate, serving as a base for the gold. The variation in the intensity of the Au peaks is also likely due to one or two layers of gold, depending on whether we analyse an original or intervened area.

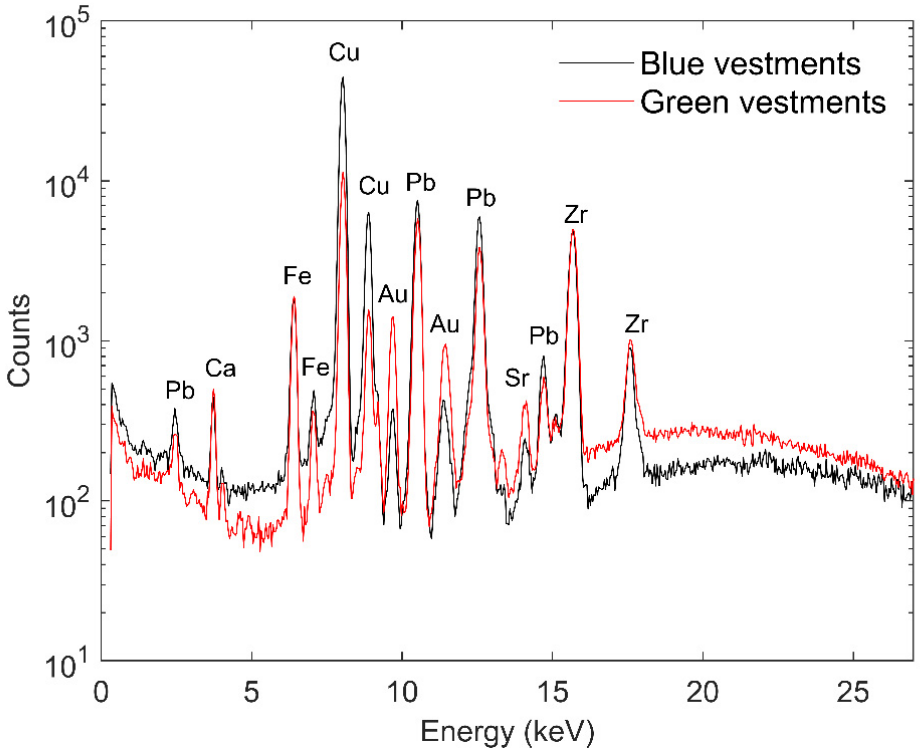


**Figure 7.** XRF spectra of blue and green vestments.

Saint Peter and Saint Paul

The flesh tones of Saint Peter and Saint Paul share a similar composition to those found in Saint Joseph and the Shepherd of the Nativity: lead white, vermilion, and ochre. However, these flesh tones include a small amount of a Cu-based pigment, which might be blue azurite or a Cu-based green pigment, according to old receipts for some flesh areas [25].

The estofado of the clothing of both saints is based on gold leaf, confirmed by the high peaks of Au. Gold is detected in every analysed point of both sculptures, excluding the flesh and hair areas, as observed in the relief. It was also applied over the bole, as indicated by prominent Fe peaks.

Saint Paul's red cloak was made mainly of vermilion mixed with ochre, supplemented possibly with a Cu-based green due to its darkened hue. On the other hand, the green colour of the tunic was painted with a Cu-based green (unidentifiable between malachite, verdigris, copper resinate, etc.) mixed with ochre and a bit of umber, while the violet shades may be obtained by combining azurite with red earth and/or red lake.

Looking at the sculpture of Saint Peter, the colour of the cloak was primarily obtained with a substantial amount of ochre, identified by intense Fe peaks, mixed with a small amount of umber and Cu-based green (more likely than Cu-based blue pigment for this colour). The blue tunic is painted most probably with azurite and a bit of smalt, the combination explained in Pacheco treatise for darkening of azurite [24,28]. The blue pigment could have been mixed with ochre or overlaid on a layer of ochre to intensify the colour (Figure 8) [25].

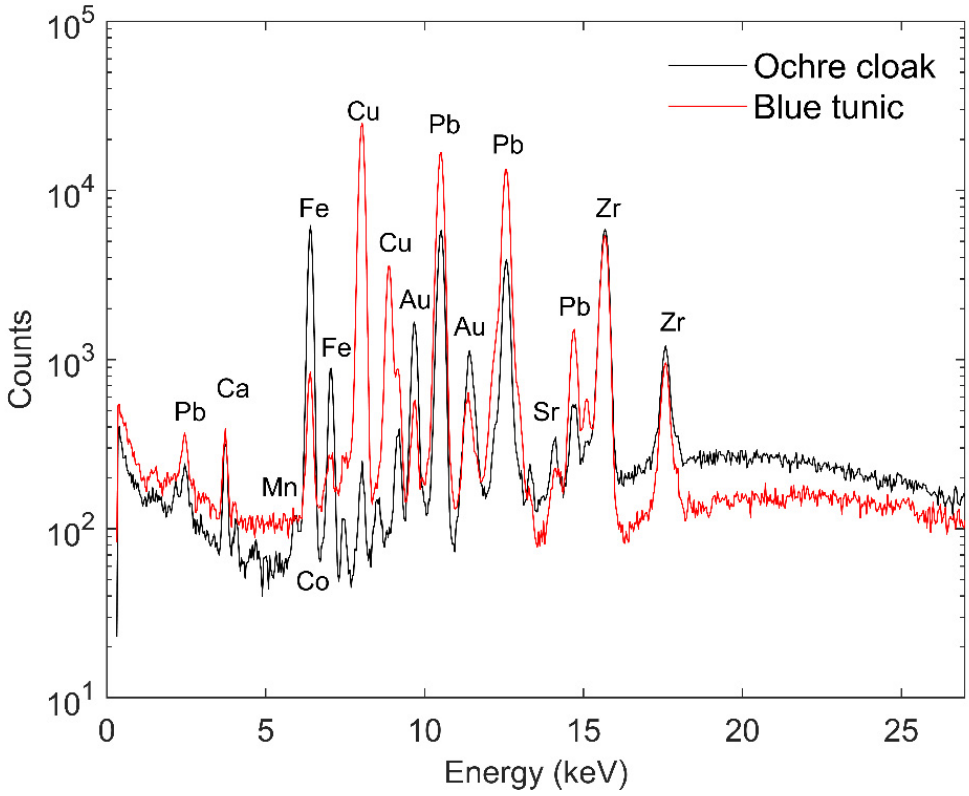


**Figure 8.** XRF spectra of Saint Peter's clothing.

Finally, the golden hues adorning the key, sword, and books carried by both figures were made with ochre, probably a Cu-based green, and a small amount of umber, while the sword presented silver.

Christ Crucified

Different areas of the flesh tones, hair, and cross were analysed. The flesh tone consists of a significant amount of lead white, blended with ochre, and a minimal amount of lead-tin yellow. Unlike the other sculptures analysed, vermilion was not detected in Christ's flesh tone, as it represents a lifeless body. Furthermore, it is the only figure whose flesh tone presents the addition of lead-tin yellow, giving it a lighter hue.

The blood running through Christ's body was painted with vermilion and applied over the flesh colour layer. In the shaded areas of the crown, hair, and cross, there is a decrease in the amount of lead white compared to the flesh tone. Christ's hair and the cross, both rendered in dark brown hues, were prepared with ochre, umber, a Cu-based green pigment [30], and some vermilion to give it a reddish undertone. Next, in the darker areas of the cross, high peaks of Ca were observed, indicating the use of bone black, further corroborated by a small amount of P. Lastly, the crown's ochre colour with greenish tones was mainly achieved with a Cu-based green pigment mixed with earth pigments (see Figure 9).

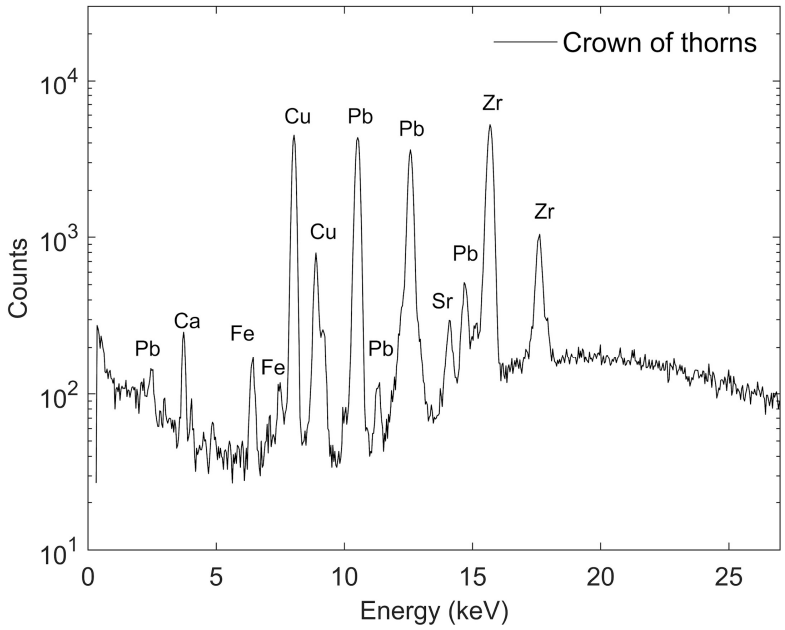


**Figure 9.** XRF spectrum of the crown of thorns.

## 4. Discussion

The analysis of the exceptional condition of the joint in the sculptures adorning the Santa Clara altarpiece reveals Montañés' mastery of woodwork. Unlike sculptures by other artists that exhibit evident signs of deterioration, Montañés' works display a notable absence of typical wood-related damages such as natural cracks and fissures. This observation suggests that Montañés had a profound understanding of wood's behaviour as an organic material, allowing for him to apply preventive measures and compositional strategies for the joinery that prevented future damage.

Montañés' skill in identifying and treating areas affected by natural cracks becomes evident in the CT examination of the sculptures. Montañés prevented the expansion of fissures over time by replacing compromised sections with pieces of wood without problems, shaped like dovetails, to ensure a robust connection. In addition, the careful hollowing of the sculptures reduced the likelihood of wood movement, thus minimising the risk of long-term structural damage. Figure 10 shows a recreation of the process followed by Montañés to sculpt the image of Saint Anthony.

The observation under UV light revealed many interventions primarily located in the flesh areas. It is common for these areas to undergo restoration more often than the garments, as the latter are usually more complex due to the diverse techniques used in their creation: gilding, tempera, gesso, and sgraffito, among others. Additionally, there is an aesthetic consideration, as damages or losses in the flesh areas are more noticeable than those in the clothing, which can be more easily camouflaged within the overall decoration.

We also observe that sculptures tend to have more interventions when they are closer and more accessible. The sculptures of Saint Peter and Saint Paul located on the lower part of the altarpiece show more interventions than the Nativity on the second body. At the same time, the Christ Crucified sculpture in the attic has barely been intervened. Therefore, the intervention criterion seems influenced by accessibility (the ease of reaching the image, requiring scaffolding for higher elements) and the visibility of the losses or damages.

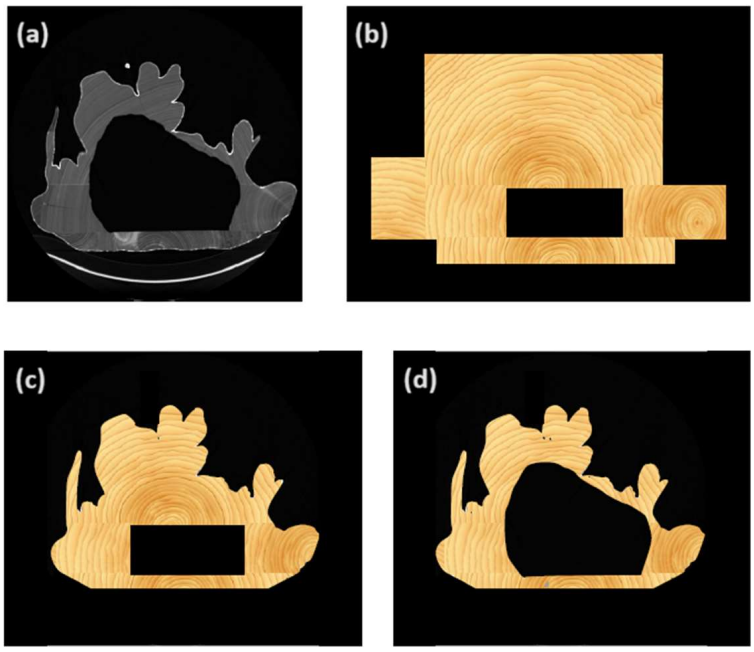


**Figure 10.** Recreation of the construction process of a (**b**) joint, (**c**) carved and (**d**) hollowed, based on the (**a**) transversal image of the CT of the sculpture of Saint Anthony.

On the other hand, we can verify how the use of the pigments in the polychromy significantly corresponds with contemporary treaties and documents [6,7,33]. It is important to mention that these studies only show the material composition of the works; however, they overlook the artist's creativity and decorative aspects, which are visible to the naked eye.

The polychromy of the Santa Clara altarpiece was commissioned to a single workshop under the direction of the painter Baltasar Quintero. This can be observed in the garment decorations, executed using distinct templates characteristic of each workshop, thus limiting the artists' creativity. In addition, there are no differences in the chemical composition of the materials used throughout the altarpiece, as they all originate from the same source and were procured by the workshop for general use. However, it is evident that, in a work of such magnitude, the master relied on the assistance of workshop members (journeymen and apprentices), reflected in subtle differences observed in the execution and finishing quality of decorative elements such as gilding and sgraffito.

The process of preparing colours and mixtures can be considered personal to each artist rather than specific to each workshop, depending on how they conducted the grinding process. It is essential to bear in mind that pigments, usually in powder or mineral form, need to be grounded, meticulously washed and purified, and then mixed with a binder. Variation in pigment grinding results in different hues obtained with the same pigment, as colour is influenced by the particle size and light reflection [6,7,32]. This aspect remains undisclosed due to the impossibility of conducting an exhaustive analysis of all the colours used in the garments and flesh tones across all the sculptural pieces. We cannot confirm whether the pigments were ground by the same artist or an apprentice, who generally prepared all the materials, and we cannot determine if they were prepared at different times by different individuals.

A gypsum ground layer was observed in the three stratigraphies, and the XRF analyses are consistent with this primer applied on the entire surface, except for the flesh areas where Ca peaks were not detected. As mentioned in the terms of the contract for the polychromies, the ground layers consisted of four layers of coarse gypsum and four layers of matte gypsum, which would explain their thickness of over 500 µm. It is a common procedure for baroque sculpture grounds to apply these two kinds of gypsum, as suggested by Pacheco and found in contemporary Baroque polychromed sculpture [25]. Nowadays, gypsum is principally a calcium sulphate; however, in the 17th century, we can distinguish

a coarse gypsum that predominantly consisted of sulphate anhydrite (being mixed with only a little amount of water), while the matte one used for the upper layers needed more water and was finer, consisting mostly of sulphate hydrate [35]. Since each layer of gypsum (coarse or matte) is identified by Ca, it is not possible to differentiate between them.

The contract emphasises the importance of respecting the flesh area to the fullest extent possible, ensuring it does not resemble wood prepared for polychrome. The analyses corroborate this condition, as characteristic Ca peaks of gypsum are not detected in the flesh areas. However, the documentation does not specify the type of primer these areas received, but scientific analyses corroborate what was documented in the treaties of the time and what the painter Francisco Pacheco exposed in his work "Arte de la Pintura" [6,7] (book III, p. 406): "...they shall be more finely finished and sanded in the wood, and shall spare the painter many ground layers (as was the case with those of Delgado and Martínez), and it shall suffice to give unto the flesh a coat of *giscola* with dead model plaster and a little ground white lead, all mixed in water and mingled with scrap glue, somewhat stronger than a bowl tempera, to apply two or three coats, and after it hath dried, to sand it once or twice, until all hair and beard, and all the highs and lows be without a granule, and very tender and smooth to the touch: priming over it with oil colours of flesh and a little red lead or litharge for a drier, all that which is to be incarnate in a matte finish."

In the faces of the shepherd and Saint Joseph, Ca was observed to have a low presence. This could be attributed to the preparation method for the matte flesh tones. In this process, only *giscola* (glue with garlic as a degreaser) [6,7] was applied along with a small amount of dead gypsum (gypsum that had already set and dried and was ground again) and ground lead white, all mixed in water with scraps of glue (pieces of leather from glove manufacturing waste that provided a purer and finer glue), applied in two or three layers. However, the impregnation of glue on the surface, which appears in the stratigraphy analysis, was uncommon in this type of matte flesh tones. This would contribute shine to the finish, contradicting the intended matte effect. Baltasar Quintero possibly added calcium carbonate to the colour mixtures to rectify this. Besides providing more opaque colours, this addition reduced the oil paint's glossiness. The combination of the glue layer and the calcium carbonate provided a satin finish characterised by a waxy shine, which was distinctive of this painter.

The analysis of the polychromy of the relief of the Nativity is particularly interesting. Two types of flesh tones were identified, perfectly reflecting the descriptions found in contemporary treaties [6,7,32,36], as well as in the conditions of contracts for other works of many artists: a rosy hue for children, women, and angels, and another ochre for male characters. The rosy tones were mainly achieved with a mixture of lead white and vermilion, as confirmed by stratigraphies, although sometimes with lead white and a bit of carmine. Francisco Pacheco [6,7] mentioned that over time, the oil in the mixture would naturally add a slight yellowish tint due to material ageing. In the case of male figures, a certain amount of ochre was added to the mixture, precisely as identified by XRF analyses. Finally, for the flesh tones of elderly male characters, it was common to add umber; however, in the images of Saint Peter and Saint Paul, the presence of Cu is observed, indicating the use of a Cu-based green or blue pigment.

Another characteristic of Baltasar Quintero was painting the pupils in light tones (bluish-green), rarely brown or black. This produces a certain sweetness to the faces and gazes. XRF measurements demonstrated that the angel's eyes are painted with azurite. Due to environmental conditions and ageing, azurite tends to acquire a greenish hue, so these bluish-green tones are visually appreciated in various parts of the altarpiece.

The hair treatment presents peculiarities. Brown tones were achieved solely by combining ochre and umber, while Cu-based green and vermilion were employed to provide highlights and seek nuances, avoiding a homogeneous tone. There are no data describing these characteristics until Antonio Palomino mentions them in the early 18th century [32]. These nuances would replace ground gold for hair, which persisted in children, women,

and angels until the early 17th century. On the other hand, the use of bone black in darker hair was quite common, given its high opacity [32].

The variety of tones found in Baltasar Quintero's work is typical. It is also quite peculiar that a high percentage of pigments containing Cu appear blended in different colours. We can observe numerous estofados painted with azurite and/or a Cu-based green. Occasionally, depending on its source, the azurite could be quite dark when mixed with oil for painting, so lead white was often added to lighten the hue or to serve as a drier.

The polychromy of the Christ Crucified sculpture in the attic is extremely interesting due to its complete originality, preserved thanks to its inaccessible location. It follows the chromatic standards of the time, with a flesh tone composed mainly of lead white and ochre. A lead-tin yellow is employed instead of a green pigment commonly used in depictions of deceased bodies, producing an impression of lifeless yet delicate skin. The absence of vermilion in the lifeless body enhances its realism, a sought-after characteristic in Baroque representations.

It was also common in those years for the crown of thorns to be painted in greenish tones, contrasting with the current representations in very dark hues. This greenish tone contributes to the realism, as a braided crown should be made with fresh green branches, as dried ones would break if bent. Both the hair and the cross display the artist's singularity, achieving the dark brown colour by mixing different tones, including reds and greens.

Finally, the intense peaks of Au observed by XRF in all the garments and the stratigraphy in Table 1 showing a gold percentage higher than 90% offer evidence of adherence to the contract, which mandated the use of the highest quality gold available in Seville, due to the abundance of this precious metal in the region.

## 5. Conclusions

The detailed analyses of the wood carvings from the altarpiece of the Church of Santa Clara in Seville (Spain) reveal Montañés' excellent technical mastery and precise work with wood, surpassing that of his contemporaries and successors. His comprehension of the behaviour of this organic material enabled him to implement preventive measures and compositional strategies that protected his works from future deterioration.

The study of the polychromy verified adherence to the conditions stipulated by Montañés in the contract, along with an insight into the techniques and materials used by the painter Baltasar Quintero. Differences in the flesh tones based on the gender and age of the depicted characters were identified, as well as the use of specific pigments to achieve realistic effects. Furthermore, no ground layer of gypsum was applied over the flesh areas, and it is worth noting the exceptional quality of the gold used, which met the strict requirements.

The multidisciplinary study of the altarpiece of Santa Clara church provides a deep insight into Montañés' technical skills. It also enhances our understanding of the techniques and materials used in sculpture and polychromy during the Baroque period. These results significantly enrich our appreciation and comprehension of sacred art from the "Golden Age" of Spanish art.

**Author Contributions:** J.M.-S.: Conceptualisation, Methodology, Formal Analysis, Investigation, Writing—Original draft, Writing—Review and Editing, Validation, Visualisation. A.K.: Conceptualisation, Methodology, Formal Analysis, Investigation, Validation, Visualisation, Writing—Review and Editing. C.M.-G.: Conceptualisation, Writing—Original draft, Validation. A.G.-O.: Conceptualisation, Writing—Original draft, Validation. F.J.A.: Visualisation, Writing—Review and Editing. A.M.-d.-S.: Conceptualisation. M.Á.R.: Supervision, Project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The raw data supporting the conclusions of this article will be made available by the authors on request.

**Conflicts of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## Appendix A

**Table A1.** Elements and proposed pigments in each spot analysed by XRF in Figure A1. The ground layer is assumed gypsum from the analysis of the samples.

| Spot | Elements | Proposed Pigment |
|---|---|---|
| 1 | Ca *, Fe, Cu, Au, Hg, Pb | (g.b.g), Cu-based green, vermilion, lead white |
| 2 | Ca, Ti *, Fe, Cu *, Au, Pb * | (g.b.g), titanium white, most probably azurite, lead white |
| 3 | Ca, Fe, Cu, Au, Pb * | (g.b.g), most probably azurite, lead white |
| 4 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, most probably azurite, lead white |
| 5 | Hg, Pb | Vermilion, lead white |
| 6 | Ca, Ti, Fe, Zn, Hg, Pb | Gypsum, titanium white, ochre, zinc white, vermilion, lead white |
| 7 | Ca, Ti *, Mn *, Fe, Cu, Au, Pb | (g.b.g), titanium white, umber, ochre, Cu-based green, lead white |
| 8 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, Cu-based green, lead white |
| 9 | Ca, Mn *, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 10 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, most probably azurite, lead white |
| 11 | Ca, Ti *, Fe, Cu, Zn *, Au, Pb * | (g.b.g), titanium white, ochre, Cu-based green, Zinc white, lead white |
| 12 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, Cu-based green, lead white |
| 13 | Ca *, Fe *, Hg, Pb | Ochre, vermilion, lead white |
| 14 | Hg, Pb | Vermilion, lead white |
| 15 | Ca, Mn *, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 16 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, red lake, most probably azurite, lead white |
| 17 | Ca *, Fe *, Hg, Pb | Ochre, vermilion, lead white |
| 18 | Ca, Mn, Fe, Cu, Hg, Pb | Gypsum, umber, ochre, Cu-based green, vermilion, lead white |
| 19 | Ca, Mn, Fe, Cu, Zn *, Hg, Pb | Gypsum, umber, ochre, Cu-based green, zinc white, vermilion, lead white |
| 20 | Ca, Fe, Cu, Au, Pb * | (g.b.g), ochre, Cu-based green, lead white |
| 21 | Hg, Pb | Vermilion, lead white |
| 22 | Ca, Mn, Fe, Cu, Zn *, Hg, Pb | Gypsum, umber, ochre, Cu-based green, zinc white, vermilion, lead white |
| 23 | Ca, Mn *, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 24 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, most probably azurite, lead white |
| 25 | Ca, Fe, Cu, Au, Pb | (g.b.g), Cu-based green and/or most probably azurite, lead white |
| 26 | Ca, Fe, Cu, Au, Hg, Pb | (g.b.g), Cu-based green and/or most probably azurite, vermilion, lead white |
| 27 | Ca, Mn *, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 28 | Ca, Fe, Cu *, Au, Pb | (g.b.g), ochre, Cu-based green, lead white |
| 29 | Ca, Mn, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 30 | Ca, Fe, Cu, Au, Pb | (g.b.g), ochre, most probably azurite, lead white |
| 31 | Ca, Mn, Fe, Cu, Hg, Pb | Gypsum, umber, ochre, Cu-based green, vermilion, lead white |
| 32 | Ca, Fe, Cu *, Au, Pb | (g.b.g), ochre, Cu-based green, lead white |
| 33 | Ca, Mn, Fe, Cu, Hg, Pb | Gypsum, bone black, umber, ochre, Cu-based green, vermilion, lead white |
| 34 | Ca *, Fe *, Hg, Pb | Ochre, vermilion, lead white |
| 35 | Hg, Pb | Vermilion, lead white |
| 36 | Fe *, Cu *, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 37 | Mn *, Fe, Cu, Hg, Pb | Umber, ochre, most probably azurite, lead white, vermilion |
| 38 | Fe *, Hg, Pb | Ochre, vermilion, lead white |
| 39 | Ca, Mn *, Fe, Cu, Au, Pb * | (g.b.g), umber, ochre, Cu-based green, lead white |

g.b.g: Gypsum, bole, and gold. * Low proportion.




**Figure A1.** Numbers indicating the spots analysed by XRF in the Relief of the Nativity.

**Table A2.** Elements and proposed pigments in each spot analysed by XRF in Figure A2. The ground layer is assumed gypsum from the analysis of the samples.

| Spot | Elements | Proposed Pigment |
|---|---|---|
| 1 | Ca, Fe, Cu *, Hg, Pb | Gypsum, ochre, Cu-based green, vermilion, lead white |
| 2 | Fe *, Cu *, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 3 | Fe, Cu, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 4 | Ca, Fe, Cu, Hg, Pb | Gypsum, ochre, Cu-based green, vermilion, lead white |
| 5 | Ca, Ti *, Fe, Cu, Au, Pb * | (g.b.g), titanium white, ochre, Cu-based green, lead white |
| 6 | Ca, Ti, Mn *, Fe, Cu, Zn, Pb * | (g.b.g), titanium white, umber, ochre, Cu-based green, zinc, white, lead white |
| 7 | K, Ca, Ti, Cr *, Mn, Fe, Cu, Zn, Au, Pb * | (g.b.g), titanium white, chrome green, umber, ochre, Cu-based green, zinc white and/or yellow, lead white |
| 8 | Ca, Ti, Ba, Cr *, Fe, Cu, Zn, Hg, Pb | Titanium white, barium white, chrome green, ochre, Cu-based green, zinc, white, vermilion, lead white |
| 9 | Fe *, Cu, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 10 | Ca, Ti *, Mn *, Fe, Cu, Au, Pb * | (g.b.g), titanium white, umber, ochre, Cu-based green, lead white |
| 11 | Ca, Co, Fe, Cu, Au, Pb, As | (g.b.g), smalt, ochre, most probably azurite, lead white |
| 12 | Ca, Ti, Fe, Cu, Au, Pb * | (g.b.g), titanium white, ochre, Cu-based green, lead white |
| 13 | Ca, Mn *, Fe, Au, Pb | (g.b.g), umber, ochre, lead white |
| 14 | Ca, Mn, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 15 | Ca, Mn, Fe, Cu, Pb * | Gypsum, umber, ochre, Cu-based green, lead white |

g.b.g: Gypsum, bole, and gold. * Low proportion.




**Figure A2.** Numbers indicating the spots analysed by XRF in Saint Peter.

**Table A3.** Elements and proposed pigments in each spot analysed by XRF in Figure A3. The ground layer is assumed gypsum from the analysis of the samples.

| Spot | Elements | Proposed Pigment |
|---|---|---|
| 1 | Fe *, Cu, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 2 | Ca *, Fe, Cu *, Hg, Pb | Gypsum, ochre, Cu-based green, vermilion, lead white |
| 3 | Ca, Ti, Fe, Cu, Au, Pb * | (g.b.g), titanium white, ochre, Cu-based green, lead white |
| 4 | Ca *, Mn *, Fe, Cu, Au, Pb | (g.b.g), umber, ochre, Cu-based green, lead white |
| 5 | Ca, Ti, Cr *, Mn *, Fe, Zn, Hg *, Pb, Ag | Gypsum, titanium white, chrome green, umber, ochre, zinc white, vermilion, lead white, silver. |
| 6 | Ca, Ti, Fe, Cu *, Au, Hg, Pb | (g.b.g), titanium white, ochre, Cu-based green, vermilion, lead white |
| 7 | Fe *, Cu *, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 8 | Ca, Ti, Cr, Mn, Fe, Cu, Au, Pb | (g.b.g), titanium white, chrome green, umber, ochre, Cu-based green and/or most probably azurite, lead white |
| 9 | Ca, Ti *, Ba, Cr, Mn, Fe, Cu, Zn, Au, Pb * | (g.b.g), titanium white, barium white, chrome green, umber, ochre, Cu-based green and/or most probably azurite, zinc white, lead white |
| 10 | Ca, Fe, Cu, Au, Hg, Pb | (g.b.g), ochre, Cu-based green and/or most probably azurite, vermilion, lead white |
| 11 | Ca, Fe, Cu, Au, Hg, Pb | (g.b.g), ochre, Cu-based green, vermilion, lead white |
| 12 | Ca *, Fe *, Cu, Hg, Au, Pb | (g.b.g), ochre, Cu-based green, vermilion, lead white |
| 13 | Ca, Ti *, Fe, Cu, Au, Hg, Pb | (g.b.g), titanium white, ochre, Cu-based green, vermilion, lead white |

g.b.g: Gypsum, bole, and gold. * Low proportion.

**Table A4.** Elements and proposed pigments in each spot analysed by XRF in Figure A4. The ground layer is assumed gypsum from the analysis of the samples.

| Spot | Elements | Proposed Pigment |
|---|---|---|
| 1 | Ca, Sn, Pb | Gypsum, lead-tin yellow, lead white |
| 2 | Fe *, Cu *, Sn *, Pb | Ochre, Cu-based green, lead-tin yellow, lead white |
| 3 | Fe, Cu *, Hg, Pb | Ochre, Cu-based green, vermilion, lead white |
| 4 | Fe *, Sn *, Pb | Ochre, lead-tin yellow, lead white |
| 5 | Fe *, Sn, Pb | Ochre, lead-tin yellow, lead white |
| 6 | Fe *, Hg, Pb | Ochre, vermilion, lead white |
| 7 | Ca, Ba, Fe, Cu, Pb * | Gypsum, barium White, ochre, Cu-based green, lead white |
| 8 | Ca, Mn, Fe, Cu, Hg, Pb | Gypsum, umber, ochre, Cu-based green, vermilion, lead white |
| 9 | Ca, Mn *, Fe, Cu, Hg *, Pb * | Gypsum, umber, ochre, Cu-based green, vermilion, lead white |

* Low proportion.




**Figure A3.** Numbers indicating the spots analysed by XRF in Saint Paul.




**Figure A4.** Numbers indicating the spots analysed by XRF in Christ Crucified.

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