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# Characterization of color production in Xallás palace complex, Teotihuacan

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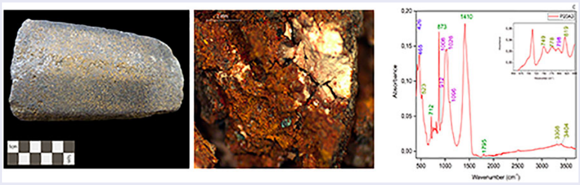
**ABSTRACT**

A multi-analytical approach was used to characterize color remains from Xalla, a Teotihuacan palace complex (project *Teotihuacan, Elite and Government. Excavations in Xalla* led by Linda R. Manzanilla). Color samples were obtained from polished lithic instruments and pigment ores. Those samples were analyzed combining microscopic and spectroscopic techniques. Our results coincide with previous studies in Teotihuacan, with the chromatic palette displaying a predominance of iron oxides such as hematite, yellow ochre and natural earths, as well as malachite, celadonite and glauconite. We have enlarged the corpus of raw materials with the characterization of jarosite and *bone white* and mica as aggregate. The identification of raw materials crossed with functional analysis of polished lithic artefacts suggests a production and application process for the pigmenting materials that were divided in four phases, from the crushing of the raw material to the application and finishing of the painted surfaces.



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Pigments; craft production; Teotihuacan; Archaeometry

## 1. Introduction

The cultural study of coloring materials in ancient civilizations includes the characterization of raw materials, analysis of the procurement process, transport, storage, production, acquisition and use. Each of these phases reveals information of interest about the specialists who worked in these processes, and the level of technological and practical knowledge of these ancient societies.

Color comprises one of the main traits in the artistic expressions of Teotihuacan, a Mesoamerican city that developed during the classic period (AD 150/200-650) located in the Teotihuacan valley of central Mexico (Cowgill 2015; Manzanilla 2009a; Millon 1981; Robb 2017). Following a pattern common in Mesoamerica, Teotihuacan must have been completely painted (Berrin et al. 1988; Berrin and Pasztory 1994; Boone 1985; Robb 2017). The chromatic palette found in this city includes the characteristic "Teotihuacan red" or *rojo guinda* (hematite or natural earths), orange (hematite mixed with lepidocrosite), pink (hematite mixed with calcite), yellow (lepidocrosite or goethite), green (malachite) and blue (azurite), each of them with various middle shades and hues (Magaloni Kerpel 1996, 2003, 2017; Martínez García et al. 2012).

This chromatic palette was applied in the urban architecture, decorating the walls with rich mural paintings (Magaloni Kerpel 2017; Miller 1973; Millon 1972), in polychrome stuccoed ceramics (Conides 2018; ÓNeil 2017), as well as in varied sculptural expressions and in plastic arts made of varied materials such as shells and textiles (Manzanilla et al. 2011; Rodríguez Galicia, Valadez Azúa, and Martínez Mayén 2017) or in funeral practices, both for practical and symbolic purposes (Doménech Carbó et al. 2012; Vázquez de Ágredos Pascual and Manzanilla 2016).

Despite the large number of polychrome archaeological remains found at Teotihuacan, only a limited number of investigations into color production have been carried out (Sánchez Morton 2013). The present research conceptualizes color as good – as a product derived from a production process – and focuses on the characterization of color samples preserved on

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polished lithic instruments and architectural elements from the Xalla palatial complex.

Thus, the polished lithic artifacts studied allowed us to deepen our knowledge about the art of making color in Teotihuacan, and together with the architectural remains painted in red, green and yellow, allowed us to obtain information about the operational sequence followed by the artisans, from the procurement of raw materials to the final painted product.

### 1.1. The palatial complex of Xalla

Xalla is a multi-functional palatial complex in the heart of Teotihuacan. The chronology of Xalla begins *ca*. AD 155 with a foundation offering from the Miccaotli phase (*ca*. AD 160) of *Spondylus* shells and jade beads from the Motagua Valley (Guatemala) and ends by AD 550 with the great fire in the core of the city, covering all the phases of Teotihuacańs Classical period. There is also evidence of post-Teotihuacan occupation in the Coyotlatelco phase (AD 650-850/900) (Flannery 1998; Manzanilla 2006, 2008, 2009b, 2017a, 2017b, 77–81; Manzanilla and López Luján 2001).

Located in the north-east section of the city, in the N4E1 square of R. Millońs map (Millon, Drewitt, and Cowgill 1973), the complex is in a privileged location to the east of the Street of the Dead and to the north of Pyramid of the Sun. Xalla is a large complex (55000 m$^2$), organized in eight squares or plazas around which there are a total of 29 buildings (Manzanilla 2017b, 2017a, 77–81; Manzanilla and López Luján 2001).

The tools and materials studied in this work come from the three plazas in the central sector of Xalla (P1, P2 and P5). The main square (P1) of the complex is intended for ritual practice, with four structures oriented to each cardinal point and distributed around a temple (E9) in the center (Figure 1).

*Plaza 2* (P2) is located north of P1, and consists of three structures, E10, E11 and E12. Structure E12 stands out from the rest; in this large mound situated to the north-west of P2, several red, orange and green nodules, in addition to other materials such as green stone beads, worked bone and the so-called treasure of mica, have been recovered (Xolalpan AD 350-550).

Plaza 5 (P5) is located to the south of the main square or *plaza* of the palatial complex. In this southern section of the complex is where the ruling elite of Xalla established the craftspeople attached to the complex: lapidaries, potters, garment-makers, bone industry workers and, probably, color artisans (Manzanilla 2017b; Manzanilla et al. 2017; Manzanilla and López

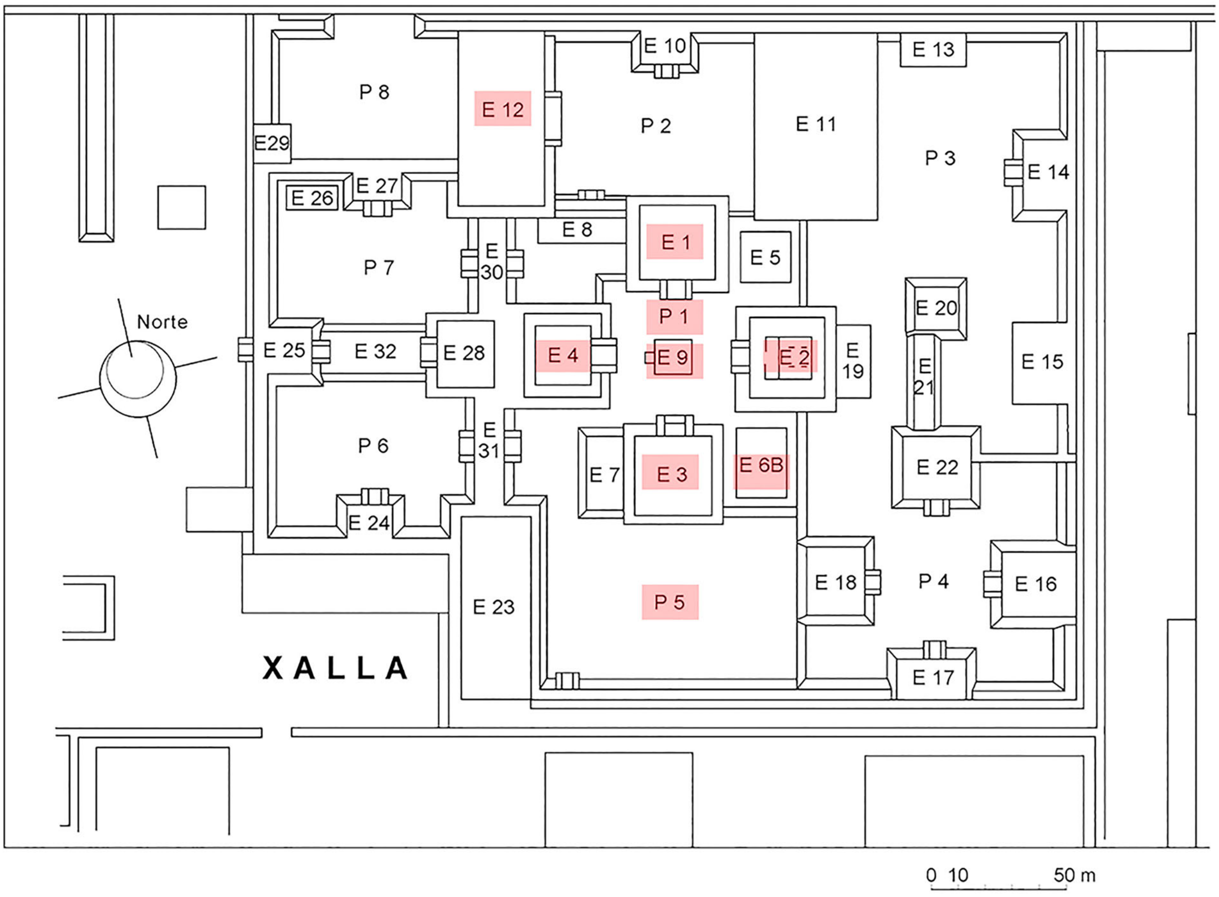


**Figure 1.** Xalla planimetry. Provenance areas of color samples are marked in red. Source *Proyecto Teotihuacan. Élite y Gobierno. Excavaciones en Xalla y Teorpancazco* (Dir. Linda R. Manzanilla), redrawn after Millon, 1973.

Luján 2001; Pérez Roldán 2005; Rosales de la Rosa and Manzanilla 2011).

This palatial complex is not an exception to the polychrome pattern elaborated in the prehispanic city. In ancient times, the floors and walls of Xalla must have been decorated with red, pink, yellow and dark blue paints. The excavations in this archaeological complex have revealed a great amount of archaeological materials with remnants of color, including on polished lithic instruments, architecture, painted stucco fragments, and nodules of green, orange and various shades of red.

## 2. Materials and methods

Color samples were obtained from diverse types of polished archaeological lithic instruments like grinders, crushers, trowels or smoothing tools, color nodules and architectural elements like *almenas* (architectural elements on structures' roofs) with remains of polychrome decoration. The materiaĺs chronology spans from AD 250–550 (Tlamimilolpa and Xolalpan temporal phases), corresponding to the 2nd and 3rd technical phases of Teotihuacańs mural painting according to previous studies (Magaloni Kerpel 1996).

The selection criteria for sampling was carried out according to: (1) the concentration of color, (2) the purity of the color[1], (3) the area of the instrument where the color is located – selecting the evidence of color that were located on work surfaces – and (4) the archaeological context, taking into account materials excavated within the areas of activity (Manzanilla 1986, 11) or the levels of occupation. For the chromatic classification of colors, the Munsell scale of soils has been followed (Munsell soil color charts 1992).

The revision of the archaeological materials and the sampling phase led to the selection of twenty-six red samples of different shades and hues, four pink, twenty-nine yellow, eight orange and four green (Figure 2). All the pigments presented a quality of brightness and iridescence, both typically found in Teotihuacańs mural paintings.

We used a combination of spectroscopic and microscopic techniques such as Light Microscopy (LM), X-Ray Fluorescence (XRF), Raman Spectroscopy and Infrared Spectroscopy (ATR-FTIR), X-Ray Diffraction

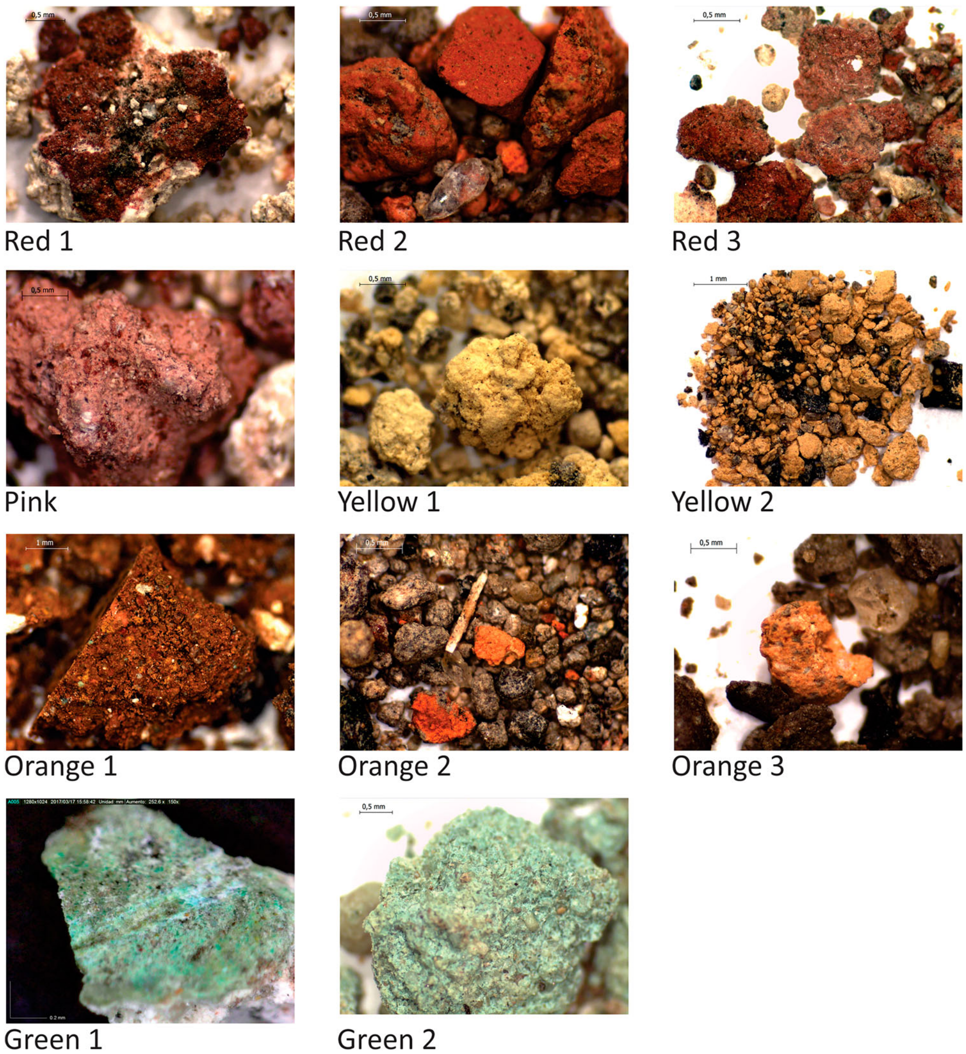


**Figure 2.** Microphotographs of color samples of Xalla and their subgroups by elemental composition.

(XRD) and Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM-EDS).

### 2.1. Light microscopy (LM)

The analysis was performed with a stereoscopic optical microscope *Leica GZ6* (10X -50X) with overhead and transversal light. Additional observations were carried out with a digital optical microscope *Dino-Lite Edge* (20X-230X) with depth of field correction.

### 2.2. X-Ray fluorescence (XRF)

XRF spectra were acquired with *SANDRA*, a system developed at the Physics Institute, UNAM (Ruvalcaba Sil et al. 2010). The system employs a molybdenum (Mo) X-Ray tube with a beryllium exit window (Be) and a 1 mm dia. collimator, and an Amptek X-123 Si-PIN X-Ray detector. The equipment has two lasers and a camera to observe the analysis area. Analytical conditions were set at 0.15 mA current, 30 keV energy, and a 200 s acquisition time, with three points analyzed per sample. Spectra deconvolution was carried out with the *PyMca* 3.3 software.

### 2.3. Raman Spectroscopy

Raman was performed by an *i-Raman EX* from *BW&TEK*, with a 1064 nm excitation laser, a maximum power of 120 mW, and a 4 $cm^{-1}$ resolution. Three points were analyzed per sample, with acquisition time ranging from 5 to 10 s, and a laser diameter between 20 and 50 μm. Spectra obtained were compared with the RRUFF database (Lafuente et al. 2015).

### 2.4. Fourier Transformed Infrared Spectroscopy-Attenuated Total Reflectance (FTIR-ATR)

FTIR-ATR spectra were collected with a *BRUKER Alpha FTIR* spectrometer using a total attenuated reflection module, covering a spectral range between 400 and 4000 $cm^{-1}$ with a 4 $cm^{-1}$ resolution and 32 scans per spectrum. The spectra obtained were compared with diverse databases (Chukanov 2014; Vahur et al. 2016).

### 2.5. X-Ray Diffraction (XRD)

Diffraction patterns were obtained with a *Bruker D8 Advance* diffractometer with Bragg Brentano geometry, θ-θ configuration, Cu radiation (Kα) with a silicon band detector (Lynxeye Bruker). Acquisitions were carried out at room temperature, in air atmosphere and atmospheric pressure. Diffraction intensity was made as a function of the 2θ angle, measured between 4.0° and 110° with a step 2θ of 0.02°, and 52.8 s per point.

### 2.6. Scanning Electron Microscopy – Energy Dispersive X-ray spectroscopy (SEM-EDS)

Backscattered electron images and elemental distribution maps – as well as the characterization of the elemental chemistry – were acquired with a *JEOL JSM6300*. Additional acquisitions were carried with a *Hitachi TM3030 Plus* with 18 kV voltage.

## 3. Results and discussion

Table 1 summarizes the coloring materials identified in this work. For each of the analyzed colors, only the techniques that provided a characterization of the coloring compounds are presented. The chromatic variety observed, the fine granulometry of the pigments and the wide tonal variety of the colors allow us to place these pigments in the 2nd-3rd technical phase of Teotihuacan mural painting (Tlamimilolpa-Xolalpan, AD 200-550) (Magaloni Kerpel 1996). These results allow us to investigate with greater depth the chromatic and material repertoire of the color production at Xalla, as well as to infer a possible operational chain.

*RED*. Red color was taken from grinders and handles, smoothing tools, polishers, crushers, ores of color and architectural elements such as walls. The red group has 26 samples with differences in shade and in the heterogeneity or homogeneity of their composition. Four types of red were defined according to their shade and hue, 10R 3/6 dark red, 10R 4/6 red, 10R 5/6, and 2.5YR 4/8 red.

All of the red samples displayed high values of Fe, with a lower presence of elements like Ca, Ti, K, Si, Sr and Mn, which are typical elements found in natural earths. The samples that only displayed these elements have been grouped as Red 1. Three samples displayed characteristic values of Pb content in their elemental composition (grouped as Red 2). The presence of this element in Red 2 allows us to hypothesize that certain natural earths may have been brought from the Teotihuacan enclaves in the Mesoamerican West, where the mining deposits of the *Cinturón de Cobre de Michoacán* present a high abundance of Cu, Sr and Pb (Doménech Carbó et al. 2012; Panczner 1987). To validate this hypothesis, further analyses on the samples and possible deposits must be done.

Raman spectroscopy identified the characteristic peaks of hematite ($Fe_2O_4$) (224 $cm^{-1}$, 291-295 $cm^{-1}$, 408-411 $cm^{-1}$ and 609-612 $cm^{-1}$) (Figure 3), which is probably the main generator of the red chroma in Xalla. FTIR-ATR spectra allowed us to differentiate two subgroups of Red 1. As shown in Figures 3(A) and 4(B), subgroup Red 1a – upper A spectrum- presents characteristic bands of calcite ($CaCo_3$) at 712, 873, 1031 and 1795 $cm^{-1}$, hematite at 455-458 $cm^{-1}$ and 536-538 $cm^{-1}$, and of a silicate clay, kaolinite

**Table 1.** Summary of compounds identified and the archaeological artefacts associated with them.

| Color | Associated polish lithic instrument | Groups | Compositions identified | Information provide by technics |
|---|---|---|---|---|
| Red | • Grinders and pestles<br>• Trowels<br>• Smashing tools<br>• Pigment ores<br>• Architectural elements | *Red 1* | • Red earth ($Fe_2O_3$ + kaolinite), calcite<br>• Red earth ($Fe_2O_3$ + kaolinite), calcite, quartz, calcium oxide ($CaO_2$) | • XRF: Fe, Ca, Ti, K, Si, Sr, Mn<br>• ATR-FTIR: calcite (712, 873, 1031 and 1795 $cm^{-1}$). kaolinite (790, 1002–1006, 1030–1031 $cm^{-1}$). $Fe_2O_3$ (455–458, 536–538 $cm^{-1}$)<br>• XRD: quartz, calcium oxide |
| | | *Red 2* | • Red earth ($Fe_2O_3$ + kaolinite)<br>• Hematite<br>• Red earth ($Fe_2O_3$ + kaolinite), quartz | • XRF: Fe, Ca, Ti, K, Si, Sr, Mn, Pb<br>• Raman spectroscopy: hematite (224, 291–295, 408–411, 609–612 $cm^{-1}$)<br>• ATR-FTIR: kaolinite (790, 1002–1006, 1030–1031 $cm^{-1}$)<br>• XRD: quartz |
| | | *Red 3* | • Ilmenite | • SEM-EDS: Fe, Ti, Mn, Al, Si, Mg, K |
| Pink | • Grinders and pestles<br>• Mortar pestles<br>• Trowels<br>• Polishers<br>• Pigment ores | *Pink 1* | • Red earth ($Fe_2O_3$ + kaolinite), calcite, quartz<br>• Red earth ($Fe_2O_3$ + kaolinite), calcite | • XRF: Ca, Fe, K, Sr, Si<br>• Raman spectroscopy: hematite (224, 290, 411, 609 $cm^{-1}$)<br>• ATR-FTIR: calcite (712, 873, 1031 and 1795 $cm^{-1}$). kaolinite (790, 1002–1006, 1030–1031 $cm^{-1}$). $Fe_2O_3$ (455–458, 536–538 $cm^{-1}$) |
| Yellow | • Grinders and pestles<br>• Mortar pestles<br>• Smashing tools<br>• Trowels<br>• Polishers<br>• Pigment ores<br>• Ritual offering in shell | *Yellow 1* | • Jarosite<br>• Jarosite, calcium carbonate, calcium oxide, stishovite ($SiO_2$) | • XRF: Fe, K, Ca, S, As<br>• Raman spectroscopy: jarosite (151, 216, 434, 447, 624, 1006, 1096 $cm^{-1}$)<br>• ATR-FTIR: jarosite (470, 504, 629, 1000, 1082, 3376 $cm^{-1}$). kaolinite (790, 1002–1006, 1030–1031 $cm^{-1}$)<br>• XRD: calcium carbonate, calcium oxide, stishovite<br>• SEM-EDS: Fe, S, K, Ca, Al, Si, Mg |
| | | *Yellow 2* | • Yellow earth (α-FeOOH + kaolinite)<br>• Yellow earth (α-FeOOH + kaolinite), muscovite<br>• Yellow earth (α-FeOOH + kaolinite) + calcium carbonate | • XRF: Fe, Ca, Ti, Si, Sr<br>• Raman spectroscopy: 224, 290, 411, 609 $cm^{-1}$<br>• ATR-FTIR: iron oxide (538, 570 $cm^{-1}$)<br>• XRD: muscovite |
| Orange | • Trowels<br>• Polishers<br>• Paving stones<br>• Architectural elements | *Orange 1* | • Iron oxide, hematite, kaolinite+, green earth, calcium phosphate | • XRF: orange matrix (Fe, As, Ca, Si). White aggregates (Fe, Ca, As, *P*, SE, K, Si, Ti, Al, Mn)<br>• Raman spectroscopy: hematite (455, 536–538 $cm^{-1}$). kaolinite (790, 1002–1006, 1030–1031 $cm^{-1}$). calcium phosphate (961–965 $cm^{-1}$)<br>• SEM-EDS: green earths (Al, Si, *P*, Fe, K, Ca, Mg, Ti, Na) |
| | | *Orange 2* | • Iron oxide + possibly cinnabar | • XRF: Fe, Ca, Ti, Si, K, Hg, Mn, Zn, S |
| | | *Orange 3* | • Iron oxide | • XRF: Fe, Ca, K, Si, Ti, Mn Cu, Zn, Sr |
| Green | • Pigment ore<br>• Architectural elements | *Green 1* | • Celadonite (green earth), magnesian calcite, mica (muscovite)<br>• Glauconite (green earth), quartz<br>• Celadonite (green earth) | • XRF: Fe, Ca, K, Sr, Si, Zn, Cr, Al<br>• Raman spectroscopy: quartz (124, 464 $cm^{-1}$)<br>• ATR-FTIR: celadonite (432, 462, 491, 676, 800, 839, 953, 970, 1023, 1084, 1109, 1413, 3357, 3601 $cm^{-1}$). glauconite (440, 563, 604, 671, 791, 975, 1020, 1200 $cm^{-1}$)<br>• XRD: mica, quartz<br>• SEM-EDS: Fe, Ca, K, Sr, Si, Zn, Cr, Mg, Al |
| | | *Green 2* | • Malachite + chonicalcite + green earth + calcite | • XRF: Cu, Ca, Fe, K, Si, Al, As, Ti, Sr<br>• Raman spectroscopy: green earth (151 $cm^{-1}$). calcite (273, 1085 $cm^{-1}$)<br>• ATR-FTIR: malachite (523, 749, 778, 819, 3308, 3404 $cm^{-1}$). chonicalcite (426, 465 $cm^{-1}$); calcita: (712, 873, 1410, 1795 $cm^{-1}$). kaolinite (798, 912, 1008, 1026, 1096 $cm^{-1}$)<br>• SEM-EDS: Cu, Si, Al, Ca, Fe, Mg, K, P, Mn, Ti |

($Al_2Si_2O_5$ $(OH)_4$) at 790 $cm^{-1}$, 1002-1006 $cm^{-1}$ and 1030-1031 $cm^{-1}$ (Chukanov 2014, 131, 250, 473). As shown in Figure 3(B) subgroup Red1b displays similar spectra as Red1a, with a lack of calcite bands (Chukanov 2014, 131).

The presence of calcite may be related to a stucco plaster (*enlucido*) over which the color was extended with smoothing tools (IL2A, IL58A, P5A), leading to an intentional reduction in the hue of the red, or to the possible development of dark rose with pestles and mortars or grinders (IL37A, IL55A, P10A). In the cases where the red pigment was pure (IL4A1, IL12A, IL54A,) or found as a red ore (P8A, P9A), natural earths were identified. In these cases, we interpreted these samples as raw materials.

SEM-EDS analyses added information to the corpus of red materials, such as a probable presence of Ilmenite ($FeTiO_3$) (grouped as Red 3), employed as a raw material by the Xalla color workers to generate red pigments. XRD identified siliceous minerals such as cristobalite, tridymite and silicon oxide for the IL12A sample. Their presence in the pigments of Xalla may be associated with the composition of natural red earths, or they have been added intentionally with grinders in order to generate brightness properties, a pattern detected in pigments from other sites in Teotihuacan (Magaloni Kerpel 2017).

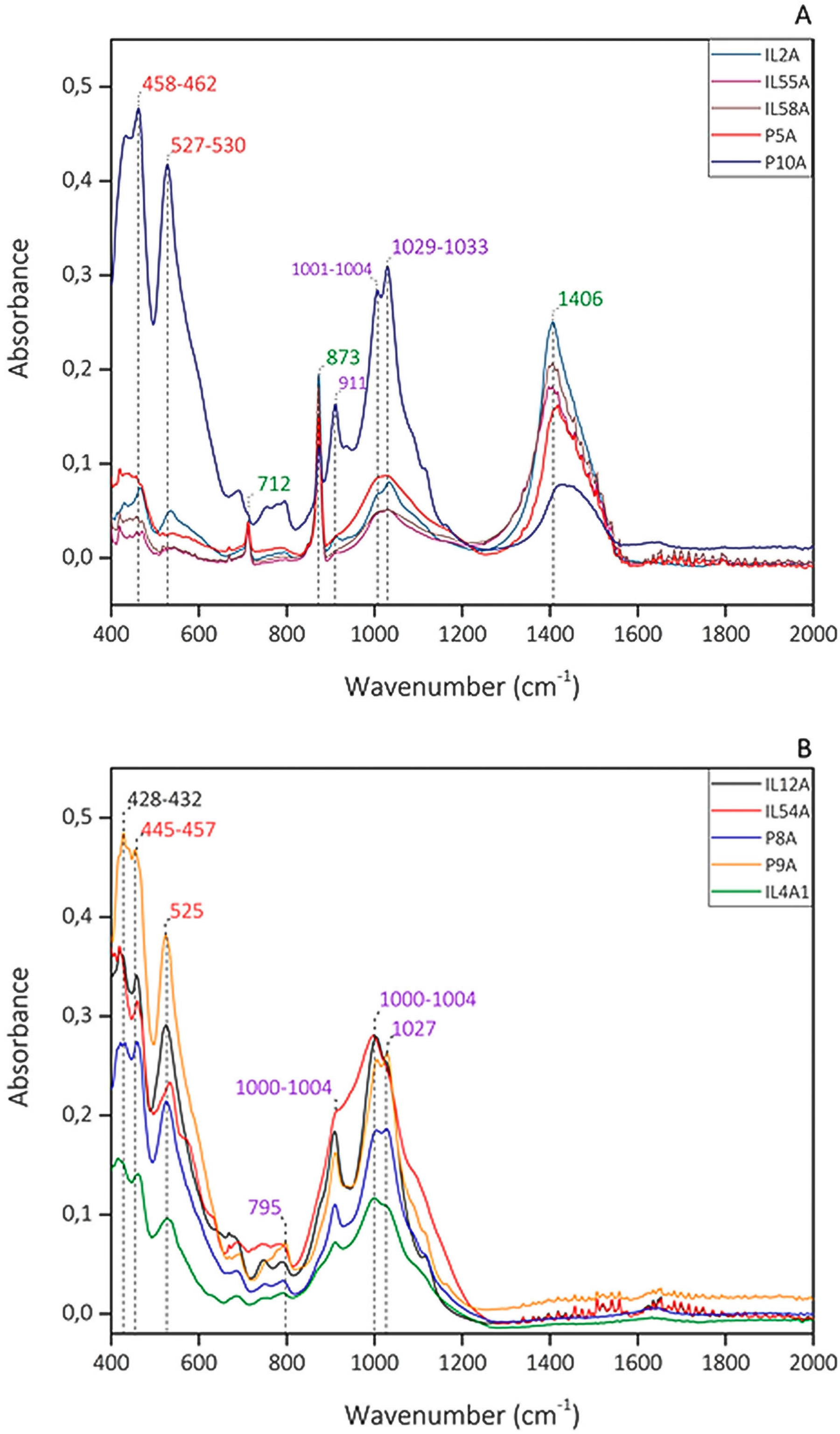


**Figure 3.** FTIR-ATR spectra of the red samples (A, B). In red, iron oxide bands; in green, calcite bands; in purple, kaolinite-montmorillonite bands. Hematite Raman spectra of red samples (C). Sampling comes from grinders, pestles and applied pigments.

*PINK*. Pink samples were obtained from the same polished lithic instruments as the red samples, with the exception of instruments dedicated to the crushing of raw materials. Four pink samples with slight tonal variations – dark pink (2.5YR 7/6 light red), light pink (10R 8/4 pink) and a medium pink (10R 7/8 light red) – were analyzed.

XRF results are similar to red samples, with a predominance of Ca, followed by Fe, K, Sr and Si, typical elements of natural earths. Raman spectroscopy and FTIR-ATR spectra confirmed the presence of iron oxides and clays, related to natural earths. Thus, Xalla pink is a mixture of red earths with calcite, and the variation between these two components generated a shade of greater or lesser clarity.

YELLOW. This color was sampled in all polishing lithic instruments associated with color craft activity at Xalla, like grinders and polishers or trowels used to apply pigments on the floors and walls of the compound. We identified six hues of yellow: (1) yellowish brown 10YR 5/8, (2) light yellowish brown (10YR 6/8 brownish yellow), (3) light reddish yellow (10YR 7/8 yellow), (4) reddish yellow (7.5YR 7/8 reddish yellow), (5) dark reddish yellow (5YR 5/8 yellowish red) and (6) light yellow luminous (2.5Y 8/8 yellow).

Elemental composition determined by XRF allowed us to differentiate two groups of yellow pigments. Group Yellow 1, composed of only one sample, has a predominance of Fe, K, Ca, sulphur (S) and arsenic (As). Group Yellow 2 is characterized by Fe, Ca, Ti, Si and Sr, elements typically present in yellow ochres.

FTIR-ATR and RS applied on yellow 1 displayed characteristic peaks and bands of jarosite ($KFe_3^{+++}(SO^4)_2(OH)_6$) (Figure 4) (Chukanov 2014, 1407). This raw material typically was used in funerary contexts in Teotihuacan, but not for mural painting. Characterization of this mineral in tools used to apply pigments – as trowels – allows us to propose its use to produce pigments for pictorial use, to paint the floors and walls of the palatial compound.

A Yellow 2 sample (IL4A), taken from a crushing instrument, presents characteristic Raman peaks related to hematite, even though it is probably related to a hydrated iron oxide with yellow color, such as goethite ($\alpha Fe^{3+}O(OH)$) or lepidocrocite ($\gamma Fe^{3+}O(OH)$), both reported in Teotihuacan mural paintings (Magaloni Kerpel 1996, 213; Torres Montes 1972, 27–28). The explanation for this resides in the heat generated by the laser beam of the equipment, where the high temperature may generate changes in the molecular bonds of the sample (Casanova González 2012). If temperatures greater than 300°C are reached during the analysis, goethite loses its water bonds, generating a phase change and thus obtaining a Raman signal typical of hematite (Gialanella et al. 2010, 869). FTIR-ATR confirmed the presence of a hydrated iron oxide, probably goethite, with additional presence of clays, kaolinite (Chukanov 2014, 255).

*ORANGE.* The presence of orange pigments was limited, being sampled from pigment ores, paving stones and architectural elements. The orange group has nine samples with notable differences in each sample color. We identified seven hues of orange: 5YR 6/8 reddish yellow, 10R 5/8 red, 10R 4/8 red, 2.5YR 6/8 light red, 7.5YR 6/8 reddish yellow/5YR 5/8 yellowish red, and 5YR 7/8 reddish yellow. Differences were found in the texture and chemical composition of the samples, with this color group being the most heterogeneous of the Xalla color sample *corpus*.

Figure 5 presents our XRF results from the orange samples studied, allowing us to identify three groups: *Orange 1*, composed of one sample, presents high counts of Fe, As, Ca and Si. *Orange 2*, with high values of Fe, Ca, Ti, K, Mn, Si, and a significant presence of mercury (Hg); *Orange 3* presents the characteristic elements related to natural earths previously reported.

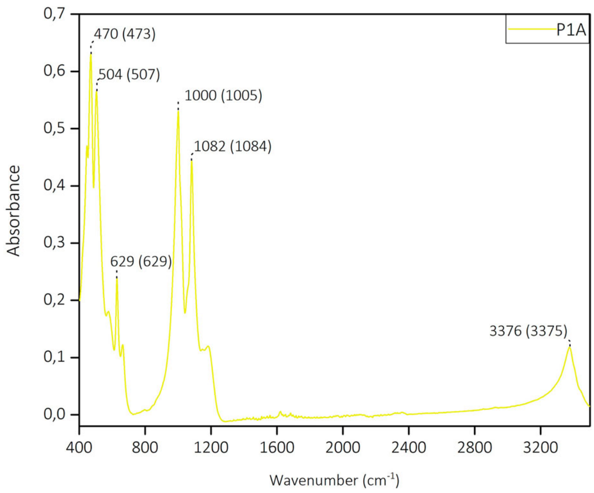


**Figure 4.** FTIR-ATR spectra of jarosite with references of (Chukanov 2014, 1407), in parentheses. Sampling from a smoothing tool or trowel.

Orange 1 presented a special case. LM analysis allowed us to observe an orange matrix of Orange 1 combined with red and yellow particles, and white and green aggregates. XRF analyses in the orange matrix provided results closer to natural earths (Figure 5).

White aggregates were analyzed with XRF and Raman Spectroscopy. XRF results shows presence of significative counts of phosphorus (P) and Raman spectroscopy of the white aggregates provides a signal characteristic of calcium phosphate ($Ca_3(PO_4)_2$) with its peak at 961-965 $cm^{-1}$ (Figure 6), indicating the use of white bone, never before characterized in Teotihuacan pigments. This white bone is present as a fine grain with a notable compact form and a clayey texture (Figure 6). These characteristics generate new questions about the technique involved in the preparation of this white bone. This texture, color and compaction may be the result of submitting the bone to a temperature between 650 and 700°C. At this temperature the bone acquires a matte white shade and a consistency similar to gypsum (it agrees with the consistency and texture observed in the whitish material analyzed), becoming an adequate material to bind pigments (Trellisó Carreño 2001, 91).

Elemental analysis of the small green aggregates by SEM-EDS determined a composition of Al, Si, P, Fe, K, Ca, Mg, Ti and Na. A semiquantitative analysis of these aggregates, together with elemental distribution maps (Figure 7), allowed us to identify this material as an iron aluminosilicate (green earth).

From the results obtained it is possible to affirm that the oranges of Xalla are composed of iron oxides present as natural earths (Orange 1 and Orange 3) or combined with other materials such as cinnabar

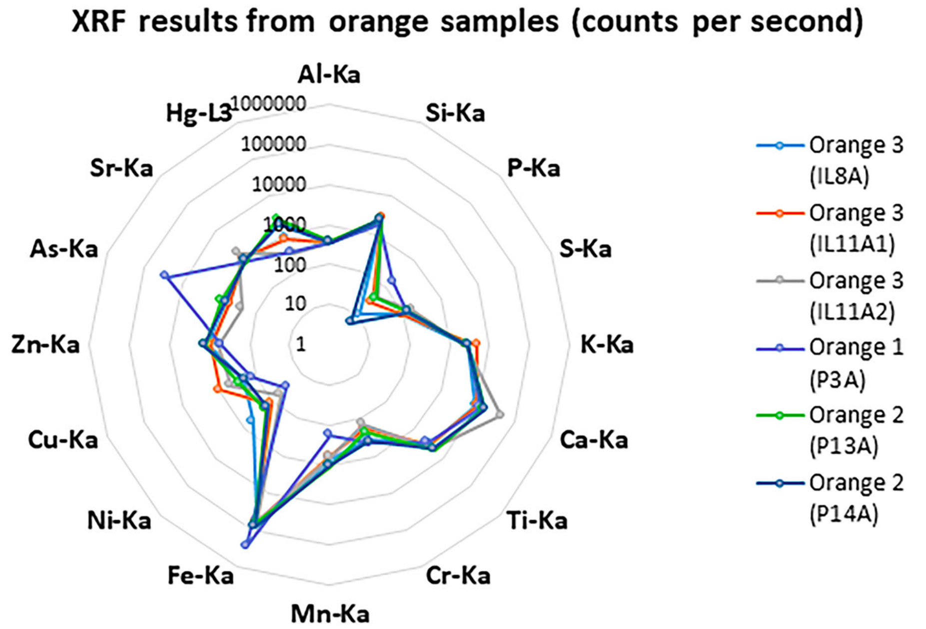


**Figure 5.** Radial graph with the average of three point of analysis per samples. The graph shows the relationship between orange samples and his characteristics chemical elements.

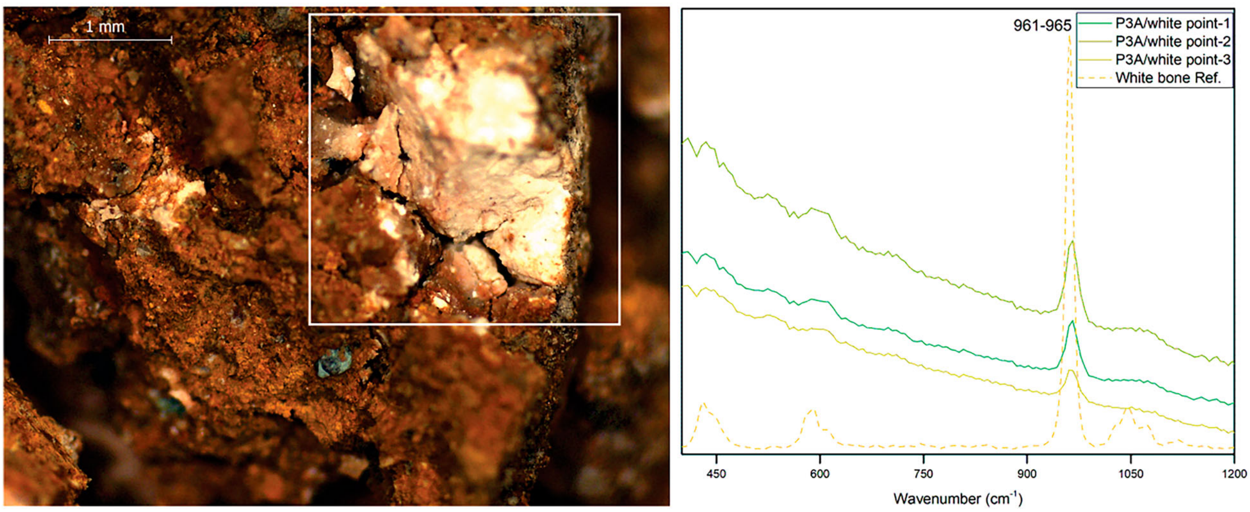


**Figure 6.** LM photography (25X) of Orange 1 (P3A), indicating with red square the white aggregates (left). Raman spectroscopy of the white aggregates providing characteristic peak of calcium phosphate (right). White bone reference spectra in dot line.

(Orange 2). The diversity in composition and grain size seen in the oranges raises the question regarding the surface on which these pigments were to be employed. These clayed pigments made with natural earths are suitable for covering large architectural surfaces such as those of Xalla, as well as being typical of the pseudo-cloisonné ceramics, with examples excavated at P5, and this tradition is strong in the Mesoamerican West (Gómez Chávez 1996; Manzanilla 2017b; Michelet and Pereyra 2009). Those pigments of finer granulometry (P12A and P13A) and with the presence of Hg could be destined for supports other than architectural ones, such as stuccoed ceramics or body painting, where the application of reds and oranges with cinnabar is common in Teotihuacan (Ejarque Gallardo 2018; Gazzola 2000; Vázquez de Ágredos Pascual, Manzanilla, and López Puértolas 2018).

*GREEN*. Green samples were obtained only in two forms, as ores and as a pictorial layer on an almena from the compound. Five samples were acquired, with two hues of green being identified; samples P20A3 (GLEY1 8/2 pale Green) have a pale turquoise green tone and correspond to pictorial layer of the almena and the pigment ores (P4A, P6A, P11A) while P7A sample has a darker crystal emerald green and was sampled from a fragment corresponding to the base of a small ceramic container (Figure 8).

The results obtained with XRF and SEM-EDS show two groups of green: Green 1 (P4A, P6A, P7A y P11A) with Fe, Ca, K, Sr, Si, Zn, Cr, Mn and Al, all of them chemical elements characteristic of natural

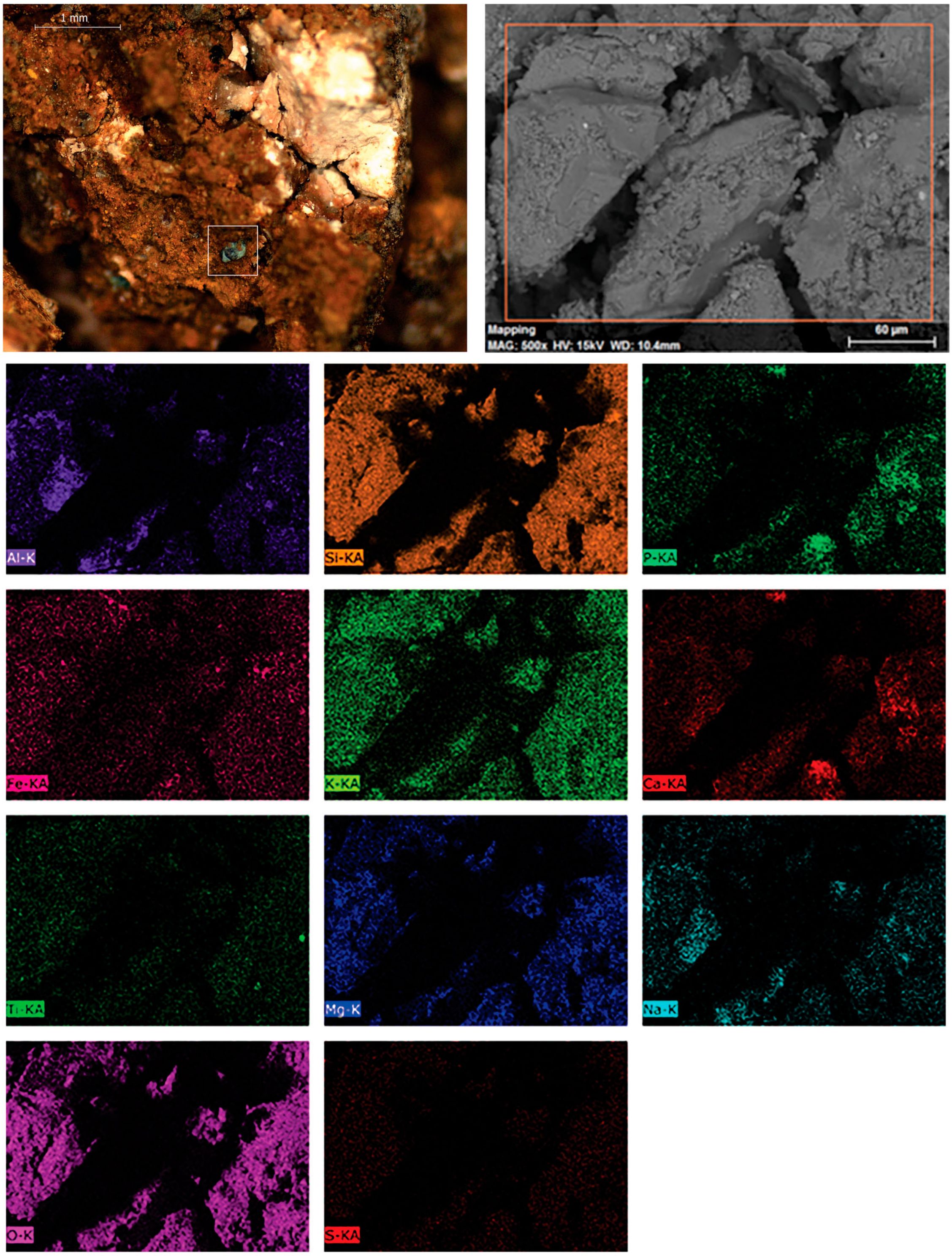


**Figure 7.** LM photography (25X) of Orange 1 (P3A) and image of backscattered electrons (500X), indicating with yellow square the green aggregates Elemental distribution maps of the small green aggregates in Orange 1.

earths. FTIR-ATR identified celadonite ($KMgFe^{3+}Si_4O_{10}(OH)_2$) and glauconite ($(KNa)(MgFe^{2+}Fe^{3+})(Fe^{3+}Al)(SiAl)_4O_{10}(OH)_2$) (Chukanov 2014, 501, 451), both characteristic minerals found in green earths (Figure 9). Group Green 2 (P20A3) presented a main composition of Cu, As, Fe and Ca. FTIR-ATR spectra identified the green minerals malachite ($Cu_2(CO_3)(OH)_2$) (Chukanov 2014, 186) and conichalcite ($CaCu^{2+(}AsO_4)(OH)$) (Chukanov 2014, 1595), together with the kaolinite-montmorillonite clay. The presence of calcite bands in the FTIR-ATR spectra may be related with a reduction of the green shade, making pigment clearer (Figure 9).

As mentioned before, the quality of brightness is found in all the pigments analyzed in this work. Nevertheless, minerals probably associated with this quality were only identified in Green 1, with quartz and mica (of the muscovite variety) being characterized by Raman spectroscopy and XRD respectively.

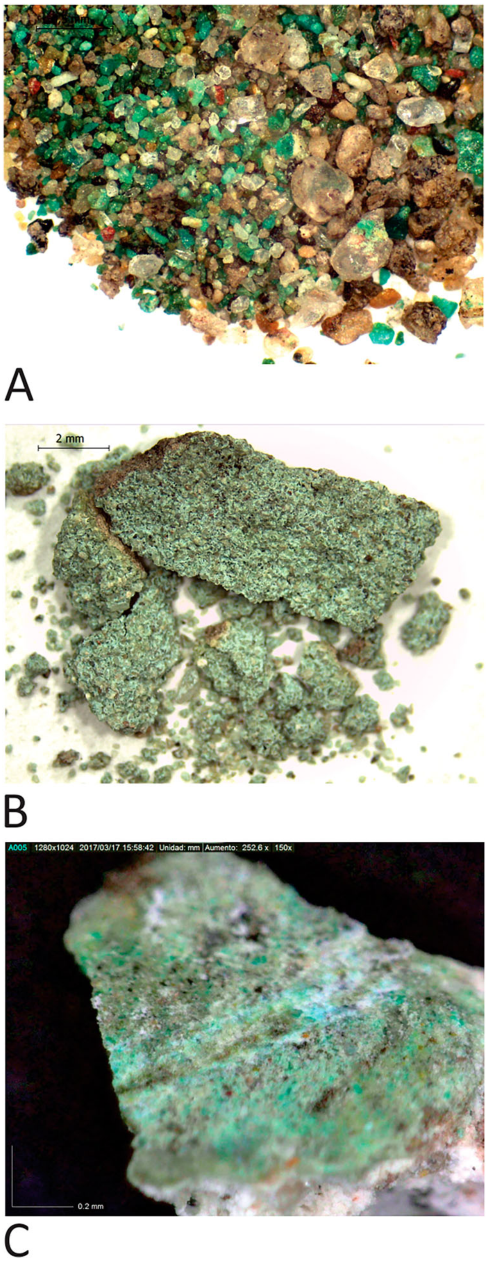


**Figure 8.** Samples of green pigment samples. (1) emerald green crystals interpreted as a raw material (P7A), (2) pale turquoise green like a pigment ore interpreted as a finished pigment and (3) the green pigment in a pictorial layer of the sample almena.

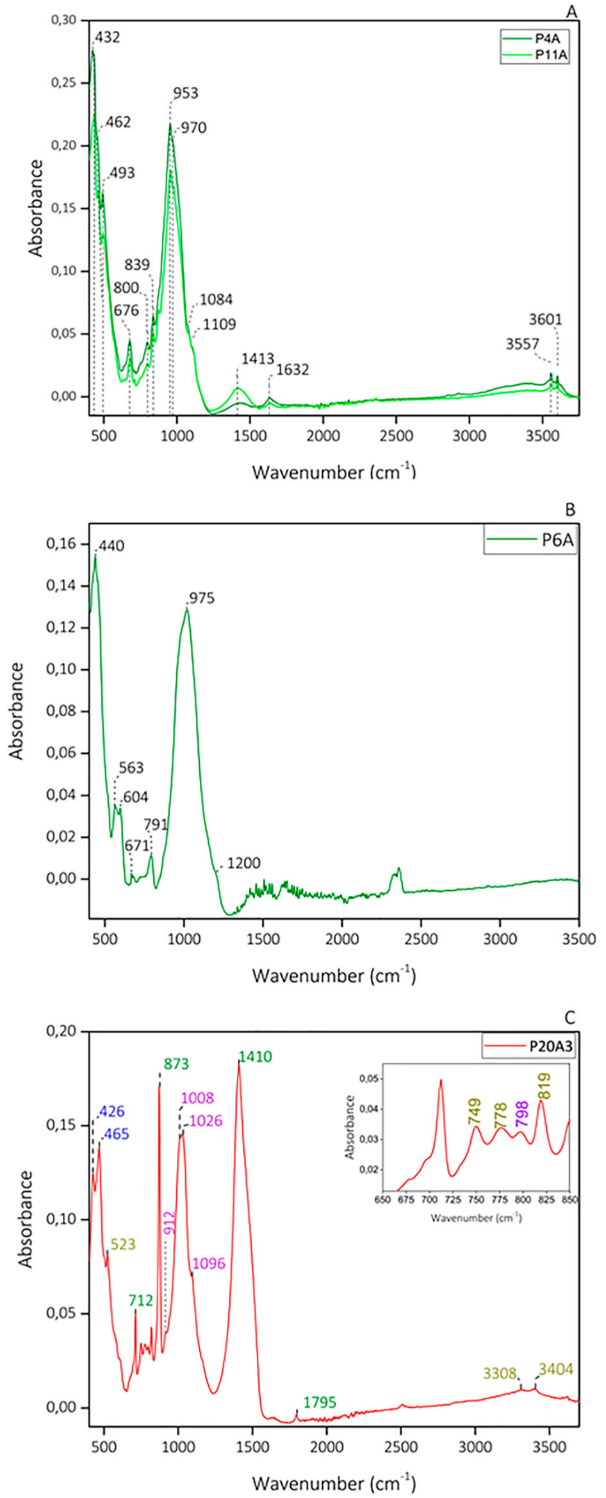


**Figure 9.** (A) FTIR-ATR spectra of celadonite, (B) FTIR-ATR spectra of glauconite and (C) FTIR-ATR spectra of conichalcite (blue), malachite (yellow), calcite (green) and kaolinite-montmorillonite (purple).

To conclude, we inquire about the operational chain of pigment production in Xalla palace. Scarcity of accurate and detailed historical documents about manufacture of pigments in Mesoamerica, none for Teotihuacan times, forced us to document the production of pigments in other chronologies and geographies. Crossing our archaeometric results with typology and functionality of polished lithic instruments and comparing the results with Ancient and Renaissance Europe painting treatises like Cennino Cennini (1947) or Pliny the Elder (1961) – where tools and grinding grades of raw material are detailed – we propose a particular operational chain. The color craftspeople of Xalla manufactured and applied pigments with polished lithic instruments in the following process:

They used raw materials like yellow and red natural earths: (I) they crushed raw materials with crushers, (II) they ground and mixed natural earths with calcite or quartz to obtain different gradients of color with grinders and pestles, (III) they ground these substances with mortars to homogenize the grain size and finally (IV) applied the coloring materials processed with smoothing tools/trowels, and polished the surface to obtain saturated colors and lustrous surfaces.

## 4. Conclusions

In the pigments of Xalla studied, colors of great intensity, a clayish consistency and homogeneous compositions, with a predominance of natural earths, have been observed. All the pigments have as a common quality the brightness and reflections that are generated by a diversity of aggregate materials like quartz or mica, which would respond to a persistent search to obtain highly luminous and brilliant pigments, something characteristic of Teotihuacan pictorial palette.

The recurrence in the use of natural earths by the color workers of Xalla may respond to the physical characteristics of the compounds, since they generate dense pigments that are resistant to external agents. Together with the above, the abundance and easy access of this type of material in the surroundings of the city, converts natural earths into suitable materials to cover large walls, floors and architectural elements such as staircases or almenas.

We identified new compositions and raw materials to prepare pigments to embellish Xalla walls and floors like a bone white or jarosite and a heterogeneous orange prepared with different natural earths, bone white, and green earth. All these coloring materials were applied on surfaces where the technical objective of the artisans was to achieve two optical properties: luminosity and saturation, both very common in Teotihuacańs mural painting. These new raw materials identified open new questions about color technology and its development throughout Teotihuacan history.

## Note

1. Color remnants that were not mixed with the dark sediment of the context were prioritized.

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