Artistic Expressions in Maya Architecture: Analysis and Documentation Techniques

Expresiones artísticas en la arquitectura maya: Técnicas de análisis y documentación

Edited by

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The role of new technology in the study of Maya mural painting: over a century of progress

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Abstract: *The recent discovery of murals in the Room of Paintings at the Chilonché Acropolis (Department of Petén, Guatemala) has made it possible to conduct a very thorough physical-chemical analysis of one of the few mural paintings of the Classic Maya period to have survived to this day in a well conserved state. The application of a multi-technique, interdisciplinary approach to archaeometric analysis has been optimized over the last ten years at the University of Valencia and the Polytechnic University of Valencia. The approach is based on a combination of microscopic, spectroscopic, electro-chemical and chromatographic techniques, and has provided an initial approximation of the materials -whether mineral or organic- and the techniques used in the execution of the mural painting, both of which have always posed a serious technological and interpretive challenge. The results obtained reveal the level of technological development reached in the art of mural painting in Chilonché during the Classic Maya period. Additionally, and in order to interpret the results obtained within their correct historical and regional context, in this case the Maya Lowlands, consideration has been given to the results gathered by the different investigators and research teams that have investigated the materials and techniques of Maya mural painting ever since the first findings at the end of the 19th century.*

Resumen: *El reciente hallazgo de los murales en la Sala de las Pinturas de la Acrópolis de Chilonché (Departamento de Petén, Guatemala) ha permitido realizar un estudio físico-químico muy exhaustivo de una de las pocas pinturas murales del período Clásico maya que ha llegado hasta nuestros días en un buen estado de conservación. La aplicación del método multitécnica que ha sido optimizado en los últimos diez años en la Universidad de Valencia y la Universidad Politécnica de Valencia para el análisis arqueométrico de estas obras, basado en la combinación de técnicas microscópicas, espectroscópicas, electroquímicas y cromatográficas, ofrece una primera aproximación a los materiales y las técnicas de esta pintura mural, tanto en su vertiente mineral como orgánica, que siempre representa un reto tecnológico e interpretativo de mayor alcance en esta clase de investigaciones. Los resultados que han sido reunidos nos aproximan al desarrollo tecnológico que había alcanzado el arte de la pintura mural en Chilonché en tiempos del Clásico maya. Por otra parte, con el propósito de interpretar los resultados obtenidos en su correcta dimensión histórica y regional, que en este caso se circunscribe a las Tierras Bajas Mayas, han sido considerados los resultados que han reunido distintos investigadores y grupos de investigación en el ámbito de los materiales y las técnicas de la pintura mural maya desde que se obtuvieron los primeros resultados a finales del siglo XIX.*

The archaeometric study of colour in the painted architectures of the Ancient Maya

Colour played an important role in Maya architecture beginning in the Middle Preclassic (ca. 900-300 BC) when buildings with important political or religious functions began to be decorated in painted, and occasionally, moulded stucco. Cerros or Lamanai in Belize, Acanceh or Calakmul, in Mexico and Uaxactún or Tikal in Guatemala are just a few of the many sites that conserve traces of the ancient use of colour. Choice of colours must have been influenced by at least two factors: the ease with which painters could locate, process and use the chromatic palette that prevailed at the time and the symbolic significance of colour within the particular cultural tradition.

The earliest and most widely used colours from the end of the Middle Preclassic to the early Late Preclassic (*ca.* 300 BC - 250 AD) were red and black. These soon became associated with the east and west cardinal points respectively, representing the life and death of the Sun at sunrise and sunset. The most powerful direction was the east, as this was the origin of time and space, and perhaps for this reason red was the most prominent colour in architectural decoration. Both colours could be readily obtained, manipulated and used. In the case of the reds, these were based on iron oxides (Fe_2O_3) and red earths of different composition, and particularly goethites (FeOOH), limonites ($Fe_2O_3.nH_2O$) and ilmenites ($FeTiO_3$) that were commonly found in the soils of the Maya area. Carbon black was created by charring different species of wood.

These two pigments had a further advantage that made them particularly attractive to the painters of the day in that they were compatible with all types of grinding processes, from the hardest to the gentlest, and with all artistic techniques, as they could accept any form of binder without jeopardizing their durability[1].

In just a short time the Maya architecture of the Late Preclassic period was enriched by new symbolic colours that were readily accessible: the white-creams and different hues of yellow, both associated with the annual journey that the Sun starts in the east (red), continues towards the north (white), then to the west (black) and south (yellow) before returning once more to the east, and in this way defining a quadripartite universe. One only has to recall the presence of these four colours in the beautiful paintings at San Bartolo, which discovery "showed that Maya beliefs on the origin of the universe and the divine nature of their rulers were highly developed 2000 years ago and were expertly expressed through mural painting and rituals"[2] (Fig. 1).

The location, processing and use of yellow iron-based pigments and lime whites with clay components ($CaCO_3$) did not pose any particular difficulty to the painters, who by the end of this period were already using the first synthetic pigment of the Maya colour palette: Maya Blue. The archaeometric identification of Maya Blue at the end of the Late Preclassic period as part of the polychromy employed to decorate the stucco facade of Substructure II-C at Calakmul (*ca*. 150 AD)[3] shows that the colour technology of Maya culture had reached its maximum expression by this time.

Fig. 1. San Bartolo North Wall mural showing the birth of the maize god. The colours employed were red, black, white and yellow. (Drawing by Heather Hurst, after Saturno 2009: fig. 1).

The achievement of a complex technology relatively early in the life of a civilisation is matched elsewhere in the world. To cite an example, the manufacture and use of the first synthetic pigment of the Egyptian colour palette, Egyptian Blue -a mixture of malachite $Cu_2 [(OH)_2 I CO_3]$, calcium carbonate ($CaCO_3$), silica (SiO_2) and natron fired at temperatures between 950ºC and 1150ºC-[4] dates back to the third millennium BC[5], coinciding with the time during which the newly-built pyramids were introduced. In the same way, archaeometric analysis by Micro-Raman spectroscopy (MRS) and X-ray diffraction (XRD) in the palatial architecture at the archaeological site of Gla, in the ancient Mediterranean, identified the first known use of lapis lazuli around 1300 BC, coinciding with the wide-ranging development witnessed at this time in other cultural manifestations, such as Linear B script[6]. It comes as no surprise, then, that the first synthetic pigment of the Maya colour palette was already in use by the last stage of the Late Preclassic and at a time when this Prehispanic culture had reached a high level of political, economic, social, religious and cultural complexity.

Maya architecture and colour technology

Painting architecture raised challenges for the painter that were resolved by new and revolutionary pigments and priming surfaces. From very ancient times one of the challenges was to guarantee the correct conservation of the painted surfaces that were always more exposed than other artistic expressions to external agents, especially those of an environmental nature.

On account of the extremely humid environment in which the buildings were found, the conservation of painted architecture undoubtedly posed challenges to the Maya painter that led to the development of new stucco and colour technologies. The addition of saps and vegetable substances in the preparation of lime

1 VÁZQUEZ DE ÁGREDOS 2004: 57-64.
2 FLORESCANO 2009: 201-202.
3 CARRASCO 2000: 12-21; VÁZQUEZ DE ÁGREDOS, DOMÉNECH and DOMÉNECH 2011:140-148.
4 PAGÈS-CAMAGNA and COLINART 2000; MAZZONICHIN 2004:129-133; CRIADO 2011: 163-166.
5 RIEDERER 1997: 23.
6 BRYSBAERT 2006: 252-266.

mortars, such as those from the *chucum* tree (*Havardia albicans*), the *holol* (*Heliocarpus spp.*), the *ha´bin* (*Piscidia piscipula*), or the *chaka´* (*Bursera simaruba L.*), made it possible to obtain a slower-drying lime that lent higher quality and durability to these painted surfaces.

This was confirmed by the first experimental archaeological works conducted by Edwin Littman on lime-based priming surfaces in the 1950s and 60s[7], and by investigations carried out more recently[8]. These latter investigations have demonstrated a greater proportion of these saps in the base mortar layers than in the final layers, which seems to show different manufacturing processes for the lime employed in one layer or another.

One of the additional challenges posed to those creating Maya murals from Preclassic times was the absence of pigments in the area that could provide the painter with blues, greens and purples. Without these colours the only possible alternative at a local level was the bright blue dye provided by indigo or "añil" through different varieties of the *Indigofera* species, and most commonly that of *Indigofera suffruticosa Mill*. (Fig. 2). However, the use of this dye on painted architecture implies a ready acceptance by the Maya of its rapid deterioration and disappearance, because while indigo blue is stable on organic surfaces, it is not stable on inorganic bases such as stone.

Fig. 2. Women from the modern-day Sahcabá Maya community (Yucatán, Mexico) collecting indigo leaves to prepare the indigo dye. (Photograph. M.L. Vázquez de Ágredos).

The question arises, then, of how to represent the quetzal tail feathers that adorned the headdresses of Maya kings or the green stones forming the ankle and wrist bracelets, necklaces and ear ornaments (Fig. 3). The sacred meaning for the Maya of the green-blue ya'ax colour meant that the mural painter had to reinvent the limited colour palette available in the Preclassic period. As noted above, this reinvention led to the appearance of the first synthetic pigment in Maya art, -that of Maya blue[9].

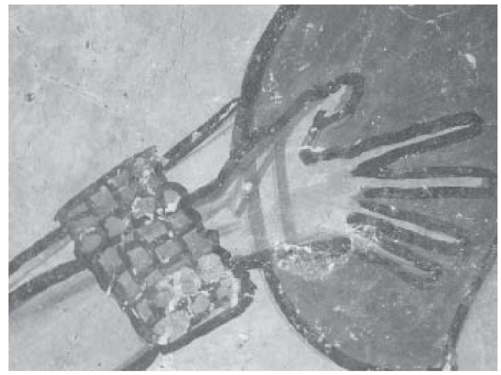

Fig. 3. Detail of the bracelet of one of the female characters painted in Substructure 1-4 of the North Acropolis of Calakmul (Campeche, Mexico). (Photograph. M.L. Vázquez de Ágredos).

As already explained in another chapter of this publication[10] in accordance with the most recent archaeometric and test findings, Maya Blue is a lake or dyed pigment -that is to say a hybrid halfway between the organic and inorganic. With time, this same colour technology served in the manufacture of other dy pigments within the cool and warm colour range (i.e. Maya green and yellow).

The aesthetic finish of a dyed pigment bears no relation to that of a pigment, as the organic nature, whether of vegetable or animal origin, of its chromatic component gives lake pigments a particular brightness with respect to pigments of geological origin, and particularly the iron-based pigments that dominated the warm colour palette of Maya mural painting. In accordance with the brightness or opacity desired in a particular work, Maya mural painters must have seen the technology of manufacturing

7 LITTMAN 1958: 172-176; LITTMAN 1960: 593-597.
8 GUASCH-FERRÉ 2009; VÁZQUEZ DE ÁGREDOS 2010:68-83.

9 The only alternative to Maya blue in the area was that of the blue and green pigments of the basic copper carbonate minerals of azurite and malachite. Chemical analysis conducted since the 1990s on Maya mural paintings has identified the presence of these copperbased pigments at the majority of archaeological sites that must have been important trading centres as was the case of La Blanca (Petén, Guatemala) at the end of the Classic period (VÁZQUEZ DE ÁGREDOS, VIDAL and MUÑOZ 2013: 11-29), and at Postclassic sites on the East Coast of Quintana Roo (MAGALONI 1996). While undoubtedly aided by the arrival of goods from other territories through river and maritime trade, the presence of these pigments is largely secondary and almost anecdotal in comparison to the vast volume of Maya blues and greens in all these works.
10 DOMÉNECH, DOMÉNECH, VIDAL and VÁZQUEZ DE ÁGREDOS in this volume (Chapter 14).

dyed pigments as an effective means of broadening the available chromatic expression.

We shall now consider the techniques of physical-chemical analysis that have allowed the characterization of the materials and techniques of Maya mural painting. These techniques have been optimized in recent years to enable the identification of components that have posed the greatest challenges to archaeometric science: the organic components. Early techniques will be reviewed to highlight the significance of the introduction of new ones that made it possible to identify binders and colorants in Maya mural painting.

Archaeometry applied to the study of materials and techniques of Maya mural painting from 1895 to 1990

Over the century that passed from the first archaeometric studies of Maya mural painting in 1895[11] and the start of the Project on Prehispanic Mural Painting in Mexico, launched and led by Beatriz de la Fuente from the Institute of Aesthetic Research of the National Autonomous University of Mexico in the 1990s, almost all results were provided by physical-chemical analysis techniques aimed at identifying components of mineral origin. Light microscopy (LM), scanning electron microscopy combined with X-ray microanalysis (SEM/EDX), Petrographic Microscopy (PM), X-ray diffraction (XRD), and occasionally spectroscopic techniques such as Fourier transform infrared spectroscopy (FTIR) were instrumental in the physical-chemical characterization of the priming and pictorial layers. While spectroscopic techniques could detect the presence of organic materials, the techniques would have required optimization in order to generate precise spectra with respect to the colorants and binders employed in manufacture.

It was not until the 1970s that the lubricating sap additives employed in the manufacture of the lime priming layers set beneath the pictorial layers in Maya mural painting were identified for the first time by X-ray diffraction[12]. The dye responsible for the colour that was already known as Maya Blue[13], the particles of which were of vegetable origin, was not identified at a physical-chemical level until 1966, although these particles were initially observed by Anna O. Shepard in 1957[14]. The dye was indigo and its precipitation and firing in fibrous inert clay matrices of atapulgite defined a manufacturing process that has continued to generate research and arouse debate among chemists, physicists, art restorers and historians[15].

Prior to this discovery, the scant amount of chemical analysis conducted on Maya murals had only managed to identify pigments of mineral origin, with the sole exception of carbon black that was more inferred than characterized. This was shown as such in the results gathered in 1931 by Herbert E. Merwin of the Carnegie Institution of Washington on fully analysing by Petrographic Microscopy the first Maya mural painting, and more specifically the Postclassic mural at the Temple of the Warriors at Chichén Itzá[16]. Those obtained at a later date following the discovery in 1946 of the murals at Structure I at Bonampak confirmed these earlier results[17].

The murals at the Temple of the Warriors at Chichén Itzá, on Structure I at Bonampak and examples found on the main buildings of Palenque were the only murals to receive detailed archaeometric study prior to the 1990s. In none of these cases was any reference made to the dye other than the indigo employed in the manufacture of Maya blue. There was similarly no reference to the gum, gum-resins, resins or oils that served as binders in order to determine the pictorial technique used by the painters. The theories regarding Maya blue's stability and fading to more turquoise tones with the passage of time required new technologies to investigate its preparation and composition on the highest possible scale of definition that would go beyond differential thermal analysis[18] and differential scanning calorimetry[19] employed to establish the possible manufacture of this synthetic pigment between the 1970s and 80s.

New technology for the scientific examination of Maya mural paintings from the 1990s to the present day

The application of new technology to further the study of Maya mural painting came about in the 1990s with the development of the research Project on Prehispanic Mural Painting in Mexico, mentioned above.

This project introduced three main innovations that set the groundwork for subsequent investigations in this area. The first of these was the analysis and conservation of all traces of mural painting that had survived the passage of time, and not just the large murals themselves, making it possible to generate the first corpus of these paintings. The second innovation was a research protocol that combined the use of visible and invisible light photographic techniques and the use of archaeometric techniques that without rejecting the microscopic and spectroscopic techniques employed since 1895, these new techniques could provide more information on the organic components of these paintings. Last, but by no means least, the integral study of these murals using both long-existing and new techniques for the scientific examination of works of art required the first-ever combination of interdisciplinary teams in which archaeologists, architects, art historians, historians, epigraphers, physicists, chemists, restorers and

11 HOLMES 1895: 168.
12 DUBOIS 1978: 101.
13 VAN OLPHEN 1966: 645-646.
14 SHEPARD 1962: 565-566; SHEPARD and GOTTLIEB 1962.
15 See DOMÉNECH, DOMÉNECH, VIDAL and VÁZQUEZ DE ÁGREDOS in this volume (Chapter 14).
16 MERWIN 1931: 395.
17 GETTENS 1955: 66.
18 DE YTA 1977a; DE YTA 1977b: 117-123.
19 DE YTA et al., 1981: 213-227.

photographers, among other specialists, all converged in joint research with a common aim. The results were excellent.

Among the invisible light techniques infrared light photography (IR) was particularly important in order to observe the underlying layers of the pictorial film and possible traces hidden on the surface. This technique was also used by the Bonampak Documentation Project, launched in 1996 by Stephen Houston, Mary Miller, Karl Taube and Beatriz de la Fuente. The team also experimented with infrared video and, according to Miller, "…this process of video 'prospecting' has revealed fascinating details -hieroglyphic texts and figures of gods and mortals engaged in a variety of ritual activities -all but invisible to the naked eye"[20] (Fig. 4).

Fig. 4. Detail of one of the characters from Room 1 at Bonampak. Image taken by infrared video stitch. © Bonampak Documentation Project, 1996. (After Miller and Brittenham 2013: fig. 229).

With regards to the new technologies for physical-chemical characterization, two main innovations were introduced: gas chromatography/mass spectrometry (GC/MS) and high-performance liquid chromatography (HPLC), both of which were instrumental in the precise identification of the binders. Through the incorporation of these two chromatographic techniques it was possible to confirm the use of the sap additives, suggested by Littman several decades earlier, for the manufacture of the primer or preparation layers of Maya mural paintings. Additives such as *chuchum* (*Havardia albicans*) were confirmed along with others and it was also possible to identify some of the most widely employed pictorial binders, such as the gum obtained from the pseudobulbs of local orchids[21].

As a result of these studies, the archaeometric study of the Maya Prehispanic murals advanced considerably. Two important voids remained pending, namely the refinement of non-destructive analysis techniques for the study of these works of art and the optimization of scientific examination methods that could potentially broaden our knowledge of the use of colorants for the manufacture and use of lake pigments. Knowledge of the use of dyed pigments for the preparation of Maya blue was so far restricted to indigo, but the issue of the fading to more turquoise tones continued to be unanswered. Two investigative teams have successfully managed to cover both gaps, one managed by the Institute of Physics at the National Autonomous University of Mexico under the ANDREAH Project (Non-Destructive Analysis for Art, History and Archaeological Studies), and that of the Department of History of the Art at the University of Valencia and the Institute for Heritage Restoration at the Polytechnic University of Valencia under the line of research "Materials and Techniques of Prehispanic Painting". This line of research was further consolidated in 2004 under the framework of the La Blanca Project (Petén, Guatemala) for the study of these works and their traces from a regional perspective[22].

The main breakthroughs with respect to the physical-chemical identification of materials in mural painting corresponded, in the case of the ANDREAH Project, to the promotion and optimization of non-destructive methods and particularly by means of X-ray fluorescence (XRF), particle-induced X-ray emission (PIXE) and Micro-Raman spectroscopy (MRS). The main contribution of the Valencian team has been the optimization of methods to characterize the organic components, both with respect to binders, by means of pyrolysis-gas chromatography/mass spectrometry (Pyro-GC/MS), and that of colorants by means of microparticle voltammetry (MPV)[23].

However, when it appeared that everything that had to be said about Maya mural painting had been said, the physical-chemical study of the colour palette and the pictorial techniques of the mural recently discovered by La Blanca Project at the Acropolis of Chilonché (Department of Petén, Guatemala) have shed new evidence on the wealth of technical solutions employed by the painters of the Maya Lowlands.

20 MILLER 1997:34. See also MILLER and BRITTENHAM 2013: xvii.

21 MAGALONI 1996; MAGALONI 1998: 88-109.

22 DOMÉNECH, VÁZQUEZ DE ÁGREDOS and VIDAL 2007:105-120; VIDAL, MUÑOZ and VÁZQUEZ DE ÁGREDOS 2014.

23 See DOMÉNECH, DOMÉNECH, VIDAL and VÁZQUEZ DE ÁGREDOS in this volume (Chapter 14).

The mural painting at the Acropolis of Chilonché

The Acropolis of Chilonché

Two years after the discovery of the "mask" of Chilonché in 2009[24], another exceptional find occurred at the same Acropolis, unearthed as a result of attempted looting that was successfully prevented by the permanent surveillance maintained by the La Blanca Project. We are referring to the mural paintings that cover the walls of one of the Late Classic palatial rooms that crown this monumental complex. This palace (3E1) had already been the victim of numerous and highly destructive looting activities. The ensuing work conducted under the auspices of La Blanca Project in 2011 included the drawing of the visible architecture, the surveying and recording of the tunnels made by the looters, and urgent repair works to the more damaged structures (Fig. 5).

The looters had entered from the vault in Room 6 of this building, and on passing through the looters' hole, a painted frieze that ran the entire length of the springing to the vault could be discerned. This room, as with the adjacent Room 5, was filled with rocks and earth in ancient times to seal off the rooms and to use these as the foundations for the construction of a building of larger dimensions. However, this upper building was never completed, most probably as a result of events that occurred at the end of the Classic Period and coinciding with the crisis that affected the entire Maya area. In order to ensure the correct excavation of both rooms, the backfill was carefully removed in Room 5 until the opening communicating the two rooms was located, and then the rubble was removed from Room 6. The emptying of the room soon exposed extraordinary mural paintings, which demanded that the backfill be removed with utmost care, particularly in the areas closest to the walls.

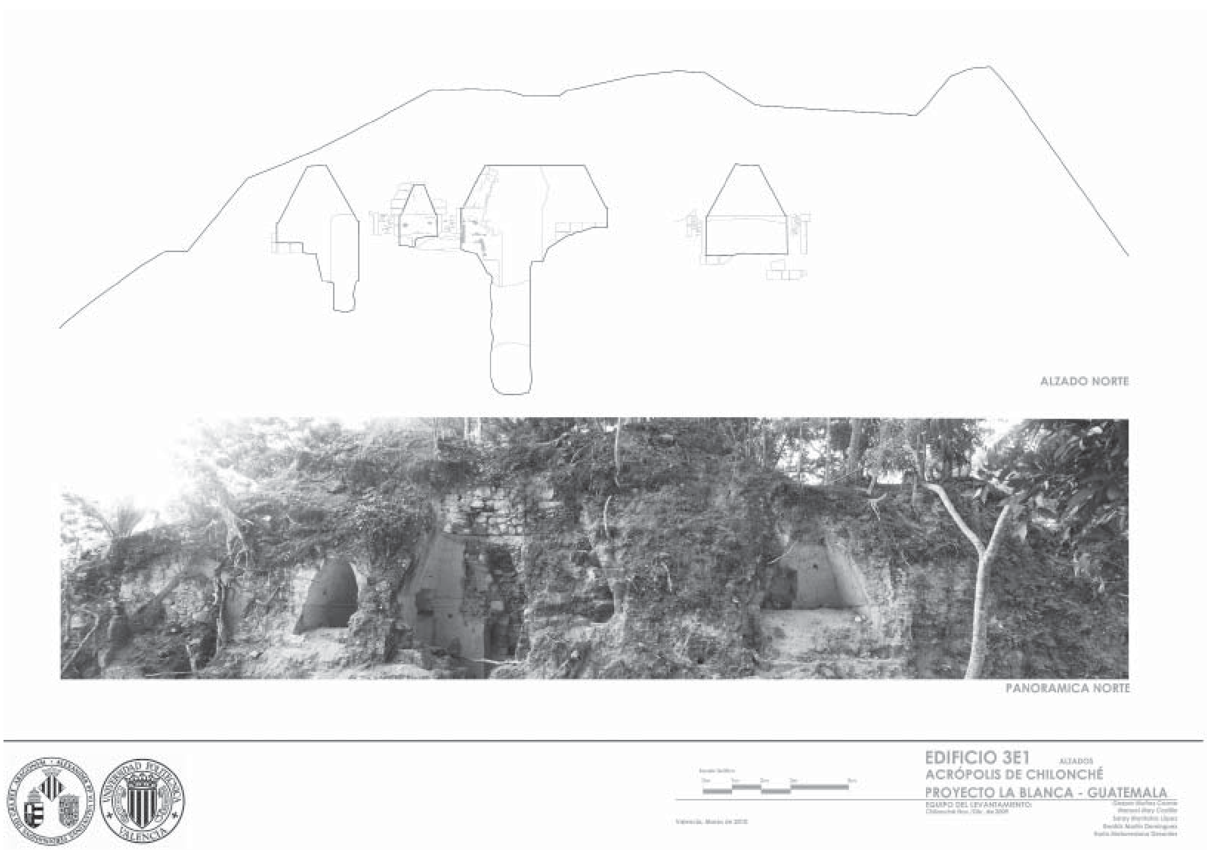

Fig. 5. Building 3E 1. North view and elevation of the Chilonché Acropolis, revealing the looter's tunnels that have taken place. (PLB 2010).

24 See VIDAL and MUÑOZ in this volume (Chapter 8) and MAY and MARTÍN in this volume (Chapter 9).

Room 6, also known as the Room of Paintings, is a 4.20 m long by 2.15 m wide room covered by a vaulted ceiling set on a north-south axis. A large 1.35 m wide bench runs the entire length of the room with sloping 0.56 m high arms set at both ends. The room has two entrance doors, a main, 1.72 m wide door set in the eastern wall and another smaller door, 0.86 m wide, set in the north wall and connecting with Room 5, which undoubtedly served as an auxiliary space to the Room of Paintings (Fig. 6). On both sides of the door in the eastern wall there are two cord holders, the one set to the south side of the door being particularly notable as the cord recess is formed by a blue ceramic inset housed in the wall and incorporating a bone peg insert. The springing of the vault covering the Room of Paintings extends 0.06 m out at the impost and the vault slopes up to a capstone, which closes the vault some 3.60 m above floor level.

The figurative scenes represented in this mural cover the northern, western and southern walls. The east wall is largely taken up by a broad opening that would have led out onto a courtyard or open area and which would have allowed the morning light to enter and illuminate these beautiful scenes. As in the case of the paintings at Bonampak[25], there is no evidence (such as smoke smudges) to suggest that these were lit by torches, and we may then ask how, exactly, these paintings were viewed in all their splendour. Due to the position of this opening, the most well-lit scene would have been the central section, which shows numerous figures all in a highly dynamic state of movement, arranged in two adjoining planes one above the other. Their bodies are painted in different colours (mainly black, red and ochre), and the sensuality and elegance of their postures and body language is very much evident, particularly among those in the foreground (Fig.7).

Fig. 6. Floor plan of Palace 3E1 of the Chilonché Acropolis. The mural is found in Room 6. (PLB 2011).

As indicated above, Room 6 was intentionally backfilled and from the evidence obtained during the clearing operation, while this was seen to have been filled in a very orderly manner, parts of the paintings were unfortunately damaged since ancient times by some of the backfill stone resting on the walls. However, it should also be noted that as a result of the sealing of the room, the paintings managed to remain well preserved right up to the present day.

The north and south walls also reveal colourful scenes in which some of the figures are accompanied by hieroglyphics that evoke their names and titles. The principal actor of the paintings is represented at the ends of both walls (Fig. 8).

25 MILLER and BRITTENHAM 2013: 33.

Fig. 7. Chilonché West Wall mural. Detail. (Drawing by M. A. Núñez, PLB 2013).

Fig. 8. Chilonché South Wall mural showing female characters together with their names. (Drawing by M. A. Núñez, PLB 2013).

Physical-chemical study of the mural

We shall continue by describing the research and documentation techniques that have been employed to date and which have proved absolutely essential for the epigraphic and iconographic study of these paintings, still currently underway.

First stage: On- site appraisal of the painting and taking of samples

The good state of conservation of the mural painting found in Room 6 demanded a detailed study of the materials and pictorial techniques used by the local painters during the Late Classic period. A focus on Room 6 is especially important when taking into account that the vast majority of wall paintings found in the Maya area have lost almost all of their pictorial surface.

A thorough inspection of the mural allowed the relatively easy identification of any deviations with respect to the technical traditions of Late Classic Maya lowland mural painting. While the colour and texture of the pigments employed appear to correspond to those normally used elsewhere, their technical execution was far removed from that commonly seen in the area. The painters of this mural seemed to have painted the mural in rapid and diluted brushstrokes that in some of the figures and glyphs create the sensation of an uncompleted or sketch type painting (Fig.9).

Fig. 9. Detail of rapid and diluted brushstrokes on the Chilonché West Wall mural. (Photograph A. Toepke. PLB 2011).

As our first objective was to identify the painting technique used in Room 6, we opted to take micro-samples of all the polychromy of the mural, including each identified tonal variety. These micro-samples (61 in total) were taken with utmost care and in all cases came from points adjacent to already damaged areas or from parts of the paintwork that had peeled as a result of the scraping of the mural by the rock and soil backfill used to seal up the room in ancient times.

The second objective was to investigate the manufacturing process used by the Chilonché painters to prepare the pigments and dyed pigments, and the third objective was to establish how these painters had applied colour to achieve certain effects in the pictorial representation, such as the overlapping of the figures, among other aspects.

Second stage: description of the archaeometric techniques employed

The archaeometric study of the samples was carried out at the laboratories at the University of Valencia and Polytechnic University of Valencia and employed the following techniques: light microscopy (LM), scanning electron microscopy combined with X-ray microanalysis (SEM/EDX), Fourier transform infrared spectroscopy (FTIR), pyrolysis-gas chromatography/mass spectrometry (Pyro-GC/MS), transmission electron microscopy (TEM), atomic force microscopy (AFM) and voltammetry of microparticles (VMP).

The physical-chemical characterization of the mineral palette employed was made by scanning electron microscopy combined with X-ray microanalysis (SEM/EDX). The identification of the organic and inorganic elements was made by Fourier transform infrared spectroscopy (FTIR) and gas chromatography/mass spectrometry (GC/MS); the best results were obtained in both laboratories by combining GC/MS with pyrolysis (Pyro-GC/MS)[26]. In order to identify the process followed by the Maya painter to prepare this palette, TEM, AFM and VMP archaeometric techniques were employed, as TEM and AFM allow identification on nanometric scale whereas VMP helps provide the electrochemical profile. VMP has already proved of great service in providing new and revealing information regarding the preparation of Maya Blue. Last, but not least, the third of our objectives was successfully met through the stratigraphic study of the colour using light microscopy (LM).

The use of these techniques helps provide answers to a whole series of questions, such as: What was the pigment grinding process? Were pigments used in their original state or were they modified? If pigments were modified, how was this achieved? What were potential pigment purification methods (such as the sublimation of cinnabar)? Was heat treatment used for iron-based pigments to increase their tonal variability? If heat treatments were used, what were the temperatures at which modifications to the matrix were made (such as in the cases of hematite or specular hematite)? Were heat treatments the same for geothites, limonites, ilmenites and lepidocrocites?

The use of these techniques also help resolve the baking times necessary in each case and, no less importantly, help resolve the identification of errors in the manufacture of iron pigments and their association with excess or insufficient heat and/or baking times. Finally, the techniques help to establish the potential relationship between the success or failure of the manufacturing processes of iron pigments and the level of skill of the painters working at a specific site. And, if proven, the corresponding relation between the greater or lesser degree of technical skill of the painters involved in the pigment manufacturing processes and the ensuing state of conservation of their works. The deterioration of a painting is primarily due to three possible errors in the manufacturing process: an incompatibility between the base layer and the colour palette employed, an incompatibility between the colour palette and the binder employed (that is to say, the pictorial technique), and finally, an incompatibility between the pigments themselves[27].

However, this did not initially appear to be the case of the Chilonché mural. The in situ observation did not seem to reveal any conservation problems associated with these incompatibilities during the manufacturing processes. The pigments used seemed to be compatible among themselves, with the pictorial technique employed and with the base layer, while the base layer appeared equally compatible with the technique of execution.

The analysis of the pigments by TEM, AFM and VMP, as indicated above, would provide a highly precise indication of the production of the colour used by the painters in this Late Classic mural, while the physical-chemical characterization of the mineral palette through the use of the other archaeometric techniques would allow us to identify the organic and inorganic elements and to then establish the pictorial technique employed in the execution of these paintings.

Third stage: interpretation of results

The FTIR and Pyr-GC/MS analysis of the 61 micro-samples taken from the mural provided answers to some of our questions. No organic binder was identified in any of the colours. The absence of organic binder then points to the use of the fresco method as the pictorial technique employed by the painters at Chilonché in this particular work. This discovery establishes this mural as the only documented Maya mural to have been created using this technique to date. After three decades of physical-chemical examination of Maya paintings, there has only been evidence of mixed or mezzo execution or the more prevalent secco technique, and in both cases Maya painters added vegetable gums of different physical qualities in both plaster and pigments[28].

The fresco technique has always posed a technical challenge to the artist for two main reasons. First, great skill is required to complete the pictorial composition

26 DOMÉNECH-CARBÓ, OSETE, DOMÉNECH, VÁZQUEZ DE ÁGREDOS and VIDAL 2014.

27 In this case, reference may be made to the case of the pigments employed in Room 7 of Palace 6J2 at the La Blanca Acropolis, which offers a clear example of the problems of conservation of a painting caused by an incompatibility between the pigments themselves (See VÁZQUEZ DE ÁGREDOS, VIDAL and MUÑOZ 2014: 51.

28 The so-named “lime painting”, consisting of diluting colours in water with calcium carbonate, has also been suggested on more than one occasion as the technique employed in Maya mural painting, particularly in view of the layer of lime carbonate often seen to cover the pictorial film of these works. However, this type of mezzo fresco may also be produced naturally. The lime-based preparatory layer only has to exude calcium carbonate towards the surface and this will then spread over the pictorial film in the form of a whitish layer. This is a very common occurrence in very humid areas such as the Maya region and for this reason it is very difficult to define whether the paintings are the result of an intentional mezzo fresco or whether they are purely the result of this natural process.

before both the pigments and the plaster completely dry out; some haste undoubtedly explains many of the blurred brushstrokes marking the outlines of numerous characters and parts of the Chilonché mural. Second, great command of materials and techniques is demanded in fresco painting.

For example, the lime carbonation process that ensures the fixing of the diluted colours on to the base layer can corrupt many of the pigments used by the Maya, and severely limits the colour palette to a range of possibilities not much beyond the lime whites (Figs.10 and 11), carbon blacks, iron-based pigments such as hematite, ilmenite, goethite and limonite (Figs.12 and 13), and the Maya blue and green lake pigments that were all identified by SEM/EDX, FTIR and VMP on the Chilonché mural (Figs.14 and 15).

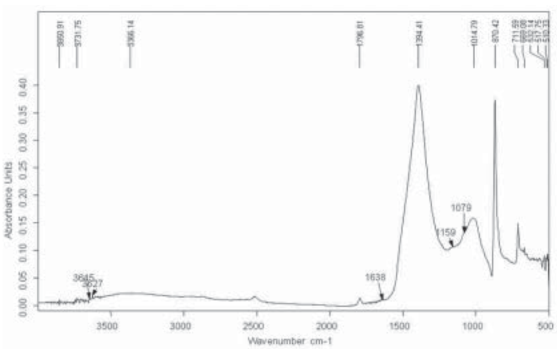

Fig. 10. FTIR spectrum of the white lime pigment found in sample CH.59-CAMP/2011 of the Chilonché mural, consisting of white clay accompanied by other clays (note peaks 3645, 3627, 1638, 1159, 1079).

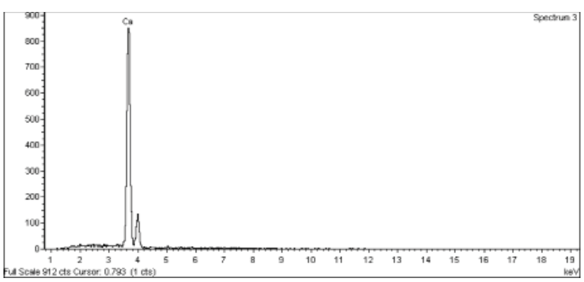

Fig. 11. SEM/EDX spectrum of the white lime pigment found in sample CH.45-CAMP/2011 of the Chilonché mural. In this case the painters used a lime white without silicate clays.

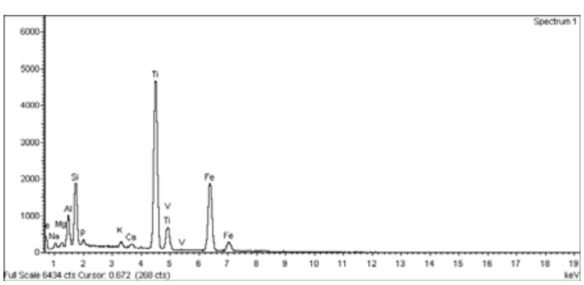

Fig. 12. SEM/EDX spectrum of one of the orange ilmenite pigments used in the mural (sample CH.19-CAMP/2011 of the Chilonché mural).

Element	Weight%	Atomic%	Compd%	Formula
Na K	1.09	1.26	1.47	Na2O
Mg K	0.55	0.60	0.90	MgO
Al K	3.11	3.08	5.88	Al2O3
Si K	5.98	5.69	12.79	SiO2
P K	0.67	0.58	1.53	P2O5
K K	0.59	0.40	0.70	K2O
Ca K	0.43	0.29	0.61	CaO
Ti K	28.20	15.73	47.05	TiO2
V K	0.31	0.16	0.55	V2O5
Fe K	22.17	10.60	28.52	FeO
O	36.91	61.61		
Totals	100.00			

Fig. 13. SEM/EDX quantitative analysis of the orange pigment taken from sample CH.19-CAMP/2011 of the Chilonché mural.

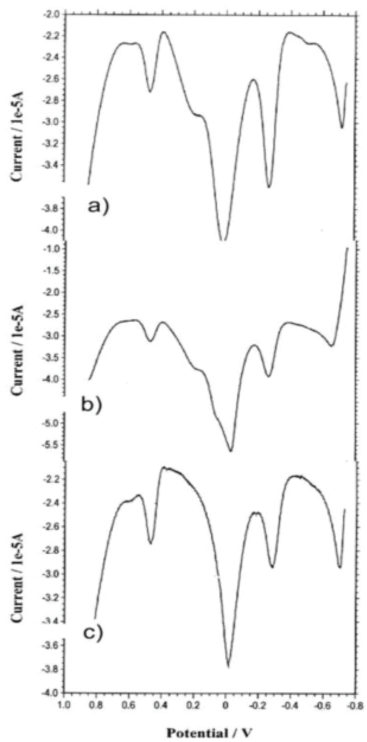

Fig. 14. Voltammetry of three samples of Maya blue from the Chilonché mural: a) dark blue: CH.2 a-CAMP/2011; b) medium blue: CH.3-CAMP/2011, c) light blue CH.34-CAMP/2011, attached to paraffin-impregnated graphite electrodes immersed into 0.50 M acetic acid/sodium acetate aqueous buffer, pH 4.75. Potential scan initiated at -0.75 V in the positive direction. Potential step increment 4 mV; square wave amplitude 25 mV; frequency 5 Hz. In this case the peaks identified indigotina and dehydroindigo, the two dyes integrated in Maya Blue.

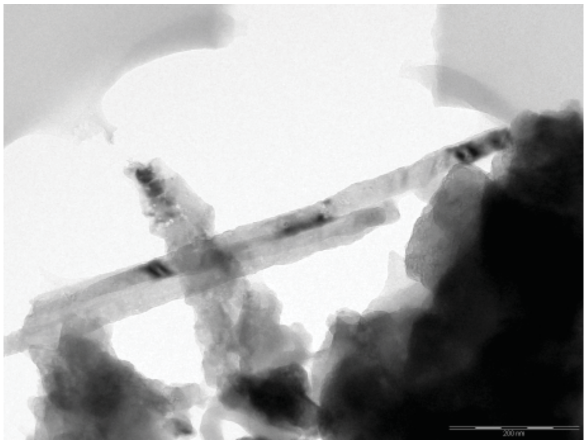

Fig. 15. TEM image of the sample of Maya blue corresponding to sample CH-3-CAMP/2011. Note the rough surface of the attapulgite in which the indigo was precipitated and baked.

The study by TEM and AFM of the iron-based pigments employed in the Chilonché mural, which formed approximately 88% of the palette, also made it possible to identify the richness of tones achieved by these artists. Many of the reds, oranges, ochres and yellows employed in the painting were manipulated by heating these pigments. The iron components, containing hematite, ilmenite, goethite and limonite, guaranteed changes in the matrix and on heat application of between 600 and 800ºC allowed deep hues, such as the skin of certain figures and background areas, as opposed to the brighter, more luminous figures that appear in the foreground and especially on the north wall. The iron-based pigments that were used on the north wall were not subject to prior heat treatment and were employed in their original form just as they were extracted from local mining areas; hence their more luminous appearance. These pigments were also used in combination with a greater proportion of cool colours, as is the case of the blue of the macaw or the white of the loin cloth of one of the characters on this same wall (Fig.16), which serves to break from the warm range of generally intense colours found on other characters of the west and south walls. Finally, the particle size of the iron-based pigments applied on the north wall is much finer, and the pigments are almost completely crushed, in contrast to the same colours of far larger particle size on some figures of the west and south walls and which subsequently favoured more saturated and less translucent finishes, as demonstrated by the study of the samples with LM.

This study serves to meet the second of our objectives, namely, the identification of possible techniques employed by the Chilonché painters to prepare their pigments. It also reveals that manufacturing processes were geared to generating a chromatic palette in which each iron pigment, e.g. hematite, could be employed in at least two different forms. The original and brighter form is produced by milling and its probable application or spreading in more diluted solutions (as in the case of the characters on the north wall or in the foreground). A more opaque and saturated form is produced by the heat treatment of iron-based pigments, more reduced milling and their dilution in solutions with smaller proportions of water and a greater amount of pigment (as seen in certain figures and areas in the background of the west and south walls of the mural).

Fig. 16. Chilonché North Wall mural showing the blue painted macaw. (Drawing by M. A. Núñez, PLB 2013).

Graphic documentation of the Chilonché mural

The graphic documentation of the mural was carried out by means of a variety of standard data collection systems. Initially, and following the cleaning and prior consolidation of the mural, detailed photographic images were taken of all parts of the mural using high-quality detail photography. A more general panning shot was also taken, with respect to previously arranged target points, in order to allow the photogrammetric reconstruction of all the walls (Fig. 17).

An architectonic survey was also made by tracing the necessary outlines and taking the corresponding measurements, using flexometer, plumb lines, levels and laser telemetry, to provide an architectural reconstruction of the room together with all the details necessary for a complete understanding of the same. Finally, the mural was traced by draughtsmen using large-size clear acetate sheets and these tracings, together with the supporting photographic documentation, served as the basis for a reconstruction of the mural on a 1:2 scale, using watercolour and tempera painting techniques on a suitable fabric in an effort to ensure the reproduction of the original colours (Fig. 18).

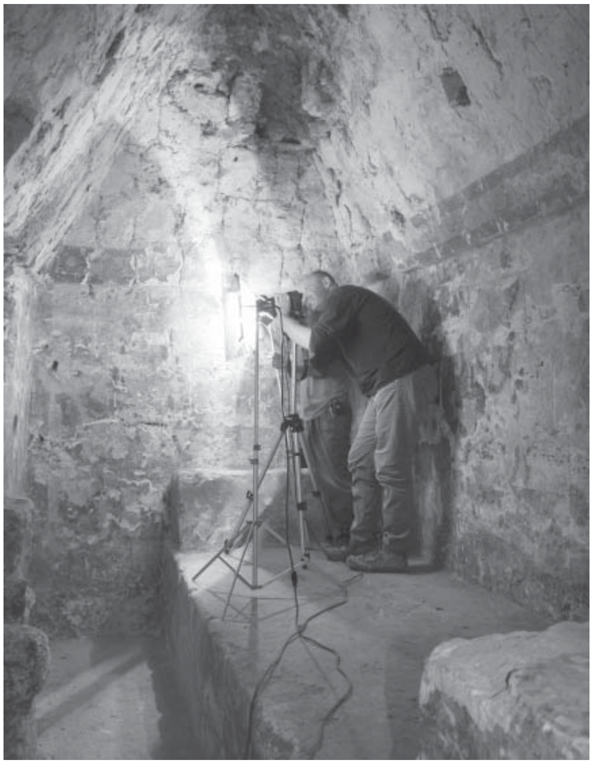

Fig. 17. Photographic survey of the Room of Paintings at Chilonché (Photograph P. Horcajada, PLB 2011).

Fig. 18. Chilonché West Wall mural showing the central scene. (Drawing by M. A. Núñez, PLB 2013).

In an effort to further supplement this documentation, laser scanning has been programmed to collect 3D data of the entire room in order to allow a precise architectonic reconstruction, as a graphic supplement to the murals, and to allow the 3D modelling of the room.

Conclusions

This chapter underlines the relevance of the physical-chemical analysis of the pictorial traces still remaining in Maya buildings, together with the importance of recording and documenting the murals.

The scientific study of the paintings provides a greater understanding of the composition of the plasters and pigments employed, and on the basis of the results obtained, it is then possible to delve into other aspects related to the level of technological skill to work with colour. In this regard, the scientific examination of the mural of Room 6 of Building 3E1 of the Chilonché Acropolis has provided information on the local origin of the pigments that were employed, and the technical knowledge of the painters responsible for the mural. The role of the fresco technique in the history of Maya painting has been highlighted, and has allowed the precise definition of the degree of technological advancement in the preparation and use of pigments that were employed with a specific aesthetic intention.

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