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Characterization of Thai Mural Paintings from Mid to Late
Ayutthaya Period (1488-1688) on the Case Studies
of Wat Chaiwatthanaram, Wat Chong Nonsi and
Residential Building of Somdet Phra Phutthakosajarn

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Abstract

Thailand's Cultural Heritage faces significant challenges in preserving traditional mural paintings, given their historical and artistic importance. To ensure effective conservation, it is crucial to investigate the sources, categories, properties, and degradation processes of these materials over time, as well as the underlying causes and mechanisms of their alterations. This understanding is essential for selecting compatible materials and appropriate conservation methods, in alignment with international standards for heritage preservation.

The present study focuses on the characterization of Thai pigments and binders used *in secco* techniques, as well as the environmental factors contributing to the degradation of murals from the Mid to Late Ayutthaya period (1448–1688). Specific sites under investigation include Wat Chaiwatthanaram (UNESCO site) and the residential building of Somdet Phra Phutthakosajarn in Ayutthaya, and Wat Chong Nonsi in Bangkok. These sites represent unique forms of ancient Thai artistic heritage, revered for their beauty and mysticism. A main aim of this work is the identification of key pigments—such as black, green, and red—which were fundamental to the Ayutthaya period's color palette. To this purpose, as a first step, non-invasive investigations with a colorimeter were carried out on site, and collected colorimetric data were analyzed to have a first overview of the possible pigments. As a second step, small fragments taken from the sites were analyzed with a range of advanced techniques, including Optical Microscopy, Micro-Raman Spectroscopy, Scanning Electron Microscopy–Energy Dispersive X-ray Spectroscopy (SEM-EDS), Micro-Fourier-Transform Infrared (microFTIR) spectroscopy and Electron Paramagnetic Resonance (EPR). Additionally, the study examined the mortar used as the ground layer in Wat Chaiwatthanaram. This research is complemented by documentary studies and qualitative fieldwork, which includes interviews with conservators and restorers involved in safeguarding Thailand's Cultural Heritage. While the study is limited to samples from selected sites, the findings will contribute to an evidence-based understanding of the materials used in 16th-century Thai mural painting. The knowledge gained highlights the adaptive strategies employed by artisans in a humid climate, characterized by heavy rainfall, river basins, and annual flooding. Additionally, the study reflects the impact of present-day environmental changes on heritage buildings.

In summary, this study offers valuable insights into the preparation of local Thai materials used in historical paintings, while also contributing to the improved management and protection of cultural heritage. The findings aim to ensure the preservation of Thailand's artistic legacy, safeguarding its intrinsic values for future generations.

Introduction

Ayutthaya is present day a very important Cultural Heritage site inscribed by UNESCO in 1991. It was the main town of the Ayutthaya kingdom, a Siamese reign who rules the territories of the current Thailand for four centuries, from XIV c. to XVIII c. This period coincided with a rich culture, a significant emporium in Southeast Asia, established upon a foundation of multiculturalism, characterized by the construction of many sophisticated, Buddhist temple compounds (“Wat”), wonderfully carved and surrounded by several statues. Mural paintings often adorned Thai architectural structures, including the interiors of pagodas, ordination halls, *Vihara*, preaching halls, scripture halls and chanting halls. These murals were influenced by international arts, particularly from India and China, and evolved to incorporate characteristics and styles that harmonized with Thai aesthetic preferences. They also integrated elements from earlier periods, such as the *Dvaravati*, *Srivijaya*, *Lopburi*, and *Sukhothai* arts. A distinctive feature of these murals is their ability to convey Buddhist teachings, including the *Dhamma* and *Vinaya*, as well as Dharmic paradoxes, philosophical ideas, and various literary themes. This was achieved through visual storytelling, grouping of images, depiction of individual characters, landscapes, architecture, and gilding decoration. These murals reflect the history and culture of Thai society and remain a significant cultural heritage and intellectual asset. They offer a valuable opportunity for further study and continue to serve as a bridge to the past, stimulating the imagination and offering insights into historical and philosophical contexts.

In addition to the mural elements mentioned above, traditional Thai paintings during the Ayutthaya period followed both fixed conventional rules, as outlined in sacred Buddhist texts, and free ideation that allowed for individual artistic expression. The nature of these paintings enabled artists—whether royal or local—to showcase their unique styles and techniques. The process of creating murals followed a systematic approach, beginning with the preparation of materials, tools, and equipment in a specific sequence. Pigments were derived from a large variety of natural sources, such as earth, rocks, metals, plants, and even some animals. For instance, black pigment was commonly derived from soot; , but yellow pigments were from yellow ochre, orpiment, or a dye extracted from *Garcinia hanburyi* (a plant diffused in South-East Asia), while; red pigments were from red ochres, Chinese vermilion, rattan palm, and red lead;. White pigments were from clay, white lead, and calcium carbonate; and blue pigments from true indigo (*Indigofera tinctoria*) and cobalt blue.; Green pigments were mainly from green earth, Chinese malachite, and, in most recent murals, (Scheele's Green (copper arsenoarsenites)).The preparation of binders from local plant sources such as *Feronia limonia Swingle*, *Ficus glomerata*, and *Tamarindus indica*, or from animal sources like cowhide and rabbit skin, is a crucial step in the mural painting process. It was essential to prepare all materials to the highest standard, since minimal pollutions in these complex mixtures could result in unexpected, final results. This is evident in the evolution of painting styles across different periods,

where the combination of various pigments resulted in distinct shades, each with its own name. These variations are deeply connected to traditional Thai culture and reflect the way of life of the Thai people in the past.

The primary focus of this research is to have a first characterization of Thai pigments and binders used during the Ayutthaya period through the application of scientific and technological processes. Both invasive and non-invasive tools have been employed. The characterization of these pigments and binders is fundamental to reach two main objectives. First of all, Thai paintings are currently affected by climate change, which accelerates their fading, decay, and deterioration. This has created an urgent need for conservation efforts.

It is essential to select materials and conservation methods carefully, adhering to international conservation principles; of course, gaining a comprehensive understanding of the original materials before undertaking any effective conservation or restoration work, is of paramount importance. As Dr. Jiraporn Aranyanak, an expert in conservation science and Former Director of the Conservation Science Group under the Fine Arts Department, stated: “It is necessary for conservator to study and analyze the causes and processes that lead to changes in artwork as the first step, before proceeding with conservation using methods that address the root causes or, at the very least, slow down the rate of deterioration as much as possible”

The case studies include Wat Chaiwatthanaram and the residential building of Somdet Phra Phutthakosajarn in Ayutthaya, as well as Wat Chong Nonsi in Bangkok. These paintings serve as exemplary representations of traditional Thai art from the Mid to Late Ayutthaya period (1448–1688), a time when the arts and crafts of Ayutthaya underwent significant development. This period saw increased contact with international cultures, leading to the adoption of advancements in arts and science, and the use of various materials, tools, and equipment. As a result, several changes occurred in Thai painting: (1) The original monochrome paintings evolved into polychrome works, incorporating lighter greens, browns, blues, and purples. (2) While scenes were traditionally presented in two dimensions, the backgrounds and scenery began to adopt a more perceptive quality, similar to Chinese painting, with frequent representations of trees and water. (3) Depictions of foreigners and scenes of travel, (e.g. sailing junks on rivers or seas), became more common, reflecting the realities of the era, though they were previously uncommon in Thai painting. These developments provide a compelling basis for studying and analyzing the background of these works.

The three mural paintings selected in this thesis represent renowned works of the Ayutthaya-school painting, showcasing three distinct and remarkable techniques. The materials used in these paintings are primarily sourced locally, although some involve contributions from abroad. These three murals date back to the Ayutthaya period (1350-1767) and are all located in central Thailand, specifically in Ayutthaya, the former capital of Thailand for 417 years. Ayutthaya was

designated as World Heritage Site and is home to the second largest number of ancient monuments in Thailand, totaling 586. One of the mural paintings is located in Bangkok, the current capital, which houses the third largest collection of ancient monuments numbering 552.

Objectives

1. To have a first characterization of Thai pigments and binders used *in secco* techniques in mural paintings, from a representative batch of microsamples.

2. To investigate the local experience in the selection of pigments and binders by Thais during Mid to Late Ayutthaya period, within the context of economic growth and international trade, focusing on the adaptation, learning, and survival of individuals, communities, and society.

3. To understand the philosophical and religious beliefs that form the foundation of contemporary knowledge, including beliefs and faith in Buddhism, and the relationship between humans and nature as reflected in the selection of materials in Thai painting.

Aims of the thesis

1. To identify the composition of pigments and binders, which helps determine whether the materials used are natural or synthetic.

2. To understand the artistic knowledge and material preparation techniques of traditional Thai craftsmen, particularly those employed in the creation of Thai paintings from the Mid to Late Ayutthaya period (1448–1688)

3. To compare an overview of pigment compositions in Thai paintings from various sources, conducted as a case study to determine whether non-local materials were used.

Chapter 1 State of the Art

Cultural heritage represents the historical identity of a nation, embodying aspects that foster pride among its people and contribute to lifelong learning. Thai mural paintings, in particular, reflect the nation's unique civilization, beliefs, and spiritual traditions over a long period of time. However, the effects of globalization and climate change have led to challenges in preserving these cultural artifacts, necessitating new approaches to conservation in order to prevent their deterioration and maintain their cultural value. The significance of this research based on:

1.1 CHALLENGES IN THE CONSERVATION OF THAI PAINTINGS

Thailand's cultural heritage faces significant challenges due to the rapid economic growth, which has led to alterations in society, culture, and more importantly, cultural management practices aimed at fostering sustainable development. Consequently, the concept of conservation must evolve, requiring an interdisciplinary approach, particularly incorporating science and technology, to study the properties and structures of ancient materials in mural paintings. The need arises from specific factors, which will be discussed in the next sections:

1.1.1 LIMITED SCIENTIFIC DOCUMENTATION ON CHARACTERIZATION OF MURAL PAINTINGS

In Thailand, the limited scientific research on material conservation contrasts with the large number of cultural heritage sites, which stands at 9,849 according to the 2025 report by The Fine Arts Department on the number of ancient monuments. This total can be broken down into 3,136 registered cultural heritage sites, 5,652 unregistered sites, 1,060 sites awaiting assessment, and 1 site that remains unidentified. The registration of ancient monuments must align with their historical, artistic, and archaeological significance. Officials in various professions from the Fine Arts Department, are responsible for evaluating the value of the sites based on criteria established by the Department, which are consistent with the Act on Ancient monuments, Antiques, Objects of Art and National Museum, 1961. The initial step in determining whether a site qualifies as an ancient monument involves the use of a preliminary assessment to distinguish between registered and unregistered sites. Subsequently, a more comprehensive assessment is conducted using an advanced evaluation, which determines the eligibility of unregistered sites for official registration. If a site meets the assessment criteria, it is formally declared as a registered ancient site through publication in the Royal Gazette. This official registration ensures the site's legal protection and systematic preservation.

These factors contribute to the challenges in managing cultural heritage and conducting comprehensive scientific research on all aspects of Thai mural paintings, including their structural components such as walls, primers, pigments, and binders. Additionally, the categories of materials,

processes of alteration, production techniques, usage, and their responses to environmental factors all require thorough investigation, as outlined by the following considerations:

1) The application of science and technology to Thai mural painting, particularly in academic research and analysis, remains limited and fragmented. More importantly, there is a notable shortage of students pursuing studies in pure sciences. According to a report by the Organization for Economic Co-operation and Development (OECD), which assessed the knowledge of 15-year-old students worldwide in mathematics, science, and reading, 59.5% of Thai students fail to meet the required standards according to the 13th National Economic and Social Development Plan (2023-2027) by the Office of the National Economic and Social Development Council and P.A. Payutto, N.d. This poses a significant challenge to the foundational development of knowledge and the integration of art and science to contribute effectively to society. The study of science should not only focus on scientific knowledge but also aim to cultivate a scientific mindset—particularly a willingness to learn, critical thinking, and a diligent approach to information-seeking and evidence verification. This gap in scientific education presents a major issue for Thailand, necessitating strengthened efforts in the education system.

2) The limited capacity for human resource development, particularly among professionals and experts in the field of conservation, has hindered the efficient advancement of cultural heritage preservation. This has led to a lack of comprehensive scientific research related to mural paintings and numerous ancient monuments. Furthermore, the Fine Arts Department (FAD) under Thailand's Ministry of Culture, responsible for the preservation of cultural heritage across various sectors, employs government officers with expertise in specific areas. However, data from 2018 to 2022 reveals that the number of retirements reached a peak of 105 individuals according to *Thairath*—ranked as the most reliable Thai press outlet by Reuters—which reported in 2020 on the Fine Arts Department's shortage of specialized personnel for the preservation of artistic and cultural heritage, including archaeologists, conservation scientists, and art technicians. This has resulted in an alarmingly low number of active officers, which is insufficient to address the urgent conservation needs and prevent the deterioration of cultural heritage.

This research aims to enhance the foundational data concerning the condition of mural paintings from the Ayutthaya period by applying scientific and technological methods to validate the evidence found at cultural heritage sites. The goal is to ensure that this data can be effectively utilized in the plan for conservation and the development of cultural properties.

1.1.2 THE DETERIORATION OF MURAL PAINTINGS IN THAILAND

The appropriate conservation of mural paintings, aimed at preserving ancient materials while incorporating new materials compatible with the original ones, requires a balanced approach. This balance must integrate scientific and technological methods alongside traditional knowledge and

local wisdom, ensuring long-term usability. Therefore, the starting point for conservation efforts is to understand the causes of deterioration, which have led to both physical and chemical changes. These factors include:

1) Intrinsic factors, such as the type and properties of material structures, the primer layer, pigment layer, and binders, play a significant role in the deterioration of mural paintings. These factors are influenced by the age of the artwork. In the past, the selection of materials often relied on trial and error, with limited understanding of the chemical reactions behind these materials. Nevertheless, artisans were generally aware of the properties of the materials they used, ensuring that they were strong enough to cover flaws in the layers, address surface absorption, and manage moisture. Additionally, many materials were sourced locally. However, the deterioration of mural paintings can be attributed to the properties of the materials themselves, such as the bond between the foundation and supporting layers, insufficient primer or paint layers, or imbalanced concentrations of fixing agents. For example, if the fixing agent concentration is too high or too low, or if the colorant contains impurities, this may lead to discoloration over time

2) Extrinsic factors, particularly Thailand's geographical location in a tropical region with heavy rainfall throughout the year, significantly contribute to the deterioration of cultural heritage. In 2025, the forecasted average annual rainfall was recorded at 1,630 mm, which is considered a high level according to Water Situation and Rain Forecast Report on February-July 2025 by Hydro-Informatics Institute. This, coupled with frequent flooding in many areas-especially in the central region, which is an alluvial plain and where much of the cultural heritage is located near rivers and canals-poses considerable challenges. As a result, heavy rains and floodings are major issues for conservation efforts. Additionally, groundwater influences capillarity, and the traditional Thai architectural structures, which typically feature multiple roofs and intricate decorations, do not provide sufficient protection against large volumes of water and moisture. Furthermore, the presence of salts and fungi leads to significant changes in the composition and properties of materials, reducing their strength and making them more vulnerable to environmental degradation.

Scientific research based on the characteristics of materials is crucial, as ancient materials differ significantly from modern ones. Modern materials generally adhere to standardized characteristics, ensuring consistency across products. In contrast, original materials are derived from natural sources and possess high porosity and distinct chemical properties. Without comprehensive knowledge of these differences, the application of new materials to cultural heritage could pose significant risks to the integrity of the original materials. Therefore, data on characterization of cultural materials is essential for identifying compatible approaches that balance the preservation of both old and new materials, ultimately contributing to effective conservation and management.

1.2 HISTORICAL AND ARTISTIC CONTEXT

The three mural paintings selected in this thesis represent renowned works of the Ayutthaya-school painting, showcasing three distinct and remarkable techniques. The materials used in these paintings are primarily sourced locally, although some involve contributions from abroad. These three murals date back to the Ayutthaya period (1350-1767) and are all located in central Thailand, specifically in Ayutthaya, the former capital of Thailand for 417 years. Ayutthaya was designated as World Heritage Site in 1991 and is home to the second largest number of ancient monuments in Thailand, totaling 586. One of the mural paintings is located in Bangkok, the current capital, which houses the third largest collection of ancient monuments, numbering 552 according to the 2025 report by The Fine Arts Department on the number of ancient monuments. In the following sections, the geographical, historical and artistic context of the three mural paintings – investigated with non-invasive and microinvasive techniques in this thesis – will be shortly described.

1.2.1 WAT CHAIWATTHANARAM, AYUTTHAYA



Figure 1 – Mural Painting at Crematorium number 5

The ancient temple, located near the river on the western side outside the city island, was constructed in 1630 during the reign of King Prasat Thong in the Late Ayutthaya Period. It is one of the ancient monuments situated within the World Heritage Site zone. The temple was built as a dedication to the king's mother and was designed to replicate the architectural model of Angkor Wat, reflecting both Buddhist cosmology and the king's architectural interests, which were influenced from Cambodia. Its mural paintings can be found in eight crematoria, created by skilled royal artisans. These murals are characterized by flowing lines and dynamic compositions. They feature patterns drawn in red and green, interwoven with black, red, and white lines. A distinctive feature of these murals is the traditional floral motif, and the flowers are depicted in red, while the leaves are green.

The primary issue facing the ancient monument is moisture, which has contributed to rapid deterioration, particularly from natural water sources such as rain, airborne humidity, and groundwater. Additionally, cement was used in the conservation efforts between 1987 and 1992, particularly in the construction and reconstruction of pavements around the crematoria. This use of cement has hindered the evaporation of moisture, causing it to remain trapped within the materials. The current conservation project, a collaboration between the World Monuments Fund (sponsored by the U.S. government) and the Fine Arts Department under Ministry of Culture, has removed the cement and replaced it with new mortar. This new mortar was developed through scientific research and experimentation conducted by professionals and experts in the field of conservation, ensuring its compatibility with the original materials.

1.2.2 RESIDENTIAL BUILDING OF SOMDET PHRA PHUTTHAKOSAJARN, AYUTTHAYA

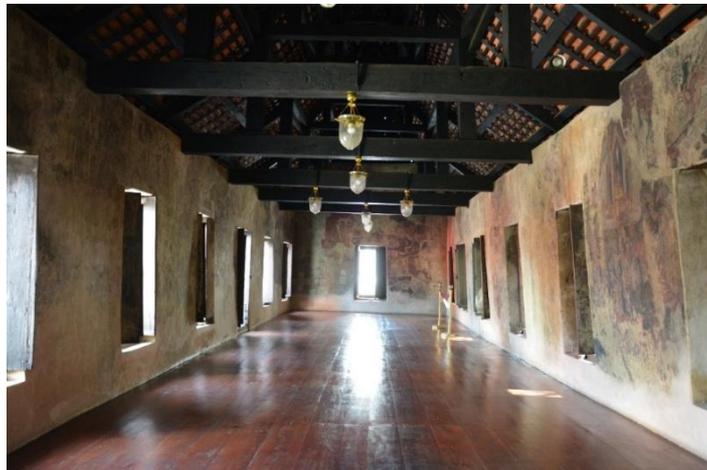


Figure 2 – Mural Paintings at Residential building of Somdet Phra Phutthakosajarn

The mural paintings in the residential building of Somdet Phra Phutthakosajarn - are believed to have been created during the reign of King Phetracha, between 1631 and 1730, in the Late Ayutthaya Period. The residential building is located in the area of the older temple “Wat Phutthaisawan”. The temple, located on the southern bank of Chao Phraya River outside the city island, was founded by King U-Thong, the first king of Ayutthaya, as a temporary residence before Ayutthaya was established as the capital in 1350. The monastery was changed into a temple for commemoration the significance of this location. These murals were dedicated to senior monks and the king's teachers. A distinctive feature of these murals is the use of dark, multicolored tones, predominantly red and green, with simple, flowing lines. The style of the paintings conveys various stories, including scenes from the *Traibhumi*, the Buddha's temptation by *Mara*, the five footprints—namely the Buddha's footprints at *Khao Sumonakut*, the *Nammatha River*, and *Sattabappa* in Saraburi—the *Ten Lives of the Buddha*, and depictions of the life of Buddhaghosacariya during his

journey to Sri Lanka. These murals reflect the ancient beauty of Thai religious art and illustrate the deeply rooted Buddhist beliefs and faith in Thai society. (The Fine Arts Department, 1995)

The current condition of the paintings is very poor, since murals are severely deteriorated, primarily due to moisture damage. Rain has caused significant erosion, resulting in the loss of many details and traces of the original artwork. The restoration of the paintings at the residential building of Somdet Phra Phutthakosajarn employed a technique known as *tratteggio*, in which a continuous plumb line is painted over the damaged areas without compromising the overall aesthetic integrity of the work.

1.2.3 WAT CHONG NONSI, BANGKOK



Figure 3 – Mural Paintings at ordination hall in Wat Chong Nonsi

The temple, active from the middle to the late Ayutthaya period, dates from the reign of King Narai the Great (1656–1688). Considering the evidence of murals in the ordination hall, they have never been repainted by the conservator, therefore the paintings are original. The colors used are predominantly warm tones, with a color scheme comprising shades of red and pink, accented by black lines, and featuring white and green highlights. These elements effectively convey the lifestyle and cultural context of the Ayutthaya period. Additionally, the murals have not undergone any restoration efforts, except for external repairs. Villagers applied white mortar to smooth the exterior surface, but no other interventions were made. It was not until the conservation efforts in 1982 that the murals, which possess the following distinctive features, were examined in detail according to The Report on the Conservation of Wat Chong Nonsi’s Mural Painting by The Fine Arts Department :

1) The paintings exemplify the late Ayutthaya technique, which involved applying a layer of white dust to the walls prior to painting. Certain sections of the artwork, particularly large areas, retained a white background, distinguishing it from the artistic style of the Rattanakosin period, where outstanding colors, for example red, were applied to the floor. In contrast, the figures and objects are depicted in lighter tones, creating a visual contrast that enhances the prominence of the image.

2) The gilding is applied selectively, covering only significant elements, such as the Buddha’s

image and a few other desired features. This deliberate restraint ensures that these gilded components do not overshadow the principal Buddha image in the ordination hall.

1) The paintings convey the social and cultural conditions of the time through depictions of architectural building structures. Notably, a two-story brick building is represented, with square windows on the upper floor and pointed arched windows on the ground floor, resembling the architectural style of Wat Phutthaisawan.

2) The residences of the nobility are depicted with roofs covered in clay roof tiles, while the roofs of the royal palace are shown covered with tin roof tiles, reflecting the typical architectural style of the Ayutthaya period.

3) The background of the painting is typically rendered in red, upon which leaves and flowers in the Ayutthaya style are depicted. Additionally, a pattern of waves, resembling water, is painted with lines in the same red hue, similar to the decorative elements found on the residential buildings of Somdet Phra Phutthakosajarn.

4) The depiction of the Buddha's temptation by Mara at Wat Chong Nonsi does not include representations of foreigners, Muslims, Cham, or other nationalities, in contrast to others. Instead, the scene is populated with figures of demons and various animals.

Although the murals are currently being preserved and repaired, they continue to suffer from damages. Issues such as a leaking roof and rainwater seeping onto the walls have caused the paint to peel and fade. Consequently, the walls are exposed to high humidity, compounded by moisture rising from underground water. As this moisture evaporates, it has caused severe damage to both the walls and the paintings.

The Thai mural paintings discussed above exhibit distinct characteristics in both their drawing style and the use of traditional Thai colors. These murals effectively represent traditional Thai art while also showcasing the Ayutthaya artistic style, reflecting the complex and nuanced thoughts and beliefs of their creators. The artwork is imbued with ideals and philosophies of Buddhism, deeply rooted in the history, culture, and way of life of the Ayutthaya period. As such, these murals are invaluable as artistic, religious, cultural, and archaeological heritage of Thailand.

As the future depends on preserving the past, it is essential to explore how ancient sites can be safeguarded for future generations. This research emphasizes the importance of applying scientific knowledge to the study of Thai painting materials, which can serve as a valuable database for architects, archaeologists, conservators, engineers, art historians, conservation scientists and other scholars in the field of conservation. The primary objective of this study is to provide a preliminary scientific investigation of Thai pigments and binders used in secco techniques.

Chapter 2 Thai mural painting and its materials

Murals are an essential aspect of cultural heritage, preserving history, archaeology, customs, traditions, way of life, beliefs, and aesthetic values that vividly reflect the prosperity of local communities. In particular, Thai paintings, exemplified by case studies such as Wat Chaiwatthanaram, the residential building of Somdet Phra Phutthakosajarn at Wat Phutthaisawan, and Wat Chong Nonsi, are classified as traditional Thai paintings. These murals, created using the *secco* technique, date back to the late Ayutthaya period, beginning with the reign of King Prasat Thong of the Prasat Thong Dynasty in 1629 and ending with the reign of King Ekkathat of Ban Phlu Luang Dynasty in 1767, marking the final years of the Ayutthaya Kingdom. Although Thai murals were influenced by both India and China, they nonetheless reflect the exquisite craftsmanship and distinctiveness of Thai artisans, particularly in their use of unique techniques and vibrant colors.

2.1 SIGNIFICANCE AND VALUE OF THAI MURAL PAINTINGS

This section examines the history and characteristics of Thai mural painting, as well as the importance of traditional Thai painting in the propagation of Buddhism within Thai society. The details are as follows:

2.1.1 TRADITIONAL THAI PAINTING

The Thai Royal Institute Dictionary (1999) defines the term ‘painting’ as a form of visual art. Painting is an art emerging from the artist’s diligence, imagination, and inspiration, with the artist using concentration to transform ideas into a work of art. This process begins with lines and coloring, and culminates in a finished piece that embodies aesthetic value, evokes emotional satisfaction, and provides academic knowledge across various fields. As such, it is valuable cultural heritage for future generations. (1999 Thai Royal Institute Dictionary, 2003)

Santi Leksukhum, a renowned Thai art historian and archaeologist, states that Thai paintings represent a distinctive style that sets them apart from other nations. While influenced by foreign artistic traditions, these influences are adapted, expanded, simplified, or enhanced to create a unique and beautiful identity. Thai painting has evolved in both form and technique over time, and it has the potential for further development in the future.

Wannipa Na Songkhla, a Thai archaeologist specialized in painting conservation, asserts that Thai paintings are idealistic works of art. Their value lies in their harmonious proportion, exquisite depictions of costumes, intricate and meticulous lines, and systematic composition. These artworks are created by artists to convey an understanding of Buddhism, philosophy, literature, and various events, as well as to reflect the environment within the artists’ thoughts or imaginations. Such paintings serve as valuable sources for research, offering insights that can improve mental health, and contribute to societal and economic development. (Thai Fine Arts Department, 1990)

In summary, Thai paintings are characterized by idealistic representations of art. The images are typically miniature and flat, with an orderly composition. Their beauty lies in the graceful depiction of cloth and the intricate, delicate linework. Distinctive features of Thai paintings include their narrative quality, often illustrating stories related to Buddhism, traditional culture, way of life, or historical events of the period.

According to the Royal Institute Dictionary of Fine Arts (1987), traditional Thai painting is defined as either monochrome or polychromatic artwork, shaped by the beliefs of Thai painters. This form of art is expressed through various styles and traditions, as outlined below:

1) The form of objects in traditional Thai paintings is represented by figurative figures, fictional characters, or visions derived from artist's thoughts. This approach involves personification rather than depicting a realistic image.

2) The form is characterized by shapes, structures, and gestures that are artificially arranged through the reorganization of individual components. These forms are easily discernible and maintain harmony within the composition.

3) The general form is small and reduced in scale to accommodate the narrative within a limited space. For instance, large buildings are depicted at a small size to fit the composition.

4) The general form is inherently two-dimensional, displaying both height and width. As a result, the form appears flat.

5) The form and the color applied to it are flat, using a consistent color palette to distinguish between the background and the main figures within the composition.

6) The general form is depicted from a viewer-level perspective. Every figure or object in the painting is presented as if it is directly before the viewer's eyes, regardless of its position within the composition.

7) The form is used as a tool for narrative expression, with the gestures of the figures conveying behavioral meanings and helping to explain the events depicted in the story. Traditional Thai paintings typically omit light and shadow, limiting the use of these elements in favour of stylized forms.

8) The form is consistently presented in a clear and uniform manner, without reduction in size or detail, throughout the work. The features of the figures remain consistent throughout the work.

9) The forms and elements within traditional Thai paintings serve specific purposes to aid in the narrative. The elements are presented with intention, contributing to the overall storytelling.

10) The use of form and color in traditional Thai painting is primarily decorative. Thai painters do not aim for realistic representation, instead they use color for aesthetic purposes and symbolic meaning, free from the constraints of realistic depiction. (Boonyarat,2012)

In summary, traditional Thai paintings are characterized by delicacy and beauty, featuring graceful, flat colors and two-dimensional lines that allow only for width and length, without depth. These paintings do not utilize light and shadow. A distinctive feature of traditional Thai painting is the arrangement of images to tell stories in episodic sequences. Thai paintings incorporate different color schemes depending on the era, utilizing both monochromatic and polychromatic styles. Notably, the use of multiple colors in the polychromatic style became particularly popular during the late Ayutthaya period, as imported foreign pigments, brought through trade, enhanced the vibrancy and beauty of Thai art.

2.1.2 SIGNIFICANCE OF BUDDHISM IN THAI PAINTING

Buddhism in Thailand serves as a fundamental structure of society, as it deeply influences the forms of art, culture, and traditions, including Thai painting. These artistic expressions are rooted in the knowledge and understanding of Buddhist philosophy, which serves as a guiding principle in their creation. The transmission of Buddhist philosophy and Dharma to the public occurs through various media, such as Dharma talks by monks, teachings in schools, and oral storytelling by ordinary people.

Reflecting the communal nature of Thai society, where individuals support one another in groups, temples serve as central hubs for various forms of social interaction. In Thai society, temples function not only as religious centers but also as venues for traditional events and the foundational education of children. As such, paintings, which act as a medium for recording and conveying societal stories in lieu of verbal instruction, are predominantly found in temples. Buddhist murals hold significant cultural and educational value, based on the following principles:

- 1) The Importance of the Cause of Creation, which relies on:
 - a) A Tribute to Buddhism: According to His Royal Highness Prince Narisara Nuwattiwong, the great craftsman of Siam and the prince master, “The mural paintings of temples and palaces seem to present different ancient evidence. The paintings in temples are designed to inspire faith in Buddhism.” This highlights the murals’ role in reinforcing Buddhist beliefs and devotion.
 - b) Ornamentation for Architectural Enhancement: Mural paintings serve as decorative elements, enhancing the beauty and significance of buildings and architecture. In ancient times, temples were centers of knowledge, and the presence of murals depicting the life of the Buddha or *Jataka tales* helped to deepen people’s understanding of Buddhist teachings.
 - c) A Medium for Buddhist Teachings: Mural paintings function as an educational tool for Buddhism. When Buddhists listen to sermons and reflect upon the murals, they are often moved with gratitude, which in turn encourages virtuous behavior. Murals are referred to as the “language of painting,” meaning that their visual

storytelling allows people to comprehend messages without the need for prior study or experience.

- d) An Expression of Artistic Skill and Emotion: Mural paintings also reflect the skills and emotions of ancient artists. Through these artworks, the status of individuals from different social classes is depicted, as evidenced by differences in color, clothing, and the portrayal of various settings such as forests, mountains, villages, houses, and palaces. These elements are carefully recorded and immortalized in the murals.

2) The Importance of Faith: Artists create works with a deep faith in Buddhism, primarily with the intention of making merit. As a result, their creations serve as records of truth, conveying reliable evidence through the paintings. These works embody the authenticity of the artist's beliefs and intentions.

3) The Importance of Recording Stories and Traces of the Past: Murals function as a method of conveying narratives through synthetic art. Observant artists capture their surrounding environment and depict it in their works with accuracy and realism. These depictions of daily life reflect societal patterns of the past, as well as local characteristics, showcasing the culture and traditions of the community. For example, the life story of the Buddha is often portrayed in a Thai style, including specific details of dress and appearance, thus preserving the unique cultural identity of the time.

4) The importance of Refining the Mind: Buddhist stories convey moral principles that guide individuals toward appropriate behavior. The *Jataka tales*, for example, emphasize the concept of *karma*, while the *Traibhumi* images serve as reminders of good and evil, as well as the cyclical nature of existence. These stories are tools for moral and spiritual development, aiming to teach the fundamental truths of Buddhism.

5) The Importance as a Symbol of National Prosperity: Murals also symbolize national prosperity by recording historical events and reflecting the continued flourishing of Buddhism. They represent human emotions and wisdom, making them invaluable culture resources for research and knowledge. As such, they should be preserved and maintained carefully, as they are integral to the nation's heritage and history. (Phra Mahahansa Dhammhaso and Tangtulanon, 2013; Phayakaranont, 1982)

Murals, particularly traditional Thai paintings, are closely linked to Buddhism. The value of these paintings lies in their ability to elevate the viewer's mind through the aesthetic qualities of line, color, light and shadow, and composition. These elements serve to relax the mind, alleviate stress, enhance mental well-being, and foster faith in Buddhism. Moreover, traditional murals play a crucial role in disseminating the teachings of the Buddha. By focusing on Buddhist themes, they encourage

deeper engagement with and study of these teachings, thereby motivating viewers to explore and understand the religious imagery more fully.

2.1.3 HISTORY AND DEVELOPMENT OF THAI MURAL PAINTING

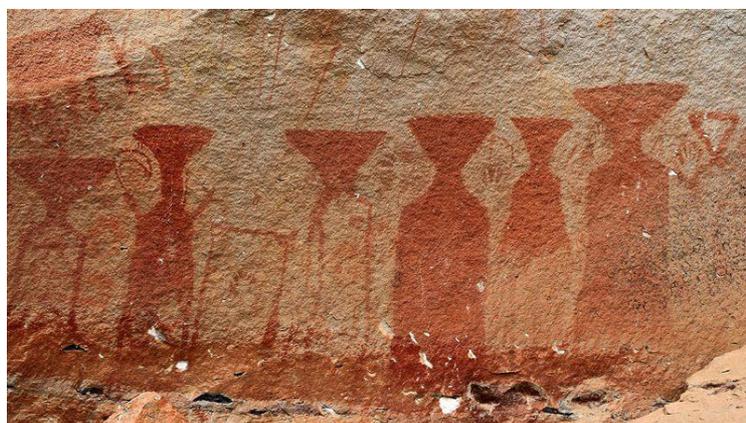


Figure 4 – 4000-year-old Prehistoric painting at Pha Taem National Park, Ubon Ratchathani Province

Source: <https://www.khaosod.co.th>

Thailand has produced cave paintings, or cave art, since prehistoric times, predating the emergence of traditional Thai painting. Early humans lived in caves or on cliffs, utilizing local materials or natural resources to construct shelters and create paintings on cave walls. The content of these paintings reflects the way of life of ancient peoples, both in naturalistic or realistic forms and in symbolic or idealistic representations. Examples include the paintings at Phu Phra Bat Historical Park in Ban Phue District, Udon Thani Province; at Pha Taem National Park in Ubon Ratchathani Province; and at Khao Chan Ngam in Nakhon Ratchasima Province. As Thailand entered the historical era, the principles of Thai writing were introduced, which are briefly outlined as follows:

1) Paintings from the *Dvaravati* period, approximately spanning the 12th to 16th Buddhist centuries (7th-11th century C.E.), are primarily found in the central region of Thailand. *Dvaravati* art was heavily influenced by India and is closely associated with Buddhism. Most of the sculptures from this period were either carved into stone or moulded with stucco. While traces of these artworks remain, there is no surviving evidence of paintings, likely due to the perishable nature of the materials used. During the flourishing of the *Dvaravati* Kingdom, the *Srivijaya* Kingdom—whose territory encompassed Sumatra, the Malay Peninsula, and parts of southern Thailand —was also prominent. Like *Dvaravati*, the *Srivijaya* was a powerful maritime and commercial kingdom. It embraced Indian art, Mahayana Buddhism, and Brahmanism-Hinduism, blending these influences with local artistic traditions. Paintings from the *Srivijaya* period, dating from the 13th to 18th Buddhist centuries (8th-13th centuries C.E.), are clearly evident in the caves of Yala Province. These paintings exhibit the distinct *Srivijaya* style, characterized by red, with accents of yellow, white, and black. The painting

technique involved the use of powdered pigments applied to cave walls prepared with a white base. The subjects of these paintings primarily depict scenes from the life of the Buddha, and the depiction of the Buddha's image closely resembles *Javanese* sculpture.

2) Paintings from the *Sukhothai* period, dating from the 18th to 20th Buddhist centuries (13th-15th centuries C.E.), are primarily found in the lower northern region of Thailand. This period is considered the first historical phase in the formation of Thailand as a unified state. During this time, there was significant contact with Buddhism from Myanmar and Sri Lanka. The Buddhist art of this period closely mirrors the styles of Myanmar and Sri Lanka, characterized by its beauty, which reflects peace, modesty, and a simple yet distinctly Thai elegance. The paintings depict *Jataka tales*, plant motifs, and images of the Buddha, which resemble those of India and Sri Lanka. The painting technique involves using powdered pigments mixed with glue, and the color palette is red, yellow, white, and black, along with gilding. The overall color tone is similar to *Dvaravati* art. The depictions of Buddha images may have been inspired by sculptures arranged in rows or by Buddha images created in panels, such as those found at Wat Chedi Chet Thaeo and Wat Si Sawai in Sukhothai Province. The primary purpose of these paintings was to venerate the Buddha and strengthen faith in Buddhism, rather than to serve as architectural decoration. (Sopha, 2022)

3) Paintings from the Ayutthaya period (1352-1767 C.E.) were created during the time when Ayutthaya served as the capital of Thailand. The art of this period was influenced by several countries, including China and India. Prior to the Ayutthaya period, Thai art was primarily focused on religious expression, particularly in the worship of Buddhism. As a result, earlier Thai painters did not place significant emphasis on decorative patterns within the spaces. However, during the Ayutthaya period, as artistic influences expanded through interaction with various cities, these decorative styles began to emerge in Thai painting. Notable examples include the murals at Wat Yai Suwannaram in Phetchaburi Province and Wat Chong Nonsi in Bangkok. Ayutthaya period paintings can be categorized into three distinct eras, as outlined below. (Saenkhat,2004)

Period 1 (1352-1488 C.E.). The mural paintings of this period feature miniature angels, possibly inspired by patterns from *Traibhumi* text. These artworks commonly depict Buddha images, disciples, *Bodhisattvas*, and various decorative patterns. The color palette is red, yellow, black, white, and gold leaf. The paintings were created using a mixture of powdered pigments and binder, primarily for worship purposes, as seen in sites such as Wat Ratchaburana, Ayutthaya.

Period 2 (1491-1629 C.E.). The paintings of this period remain predominantly monochromatic, with a continued focus on depicting Buddha images, disciples, *Bodhisattvas*, past Buddha figures, and various ornamental patterns. The backgrounds are generally light, and the paintings are flat and two-dimensional, applied with a thin primer. In some instances, no primer is present. The color palette remains similar to that of the previous period, but the addition of cinnabar,

whereas red ochres was predominantly used in previous period. The style of these paintings shows a notable influence from the U Thong and Lopburi artistic traditions.

Period 3 (1634-1767 C.E.). During this period, Ayutthaya's craftsmanship experienced significant development due to increased contact with foreign cultures. Advances in arts and sciences, as well as the introduction of new materials and tools, led to considerable changes in Thai painting techniques, including:

- a) The original color palette consisted of red, black, yellow and white, which were gradually supplemented by other mineral-based pigments that are rare in Thailand—for example, malachite and green ochre imported from China, and azurite from Europe.
- b) While the paintings remained two-dimensional, the backgrounds and landscapes began to incorporate depth and perspective, reminiscent of Chinese painting techniques. The overall color palette became brighter, with soft, flowing depictions of trees and water. White emerged as the dominant color, reflecting the influence of *Sukhothai* art.
- c) The inclusion of depictions of foreigners and ships from various countries marked a new development in Thai painting, and these images were rendered with realism. In this period, such images frequently appeared in artworks. These depictions were referred to as '12-language images,' representing figures from cultures such as Indian, Persian, French, Portuguese, Chinese, Japanese, and others. Additionally, the architectural and environmental elements featured in the murals often displayed foreign styles and influences. (Na Songkhla,1990)
- d) Paintings from Thonburi period (1767-1782 C.E.). Thai painting saw notable progress during the Thonbui period, albeit within a relatively short time frame. A significant example is the painting featured in the *Traibhumi* picture book, Thonburi Edition, which was written in 1776. The arrangement of images and the depiction of objects in this book adhered to the established characteristics and rules of Thai painting. At this time, the color palette was limited to red, black, green, and yellow.
- e) Painting from Rattanakosin Period (1780 - Present)., Painting in this period retained the same purposes, techniques, and ideals as those of the late Ayutthaya period. However, a noticeable change was the adoption of brighter colors and more intricate decorations. This period can be subdivided as follows:

Early Rattanakosin Period (1780-1850). Spanning the reigns of King Rama I to King Rama III, the early Rattanakosin period retained characteristics of the late Ayutthaya style, while exhibiting significant advancements in form and composition. The arrangement of images was highly organized,

and the paintings featured soft, delicate lines with the frequent use of bright colors. The beauty of important images was often accentuated with gilding. Early mural paintings followed the Ayutthaya style, dividing the wall into sections with *Sintao lines* (zigzag lines) and creating divisions between groups of images. (Na Songkhla,1985) The upper portions of the side walls typically featured depictions of angels arranged in layers. Literary works were commonly painted between door and window gaps, while narrow walls often depicted scenes of *Mara's* encounter with the *Traibhumi* or his departure from *Tavatimsa* heaven.



Figure 5 – Example of Zigzag lines represented at Wat Chong Nonsi, Bangkok, primarily influenced by Ayutthaya Arts.

Source: <https://samforkner.org/thaiart/zig.html>.

Later, during the reigns of King Rama II and King Rama III, literary works were frequently depicted as continuous stories, with elements like rivers, roads, trees, mountains, or city walls spanning from the floor to the ceiling. In the reign of King Rama III, Chinese artistic influences became more pronounced, leading to a fusion of styles that still preserved traditional Thai customs.

Two renowned craftsmen from this period include Master Thong Yu, a master descended from a family of craftsmen dating back to the Ayutthaya period. He was skilled in Thai patterns and served as a model for the study of ancient Thai art. The other notable figure, Master Kong Pae, of Chinese descent, was known for his keen ability to employ lines and colors effectively. This can be seen in the murals at Wat Suwannaram in the Bang Khun Non district of Bangkok.



Figure 6 – Mural Paintings at Wat Suwannaram in the Bang Khun Non district of Bangkok.

Source: https://www.silpa-mag.com/art/article_148588

The reigns of King Mongkut (1851-1868) and King Chulalongkorn (1868-1910) : these reigns marked a significant shift in the style of Thai painting, influenced by Western art. The introduction of European pigments allowed for more atmospheric expressions of color in Thai paintings. During this period, scientific knowledge began to play a role in the creation of artwork. Paintings increasingly adopted Western techniques, such as close-ups and perspective, which altered their original purpose. These paintings were no longer solely created for religious worship or to decorate religious buildings. Instead, they were designed to present those who engage in religious duties, encouraging contemplation and a deeper understanding of the *Dharma*, akin to reading sacred texts. This shift may have been influenced by the change of social conditions of the time, during which painting served as a significant medium for conveying Buddhism teaching and moral values. The intention was to encourage individuals to reflect on and comprehend the complexities of the *Dharma*, thereby reinforcing faith and promoting moral development.

Key figures in this transformation included *Khrua In Khong*, who is regarded as the pioneer of modern Thai painting. Notable works from this period include the mural paintings at Wat Bowonniwet in Bangkok. In more recent times, foreign artists have been commissioned to create frescoes in the western style, such as those at Ananta Samakhom Throne Hall.

During the reign of King Rama VI (1910-1925), the School of Applied Arts was established in 1913, marking the first formal institution for art education in Thailand. It offered instruction in a variety of fields, combining both traditional and international knowledge. During the reign of King Prajadhipok (1925-1935), notable Thai painters included Master Luang Chirong, Master Thong Yu, Master Lert Puang Phradet, Master Sawong Thim Udom, and Master Phraya Anusart Chitrakarn (Chan Chitrakarn), who began using oil paints instead of traditional powder paints. This shift in

medium contributed to a more international style of art, emphasizing emotional expression and creating a more three-dimensional effect.

Phra Soralak Likhit (Mui Chanthralak) was another key figure of this era, having received funding from King Chulalongkorn to study oil painting in Italy. In 1933, the School of Applied Arts, later known as the Fine Arts School, was founded by Professor Silpa Bhirasri (nee Corrado Feroci), an Italian sculptor who established the foundation for the study of painting and sculpture in both traditional Thai and international art forms. In 1943, the institution was renamed Silpakorn University, becoming the first higher education institution in the country dedicated to producing artists trained in both contemporary and traditional Thai art.

During the reign of King Rama VIII (1935-1946) and King Rama IX (1946-2016), there was a growing interest in the art. Notably, in 1949, Thailand hosted its first national art exhibition, marking a significant milestone in the country's artistic development.

From the above, it is evident that Thai painting has evolved over time, with notable changes in color characteristics, composition, and the level of detail. In particular, early Ayutthaya artists often focus on depicting significant events in their paintings, selecting scenes that held symbolic meaning and conveyed the essence of the entire narrative. In the late Ayutthaya period, however, artists began to incorporate more scenes, allowing for a greater level of detail in their expressions and offering a deeper interpretation of the story. This increased attention to detail required greater skill and expertise from the artists to ensure that the composition remained cohesive and visually engaging. These works provide valuable insight into the emotions, thoughts, and beliefs of the time, serving as a rich record of human behavior across different periods. Thus, they offer an important reflection of cultural and social dynamics.

2.2 CONCEPT AND THEORY BEHIND THE TECHNIQUE TRADITIONAL THAI MURAL PAINTING

The mural paintings of Thailand, exemplified by three case studies—Wat Chaiwatthanaram, the residential building of Somdet Phra Phutthakosajarn at Wat Phutthaisawan, and Wat Chong Nonsi—are classified as traditional Thai paintings in the category of *secco* technique. The artist mixes pigments with a binding substance, which adheres to the complete dry plaster wall. This technique is often referred to as the *tempera* technique, as it allows the paint to adhere well to the surface. While this method captures intricate details of the image, it is time consuming.

The process of creating traditional Thai paintings is systematic and meticulous. Craftsmen must study and prepare all materials, tools, and equipment, often creating them by hand, as ready-made tools and materials were not widely available at the time, or those available may not have been suitable. This self-sufficiency allows the artist to select the best materials for the work, ensuring that

each painting possesses distinctive characteristics. The following outlines the steps involved in the traditional Thai painting technique. (Na Songkhla,1990)

2.2.1 PREPARATION

1) Wall preparation.

During Ayutthaya period, the preparation of mortar had unique characteristics that resulted in exceptionally high-quality plaster, often referred to as ‘diamond mortar’, meaning the strength of this mortar. This type of mortar can be found on buildings from both the Ayutthaya and Sukhothai period, and many examples remain in good condition despite being exposed to the elements for centuries. The mortar is dense and strong. The lime mortar used in its preparation is derived from limestone or seashells, which are burned at temperatures of around 900°C. After this, the lime is allowed to ferment in a pond. Once the cement has fully broken down, it is filtered to remove any impurity, resulting in fire, pure cement.

Fermentation plays a crucial role in enhancing the mortar’s effectiveness. Additionally, various materials were traditionally used in mixing, as described by historical accounts. These materials included cowhide, binders extracted from the plants *Tinospora crispa* (L) Miers ex Hook.f & Thomson, *Persea kurzii*, *Phyllocarpus septentrionalis*, and from boiling sugarcane until it is thick enough, similar to the particle honey.

The plastering process was carried out in layers. The first layer, applied to the brick surface, consisted of mortar mixed with coarse sand. This layer was smoothed and leveled. The second layer was made of mortar mixed with fine sand, which was also leveled and polished to a smooth and shiny finish. The initial step involved preparing the surface by applying *Cassia siamea* leaves, which contain acidic substances such as *p*-coumaric acid, phenolic compounds, and cassia chromone. These acidic compounds, with water-soluble properties, effectively reduce the alkalinity of the walls. The leaves were applied many times over a period of about seven days to ensure thorough coverage. Once the treatment was complete, the alkalinity of the wall was tested by scraping it with fresh turmeric (*Curcuma domestica*). If the color of the turmeric remained dark orange - red, it indicated that alkalinity was still present, and the process needed to be repeated. However, if the turmeric turned bright yellow, it signified that the wall’s alkalinity had been sufficiently reduced, making it ready for painting. This step was crucial, as high alkalinity could cause some colors, such as red, to fade over time.

2) Color preparation.

The colors used in ancient Thai paintings are powdered pigments, which are natural in origin, derived from minerals, metals, plants, and animal products. These colors are typically fine powders, referred to as “powder colors.” The first five colors belong to the category known as *Benjarong* colors. The materials used to prepare these colors are as follows:

1. *Black pigments.*

1.1 Lump Black : Made from soot produced by fire, such as soot collected from the bottom of a pot. This type of black has a thin texture and, when mixed, is difficult to combine with binder, adding a small amount of rice whiskey will assist in the mixture.

1.2 Charcoal Black : Obtained from animal bones or ivory that are burned until reduced to charcoal, then finely ground. This type of black is of higher quality and is referred to as *Ivory Black*. It is denser than soot.

1.3 Chinese Ink : This black pigment is made from soot produced by burning bones, wood, tar, and other materials. It is processed into sticks and used similarly to other forms of black pigment.

2. *Yellow pigments.*

2.1 Yellow Ochre : This pigment is derived from earth containing iron hydroxide compounds, mixed with varying amount of iron oxide. The yellow soil obtained from this process is washed, filtered to remove impurities, dried, and ground into fine dust for use in painting.

2.2 Gamboge : Gamboge is derived from *Garcinia hanburyi*, which is native to Thailand and mostly found in Chanthaburi province. (Sai Thong, 1982) To prepare this pigment, the tree is at least ten years old. The resin is collected and poured into bamboo tubes, where it is grilled over low heat. If overcooked, the gamboge turns orange, which reduces its usefulness for painting as the color will revert to its original form upon drying. The resin is then solidified, and the bamboo tube is split to retrieve it in a cylindrical shape. When used for painting, the dye is ground with water to produce a clear yellow color, known as *Rong*. This pigment is unique, in that it adheres directly to the surface of the wall without the need for additional binder. It contains gambogic acid and is exported to China and Europe. The finest quality comes from Yunan, China, while resin from Thailand and Burma is of lower quality.

2.3 Orpiment. Orpiment is an orange-yellow arsenic sulfide, with formula As_2S_3 , found commonly close to volcano fumaroles or hydrothermal veins. It can be found in fibrous aggregates, granular or in powder form. It is ground to a fine powder before mixing it with a binder.

3. *Red pigments.*

Red pigments in Thai traditional pigments are derived from red soil, seeds, and minerals. The preparation methods for these red pigments are as follows :

3.1 *Red Earth*. This pigment is obtained from red soil or laterite soil, which is mixed with iron ore or iron dust. It has a dark red color and is typically applied in thick layers.

In Thailand, red ochre is commonly sourced from regions such as Songkhla, Chonburi, and Chanthaburi.

- 3.2 *Tua Pia*. This dark red pigment from China, with colour similar to red earth but with finer texture, was supposed to be of animal origin, probably kermes lac or cochineal insects. The female insects secrete a red substance to protect their eggs, which can be used as a red pigment. Additionally, some texts suggests that red pigments were imported from the Yanmen region in Shanxi Province, China, where another red pigment, called *Dai Ochre*, was sourced.
- 3.3 *Chinese Vermilion*. This bright red pigment was imported from China, known as *Ling Sha*. It is commonly used in Thai painting and has various names, such as *Aimui Vermilion*, which is the highest quality and originated from the city of Xiamen. *Cho Sae Vermillion*, also from Xiamen, is of inferior quality. Xiamen was an important port city in Fujian Province, located along the South China Sea, and it exported goods to Indochina. The red color from China may refer to Cinnabar or Vermilion.
- 3.4 *Cinnabar Red*. Although sharing the name of a mineral pigment, this blackish-red pigment is obtained from the seeds of ratten palm (*Calamus drace*). The pigment has a fine texture, and the manufacturer typically coats it onto sheets of paper and cuts it small for easy handing. To use the pigment, it must be dissolved in water, and the color is extracted from the paper. Alternatively, cotton soaked in water can be used to dissolve the color, which is then squeezed to yield a bright red liquid. Even when mixed with white, this pigment remains bright red, but it turns dark pink once dry.
- 3.5 *Red Lead*. It is a lead oxide, which was produced in the Far East regions from lead ores burned at a temperature of 600-700 °C. The Chinese referred to it as *Zhang Red* due to its origin in Hangzhou, Fujian Provincer. Depending on the amount and texture of pigment used, it can range from orange to various shades of red, which are referred to as Ripen Areca red, dark red similar to crab claw color, *Champaca* (flower) yellow, and light red. When mixed with lime, it produces a brick color. When mixed with a small amount of soot, it can produce a dark orange red or pig's blood red, which is commonly seen in ancient Thai murals. Orange red lead from China, known as *Ch'ien Tan*, has been in use since the Han Dynasty..

4. *White pigments*.

White pigments in Thai murals are obtained from kaolin, lime, and lead oxide. The preparation methods are as follows:

- 4.1 « *White Ochre* » (*Khao Kabang*). This pigment was made by burning kaolin until it was well-cooked, then grinding it into fine dust and filtering it to obtain a pure white color. White clay, rich in kaolinite, is used as a primer for mural paintings.
- 4.2 *White Lead*. White lead is made by allowing metal lead to oxidize. The result is a very fine and white pigment. Historically, the Chinese and Japanese used it as face powder.
- 4.3 *Calcium white*. This pigment is derived from limestone or seashells, which are burned until fully cooked. This resulting material is then fermented, dried, and ground into a fine dust. To clarify fermentation process, shells are belonged to such process, often using specific microorganism to break down and modify their materials.

5. *Blue pigments*.

Historically, There are two types of blue used in Thai paintings:

- 5.1 *Blue from plants, essentially Indigo dye*. Indigo was obtained from the leaves of the indigo plant (*Indigofera tinctoria*), which were boiled, or pounded and squeezed. The resulting chemical compound, *indigotin*, gives a dark blue color. The pigment was precipitated, filtered, dried, and ground into a fine powder.
- 5.2 *Blue from minerals*. Essentially, two types of blue were used : cobalt blue and azurite. *Cobalt blue* is a cobalt aluminate. It has been prepared in China since the VIII-IX c. C.E. from cobalt ores, and used generally to decorate porcelain. As a pigment it was ground and filtered to obtain a pure substance. Cobalt blue could have different hues, generally described as « indigo », « white », and « navy blue ». Additionally, blue pigment was obtained from the mineral azurite, a copper carbonate hydroxide. The preparation of azurite pigment involved grinding many times, although not ground as finely as other minerals.

6. *Green pigments*.

In Thai painting, green colour was initially created by mixing indigo and yellow pigments, such as yellow ochre or *Rong* (a type of yellow pigment). Over time, green pigments from abroad became available, most of which were derived from minerals. These included :

- 6.1 *Green Earth*. This pigment is obtained from green minerals, such as *glauconite*, *celadonite*. These minerals are crushed washed with water to separate impurities, and then finely ground to produce a permanent, stable color that does not change over time.
- 6.2 *Malachite*. Imported from China, malachite is a green pigment known as *Lu Chhing* in Chinese. It is a copper carbonate hydroxide, naturally occurring in both bright and dark green variations. Although malachite produces a vibrant color, with specific binders is not durable and darkens over time. It is abundantly found in Yunnan and Guangxi provinces.



Figure 7 – Example of natural materials used in Thai paintings

Source: Nop-Art-Studio

3) Binder preparation.

Since powdered pigments alone lack the ability to adhere to surfaces, ancient Thai craftsmen would mix the pigments with a binder to ensure they adhered properly to the surface being painted. The binders were typically derived from plants, such as *Feronia limonia Swingle*, *Ficus glomerata*, *Gum Arabic*, and *Tamarindus indica*, as well as from animals, including cowhide, buffalo hide, and rabbit hide. These binders acted to hold the pigments together and enable them to adhere firmly to the painted surface, creating a thin, cohesive film. In some cases, craftsmen also employed a secret technique for achieving uniformity in the color mixture. This involved adding a small amount of rice whiskey, especially when working with earth-derived pigments. The pigments were mixed in small containers, such as a mortar or coconut shell, and ground using a pestle to ensure a consistent and even mixture. (Boonyarat,2012)

2.2.2 DRAWING METHOD

Before the drawing, the surface was prepared with marly limestone, which consists of clay and calcium carbonate. The primary sources of marly limestone in Thailand are located in Ban Mo District in Saraburi Province, Takhli District in Nakhon Sawan Province, and Mueang District in Lopburi Province. (Thai Ministry of Culture,n.d.) The mixture containing marly limestone was realized by mixing marly limestone with a binder made from the inner part of tamarind seeds. and The mixture was boiled until soft, with a wet flour-like consistency. Then, the mixture was applied with a brush onto the mortar surface and allowed to dry completely before painting. The steps for painting the picture were as follows:

Step 1. Fine sandpaper was used to smooth the surface, then white powder was applied using a brush to cover it entirely. A perforated sheet, based on the desired pattern or shape, was placed on

the wall and pressed firmly against the wall surface. A black compress (see figure 8) was rubbed on it, so that charcoal particles entered the perforated holes. When the model was lifted, dots in the shape of the design appeared. A paintbrush dipped in paint was used to trace the lines, ensuring the pattern remains visible. Finally, brush off the black dust, leaving the pattern on the wall.



Figure 8 – a compress used to rub on perforated sheet

Step 2. Once the outline was established, the painter proceeded to paint. Usually, the painter began by painting the background (such as the ground or sky), followed by mountains or trees. Next, the figures, animals, and characters were added. If the painting included architecture, it should be drawn first, followed by the figures. Characters were the main elements of the story and were essential to completing the painting. The brushes used for painting came in various sizes. For drawing fine lines, artists used a small brush known as a “mouse-whisker brush,” which was made from cow-ear hair. For larger areas, artists used brushes made from the *Pandanus tectorius Parkinson ex Du Roi*, *Pandanaceae* or the bark of the *Ylang Ylang tree*. These brushes were cut to the appropriate size and soaked in water to soften them, allowing one end to be pounded into fine hairs to form a brush.

Step 3. Before applying gold leaf, a yellow paint was applied to the area to be gilded. This helped mark the gilded area and created a smooth surface for the gold. For gilding, a binder made from the resin of either *Calotropis gigantea (Linn.) R.Br.ex Ait.)* or *Ficus glomerata* was used before applying the gold leaf. The binder made it easier to draw lines over the gold and enhanced its shine, which is a distinctive feature of Thai painting.

Step 4. The process of drawing lines using a mouse-whisker brush involved both lighter lines and darker lines. The lines were typically drawn with a red-orange color mixed with a small amount of white, and the mixture with opposite composition was used to outline the features of the face and body. For gold areas, vermillion, cinnabar or black were typically used, as these colors enhanced the gold’s shine. To emphasize shape, black or dark brown was used for contrast.

Chapter 3 Construction Details and Description of Samples

The present study focuses on the characterization of pigments and binders used in *Secco* techniques from the Mid to Late Ayutthaya period (1448-1688). Specific sites under investigation of mural paintings include Wat Chaiwatthanaram (UNESCO site) and the residential building of Somdet Phra Phuttakosajarn in Ayutthaya, and Wat Chong Nonsi in Bangkok. The details will be described in the next sections.

3.1 BRIEF INFORMATION OF CASE STUDY CONSTRUCTION TO COLLECT SAMPLES

The mural paintings present distinct characteristics that correspond to the architectural structure of the buildings, which are of historical significance. Three case studies possess historical, archaeological, and artistic value. The architectural style and mural paintings are interrelated, for example, through construction plans and the shared artistic concepts of craftsmen, which are conveyed in a consistent visual form. These relationships are particularly relevant in determining the chronological context of Thai mural paintings. The details are as follows.

3.1.1 WAT CHAIWATTHANARAM, AYUTTHAYA

Crematorium number 5 is one of eight crematoria where the samples were taken. The construction is a brick-and-mortar structure approximately 18 meters high. Its roof consists of seven levels, with the top level shaped like *prang*. Inside, there is a niche that is about 5.6 meters wide. The four corners of the niche are supported by pillars with twelve indented corners. The capitals of these pillars are made of stucco and are shaped like lotus buds. Above the lotus capitals is a wooden ceiling, once painted and decorated with glass, but now faded and nearly gone. The walls of the niche are adorned with paintings, including floral style and cone-base pattern rendered in black, red and green pigments. These artworks have significantly deteriorated, leaving only faded images visible.

According to the Summary Report on the Conservation of Wat Chaiwatthanaram by World Monument Fund [Summary Report on the Conservation of Wat Chaiwatthanaram, 2015], in previous conservation efforts around 1990 the interior murals of some crematoria were coated with a concentrated synthetic resin, intended to serve both as a protective layer and as a consolidant to stabilize flaking paint. Currently, the wall surfaces exhibit yellow or brown discoloration in certain areas, visible on both the painted and plastered surfaces. This staining is likely due to the degradation and yellowing of the synthetic resin over time. Additionally, water infiltration has caused further staining and deterioration of the surface materials.



Figure 9 (Left) – The construction’s building including the central *prang* (tower- like spire) is surrounded by four directional *prang*, which are in turn flanked by eight crematoria, that sit outside the platform’s perimeter. Source : <https://th.wikipedia.org>

Figure 10 (Right) Crematorium number 5, the specific monument where the colorimetric data and samples were collected. Source : Image taken from Pankaew Khamsrichan, 2018

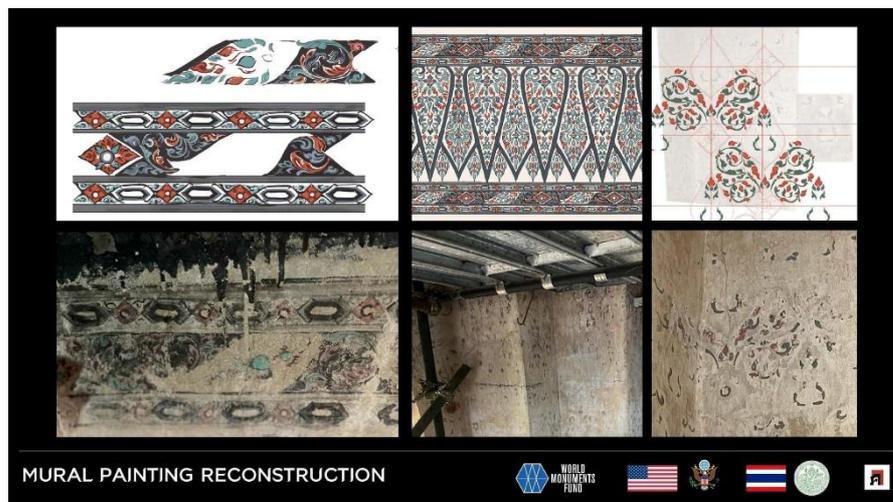


Figure 11– Mural Painting Reconstruction Pattern at Wat Chaiwatthanaram

Source : Images take from World Monument Fund

3.1.2 RESIDENTIAL BUILDING OF SOMDEJ PHRA PHUTTHAKOSAJARN, AYUTTHAYA

The structure is a two-storey rectangular building, measuring approximately 5.7 meters in width and 18.3 meters in length. It is situated within the area of Wat Phuttaisawan. The base of the building is curved in a manner reminiscent of the hull of Chinese junk, a design that was popular during the Late Ayutthaya period. Due to continuous maintenance, the building remains in an excellent state of preservation, retaining its original architectural form and stylistic features.

On the second floor, there is one rectangular window on each of the north and south walls. The east wall contains seven rectangular windows, while the west wall features six rectangular windows and a single rectangular door. The flooring consists of wooden boards, and a wooden staircase provides access to the second-floor entrance. The roof structure and gable are also constructed of wood. The roof is triangular in form and covered with tiles. Notably, there are no supporting pillars on the second floor, similar to the first floor. (Bhummichitra, 2010)

The interior walls of the second floor are adorned with murals dating from the late Ayutthaya period. These murals depict the narrative of the propagation of Siamese Buddhist sect to Sri Lanka. The artwork employs a polychromatic tone, featuring colors such as black, red, white, yellow, green and blue.



Figure 12— The structure outside the residential building of Somdet Phra Phutthakosajarn

Source : www.bloggang.com



Figure 13 – Floor plan of the upper floor of Residential Building of Somdej Phra Phutthakosajarn where the paintings are alternated with windows

Source : Thiwa Phuenpathom, “Buddhist Architecture in the Ban Phlu Luang Dynasty,” (Master of Arts Thesis, Graduate School, Silpakorn University, 2000), 484

3.1.3 WAT CHONG NONSI, BANGKOK

The *Ubosot* (ordination hall) of Wat Chong Nonsi is where the mural paintings are present. The length is measuring 4 meters in width and 8 meters in length. The base is curved like a boat, and the roof is gently curved to complement the base. There is a decorative roof element resembling the body of a *Naga*, great snake with fins, and used to close the ends of purlins made of carved wood.

The pillars supporting the instruments on the gable are octagonal, with lotus capitals. Inside the chapel is the principal Buddha image, a stucco figure in the seated cross-legged in the meditation position.

The doorway and pointed arches conform to the architectural conventions of the reign of King Narai (1656-1688). There are two small windows per arch to provide natural light and ventilation, which contrasts with the nowadays building that has windows with frame, which giving a sense of separation between the upper part above windows and the interstitial space between the windows. (Leksukhum S. and Chayawatana K.,1981)

The building is constructed using traditional wood joining techniques showcasing the craftsmanship in preparing the upper part and supported by a structure of multi-layered beams, with the painting on the wall created on a white background, depicting the *Jataka tales*. The mural paintings inside the chapel are displayed on a white background, utilizing a polychromatic tone that includes red, pink, black, white, and green. Gold leaf is selectively applied to emphasize significant figures, and only in limited areas.



Figure 14– (left) the old picture of the *Ubosot* and (Right) is present day building

Source : <https://becommon.co/culture/temple>

3.2 SAMPLES

A survey of the ancient sites included in the case studies revealed significant deterioration of the wall paintings overtime. The deterioration was attributed to several factors, including roof leakage, high humidity within the structures, and intrusion by animals such as bats, ants, termites, and birds, all of which contributed to the degradation of the artwork. Due to the limited number of original paintings remaining, their documentation required a careful and minimally invasive approach. Consequently, the study employed collected fragments of original samples and a very preliminary non-destructive analysis using a colorimeter, as detailed below.

3.2.1 REAL SAMPLES OF SECCO

Three secco fragments were collected, designated red, green, and black fragment, and a fourth sample of mortar, belonged to a mural painting in Crematorium No.5 at Wat Chaiwatthanaram in

Ayutthaya. These fragments were spontaneously detached from the wall due to aging and deterioration. Three of the samples exhibit painted surfaces with different pigments, while the fourth sample was primarily located within the primer layer. The four samples and their microscopic images (taken with a D90 Zeiss Microscopy in bright field mode, with 5X magnification) are shown in figure 15-22.

1) Green fragment

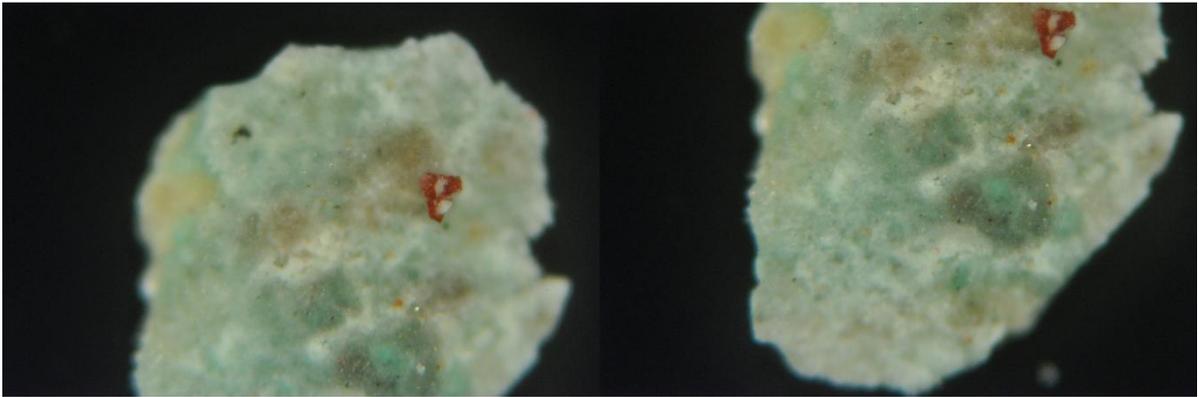


Figure 15– (Left) Upper part and (Right) Lower part of a fragment from the green sample

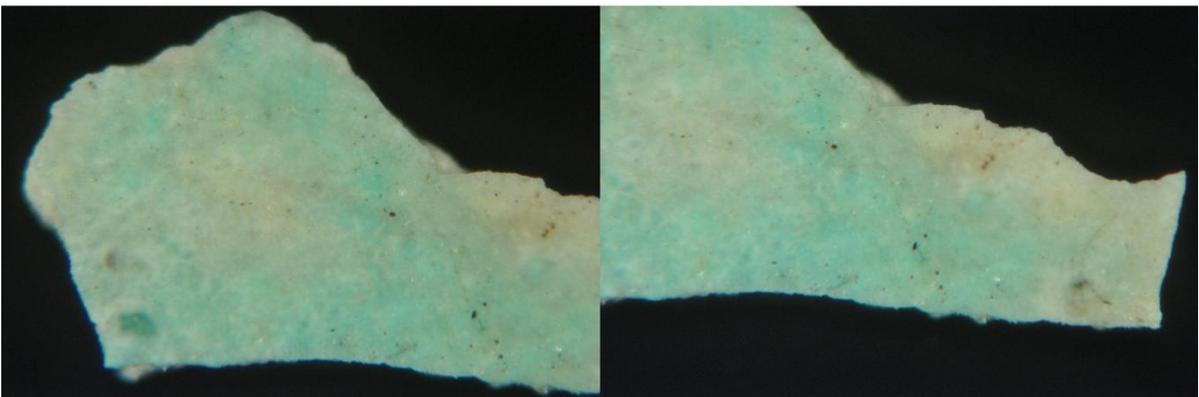


Figure 16– (Left) Left part and (Right) Right part of a second fragment from the green sample

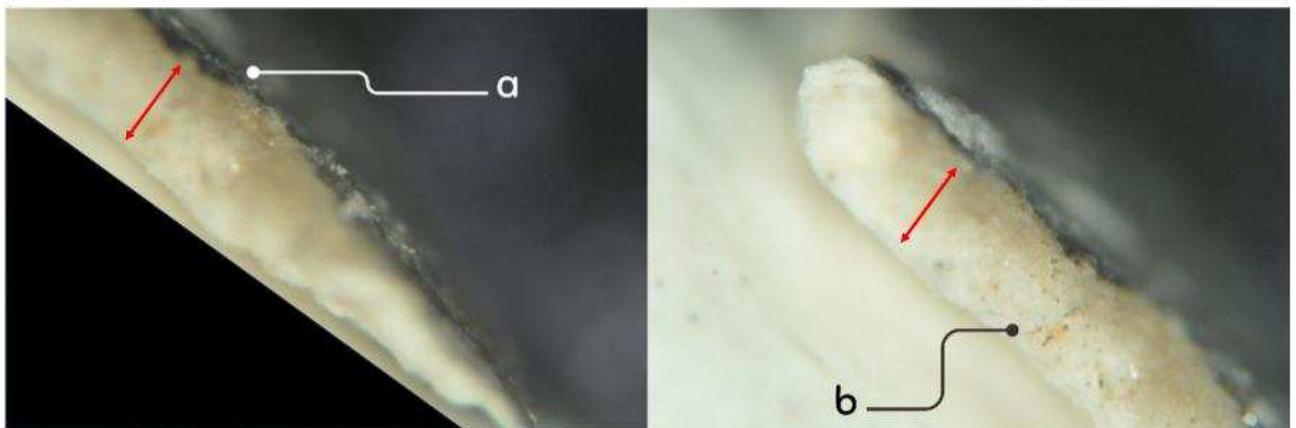


Figure 17– Cross-section of green sample (a) black layer (b) spots of red, black and yellow ochres on a white mortar layer

2) Black fragment

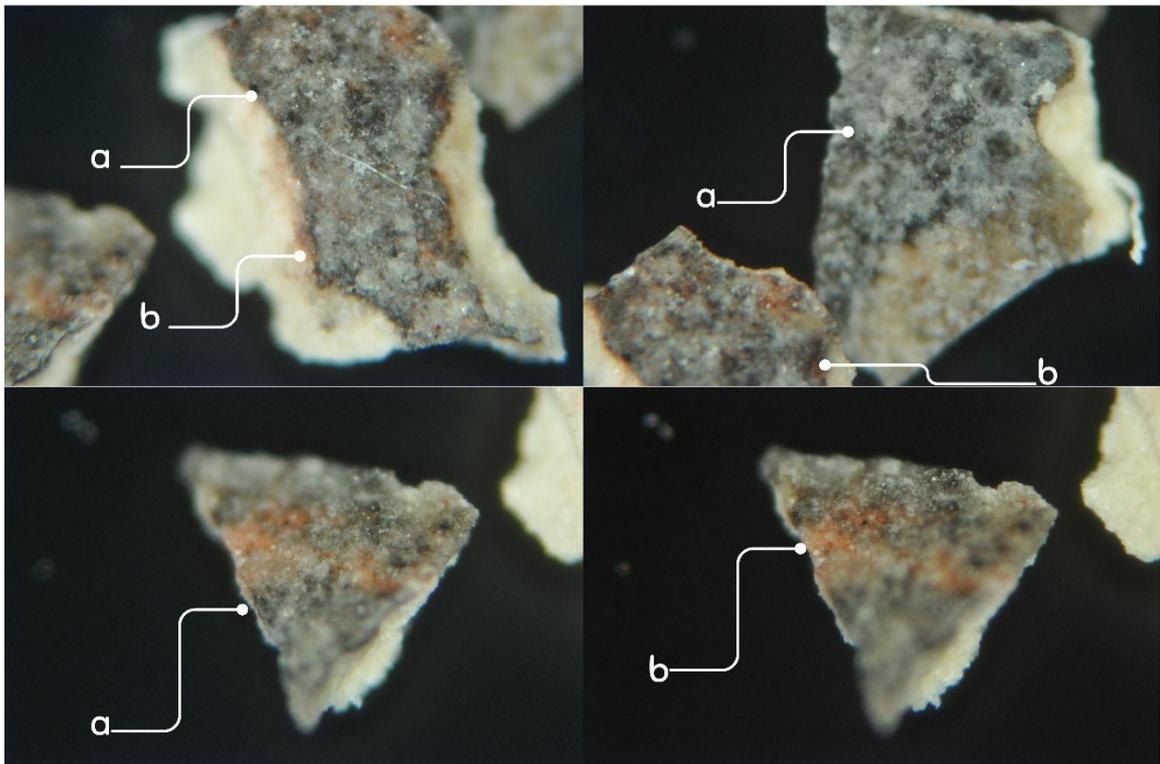


Figure 18– Various black fragments. It can be inferred that a red layer is present under a black layer.

3) Red fragment

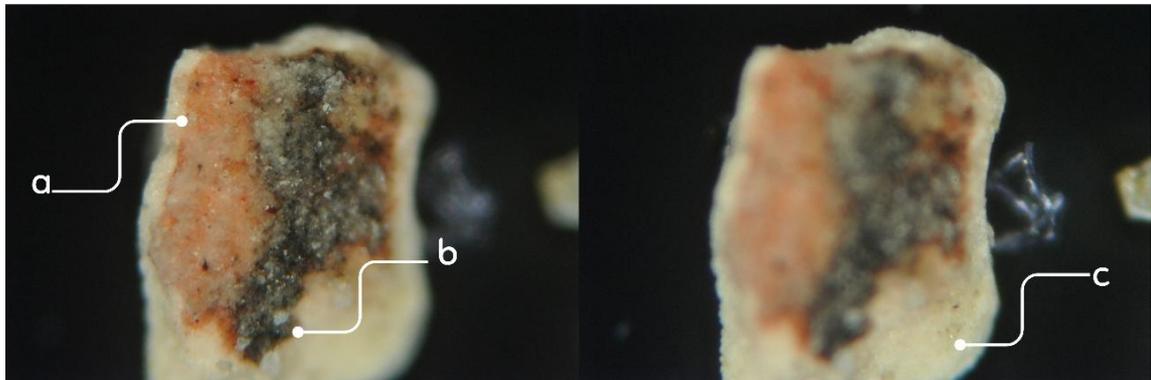


Figure 19–(Left) and (Right) shows (a) red layer is located below a (b) black layer. (c) the white mortar beneath the pictorial layers.

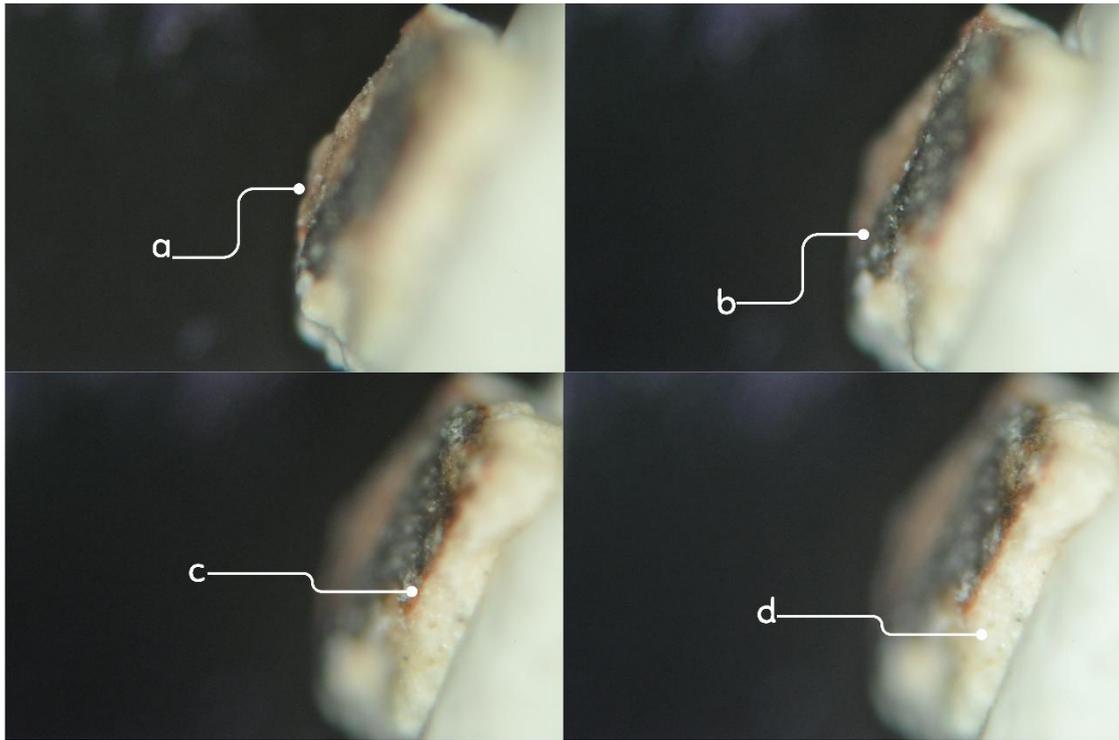


Figure 20–Cross-section of red sample indicates 4 different layer such as (a) red (b) black (c) red again, and (d) whitish layer

4) Mortar

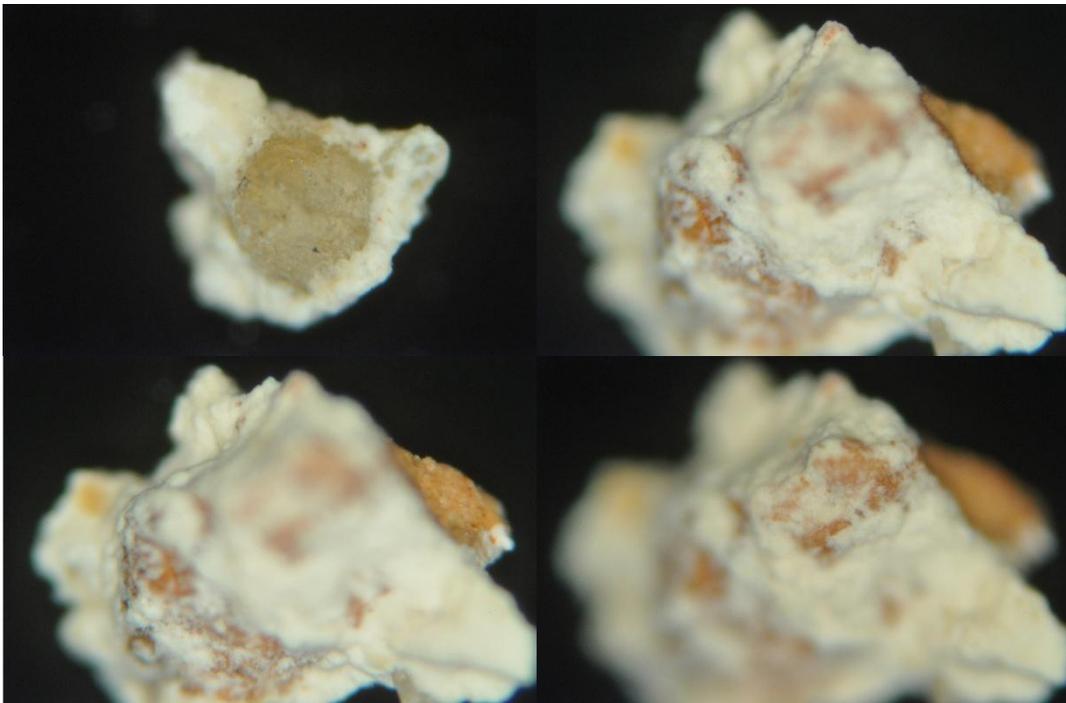


Figure 21– Various parts of two mortar samples present brownish, yellowish and orange spots on the surface

3.2.2 COLORIMETRIC DATA FROM THE THREE CASE STUDIES

According to limitations in sample collection, it was not possible to obtain material samples from all the three case studies. As a result, we employed a non-invasive approach to examine the overview characteristics of the pigments/dyes used in Thai mural paintings, ensuring no damage to the painting surfaces or the samples involved.

Specific sites for pigment analysis were identified based on visible and well-preserved color areas documented in historical records and clearly observable on-site. Nevertheless, certain limitations affected the data collection process, including the inaccessibility of certain areas, the lack of appropriate scaffolding, and the placement of murals at considerable heights.

Therefore, as a first overview and characterization of the colours, a simple colorimeter was employed to measure color absorbance, as detailed below:

1) Areas for colorimetric data from Crematorium number 5 at Wat Chaiwatthanaram, Ayutthaya

1.1) Painting Diagram to collect colorimetric data at Crematorium number 5

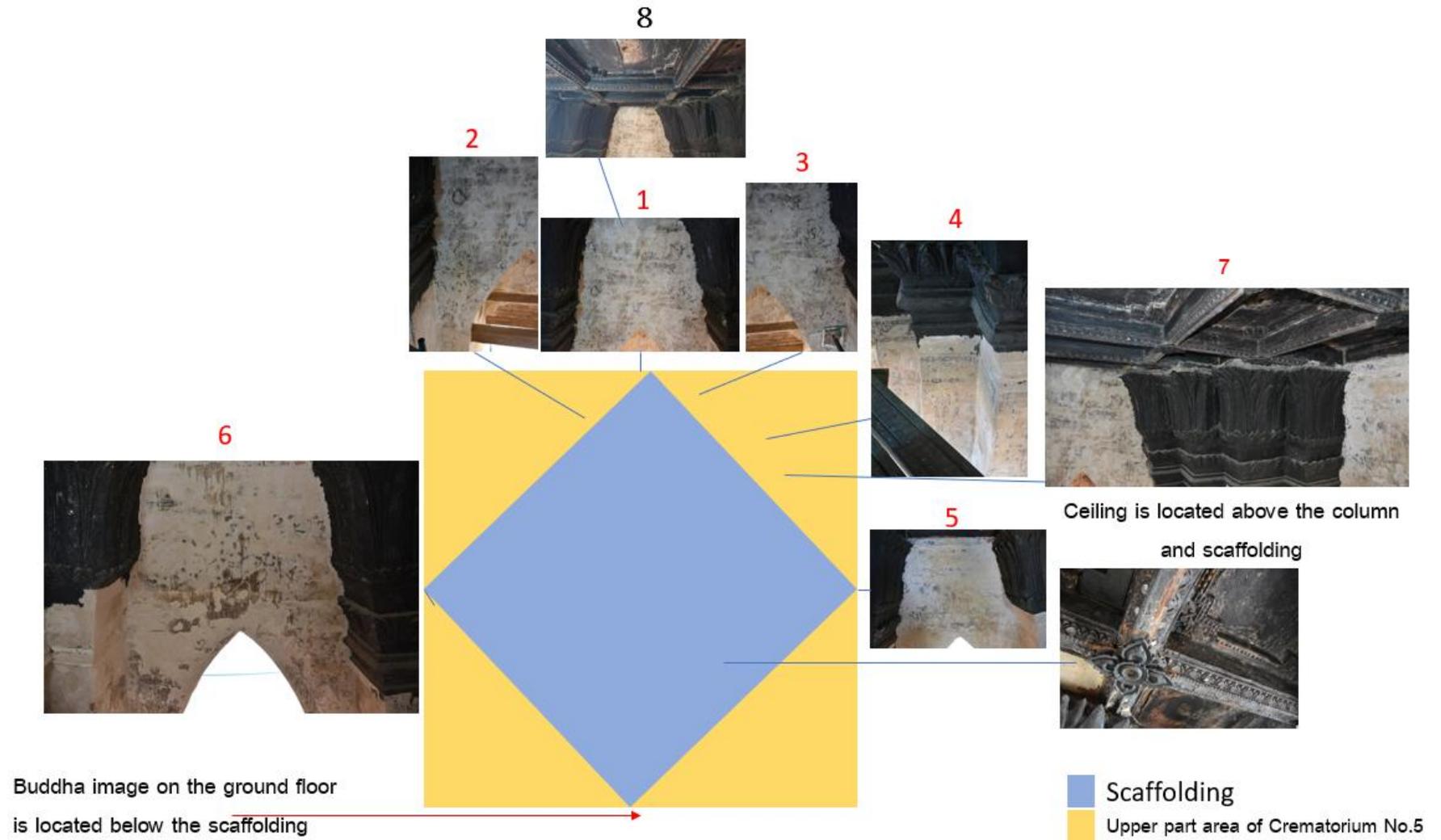


Diagram 1 – Painting Diagram to collect colorimetric data at Crematorium number 5, Wat Chaiwatthanaram, Ayutthaya

1.2) Table 2 Sampled area for the colorimetric data from Crematorium number 5 at Wat Chaiwatthanaram, Ayutthaya

Name	Spot Positions	Overview Paintings	Section number
1.Green spot WC01			1
2.Black spot WC01			4

Name	Spot Positions	Overview Paintings	Section number
3.Green mint spot WC01			4
4.Red spot WC01			4

Name	Spot Positions	Overview Paintings	Section number
5.Red spot WC02			4
6.Green mint spot WC02			5

Name	Spot Positions	Overview Paintings	Section number
7.Black spot WC02			6
8.Red spot WC03			6

2) Areas for colorimetric data from Residential building of Somdet Phra Phutthakosajarn at Wat Phuttaisawan, Ayutthaya

2.1) Painting Diagram to collect colorimetric data at Residential building of Somdet Phra Phutthakosajarn

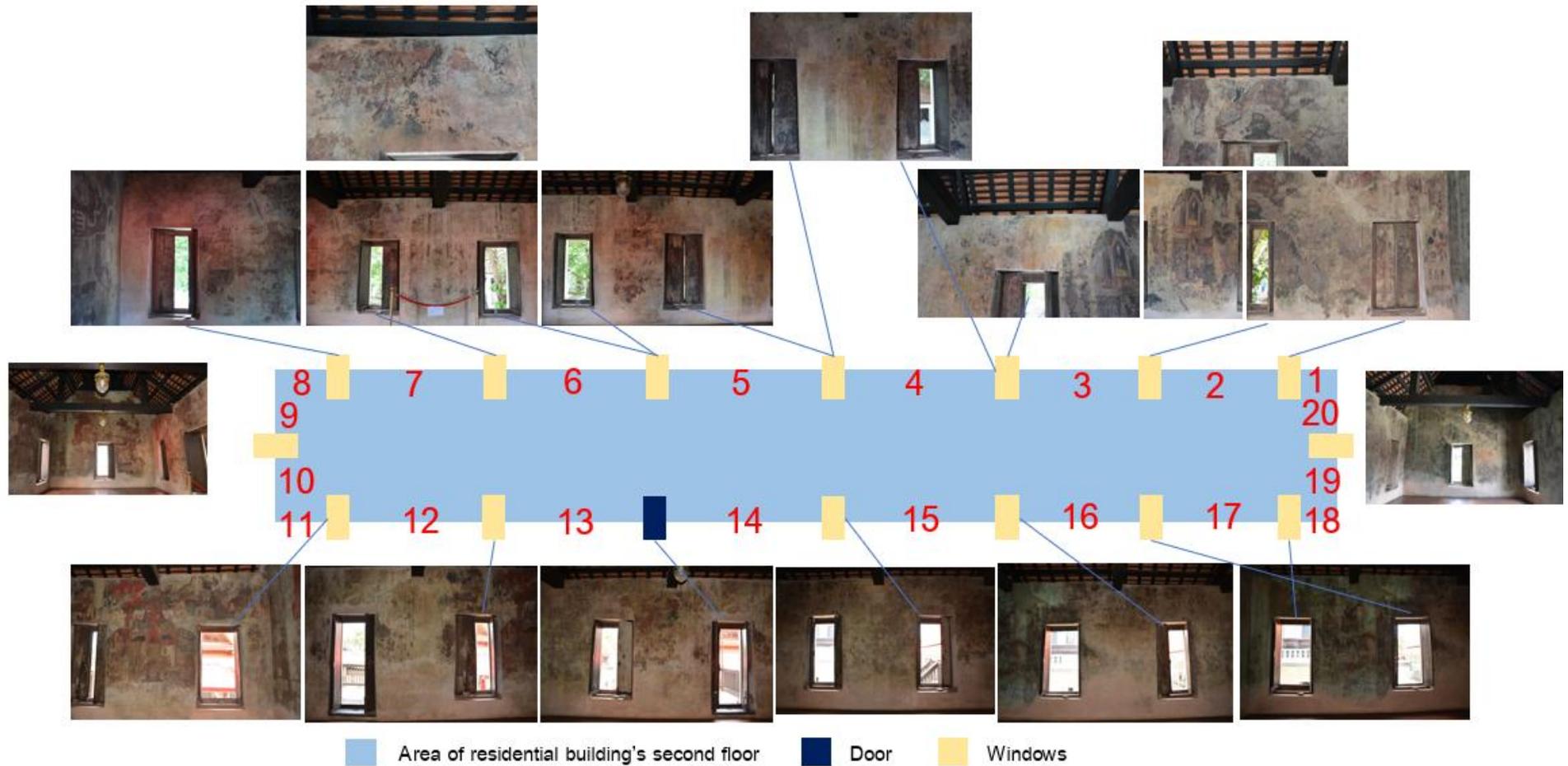
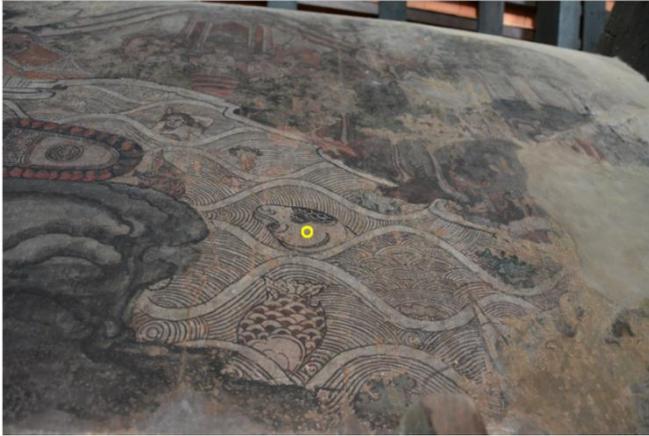
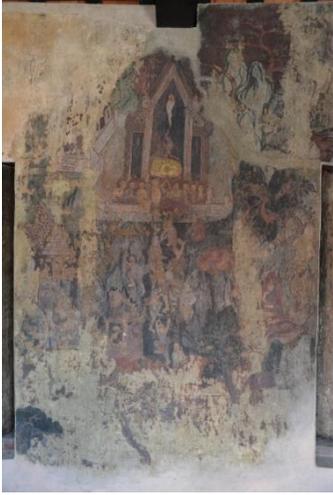


Diagram 2 – Painting Diagram to collect colorimetric data at Residential building of Somdet Phra Phutthakosajarn,

Wat Phuttaisawan, Ayutthaya

2.2) Table 3. Points for colorimetric data from Residential building of Somdet Phra Phutthakosajarn at Wat Phuttaisawan, Ayutthaya

Name	Spot positions	Overview Paintings	Section number
1. Orange tangerine spot RB01			2
2. White salt spot RB01			2

Name	Spot positions	Overview Paintings	Section number
3. Medium black spot RB01			2
4. Orange tiger spot RB01			3

Name	Spot positions	Overview Paintings	Section number
5.Grey coin spot RB01			3
6.Yellow dijon spot RB01			3

Name	Spot positions	Overview Paintings	Section number
7.Gold spot RB01			3
8.Red blush spot RB01			5

Name	Spot positions	Overview Paintings	Section number
9.Red wine spot RB01			5
10.Red-purple spot RB01			9

Name	Spot positions	Overview Paintings	Section number
11.Green sage spot RB01			9
12.Green moss spot RB01			9

Name	Spot positions	Overview Paintings	Section number
13.Red crimson spot RB01			10
14.Black spot RB01			12

Name	Spot positions	Overview Paintings	Section number
15.Red spot RB01			12
16.Green pine spot RB01			19

3) Areas for colorimetric data from *Ubosot* at *Wat Chong Nonsi*, Bangkok

3.1) Painting Diagram to collect colorimetric data at *Ubosot*

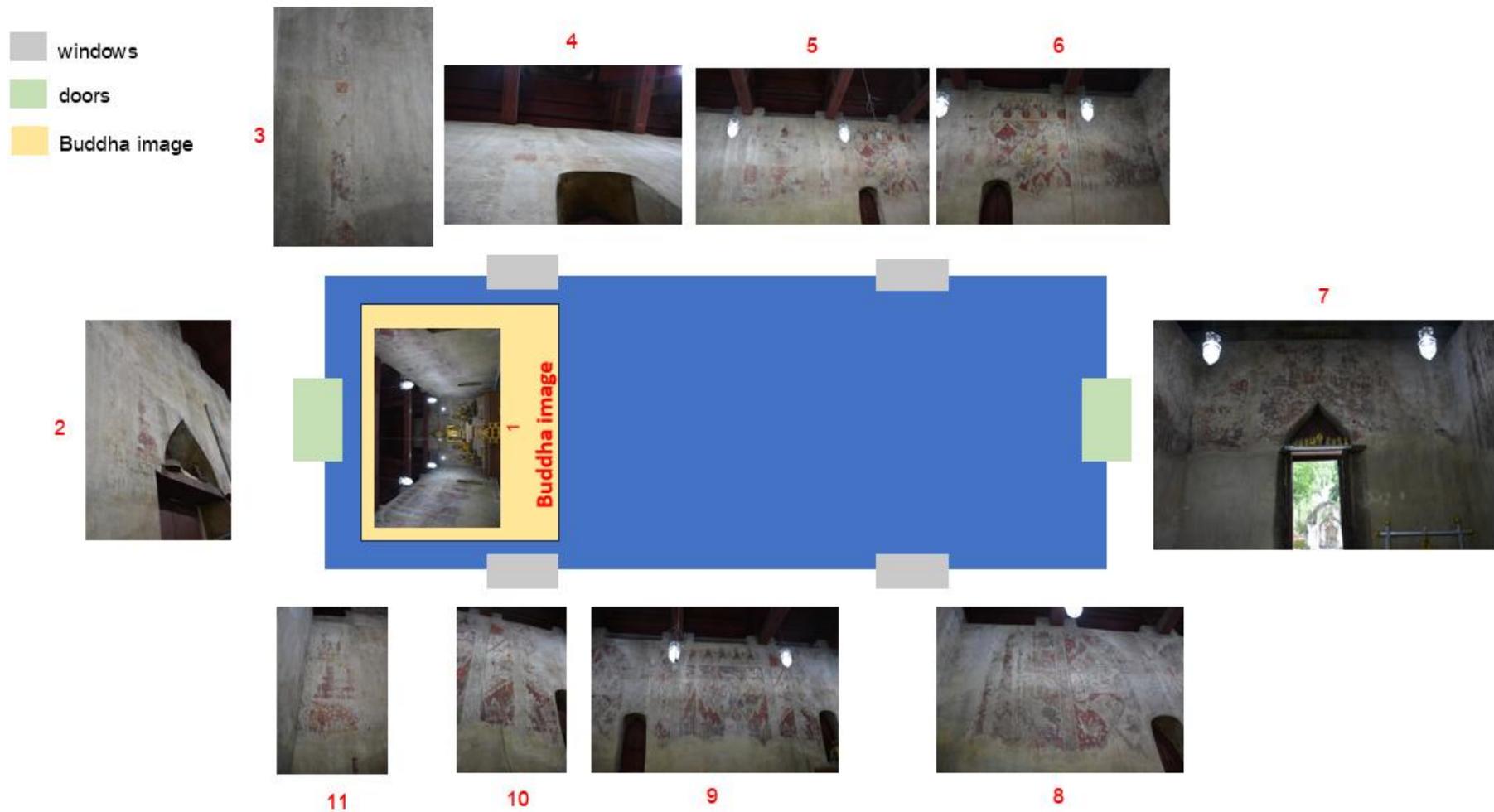
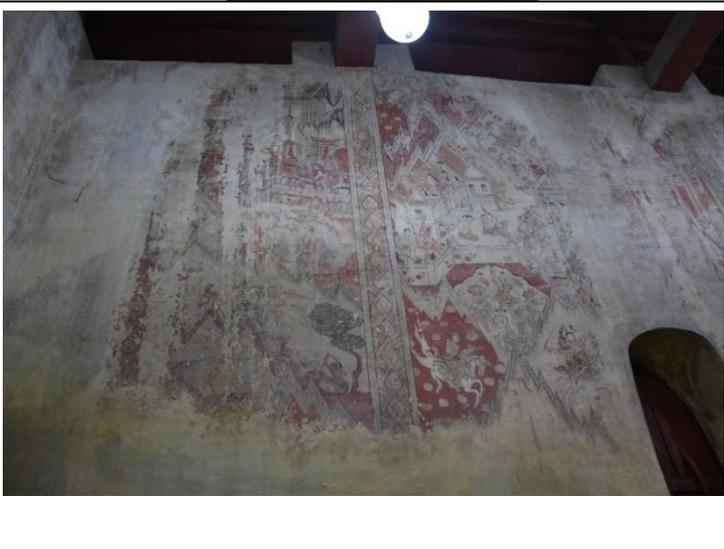


Diagram 3 Painting Diagram to collect colorimetric data at *Ubosot*, *Wat Chong Nonsi*, Bangkok

3.2) Table 4. Points for colorimetric data from *Ubosot* at Wat Chong Nonsi, Bangkok

Name	Spot positions	Overview paintings	Section number
1.Yellow dijon Spot NS01			3
2.White coconut spot NS01 3.Red blush Spot NS01			3

Name	Spot positions	Overview paintings	Section number
4.Black spot NS01			3
5.White porcelain spot NS01 6.Red scarlet spot NS01			8

Name	Spot positions	Overview paintings	Section number
7.Pink spot NS01 8.Green pickle spot NS01			8
9.Gold spot NS01			8

Name	Spot positions	Overview paintings	Section number
10.Green moss spot NS01			9
10.Green dark jungle spot NS01			9

Name	Spot positions	Overview paintings	Section number
<p>11.Green seaweed spot NS01</p>			<p>9</p>
<p>12.Red blood spot NS01</p>			<p>10</p>

Chapter 4 Experiment Methods and Results

4.1 IDENTIFICATION OF PIGMENTS

4.1.1 Non-INVASIVE ON SITE CHARACTERIZATION: COLORIMETRIC MEASUREMENTS

Colorimeter is a non-invasive instrument that measures color intensity and gives the colorimetric coordinates in the wanted color spaces. The colorimeter we used (PCE-XXM 30 by PCE instruments) provides additionally the reflectance spectrum in the visible region, allowing one to distinguish the pigment by comparison with a database. This analysis can provide an overview of the mineral composition in mural paintings by analyzing reflectance spectra, enabling the discrimination of colorants with similar hues through the identification of maximum peaks and inflection points — these latter features corresponding to maxima or minima in the first derivative spectrum. Presented below is the list of colors analyzed by means of reflectance spectral database comparison in the context of the case studies.

1) Wat Chaiwatthanaram

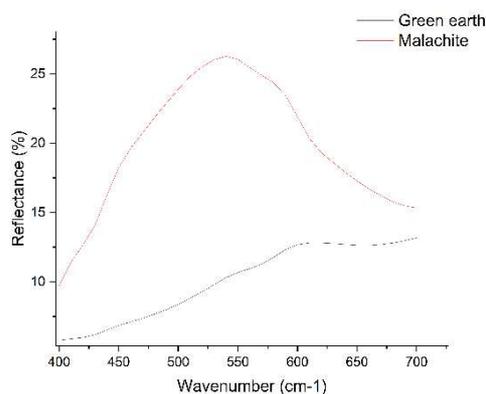


Figure 22—Spectra of green pigments

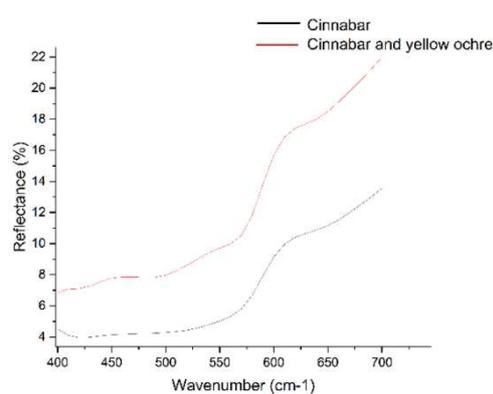


Figure 23—Spectra of red and yellow pigments

The green colorants identified include green earth, mixtures of green earth and yellow ochre, and malachite. The spectral characteristics of these pigments are distinct: yellow ochre exhibits a reflectance minimum around 660 nm with inflection point at 545 nm, while green earth shows a reflectance maximum at approximately 550 nm. In the case of malachite, the inflection point occurs near 650 nm, with a corresponding reflectance maximum between 545 and 550 nm.

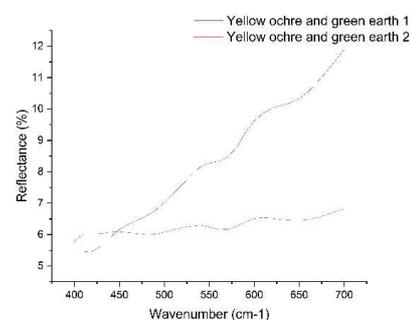


Figure 24—Spectra of yellow ochre and green earth

The red and yellow pigments identified include cinnabar and yellow ochre. Cinnabar exhibits an inflection point at approximately 595 nm, while yellow ochre, when present in combination with cinnabar, shows a further inflection point around 545 nm.

The black pigments analyzed also indicate the presence of other pigments, including yellow ochre and green earth, maybe from underlayers. However, no identification of black, gray or white pigments/dyes is (generally) possible with reflectance spectra.

2) Residential building of Somdet Phra Phuttakosajarn, Wat Phutthaisawan

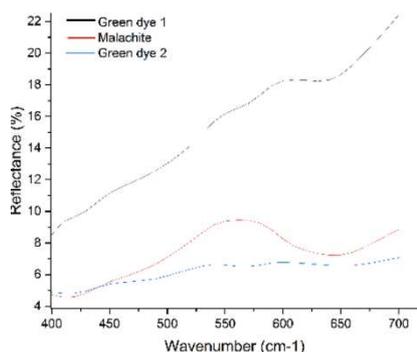


Figure 25—green pigments and green dye

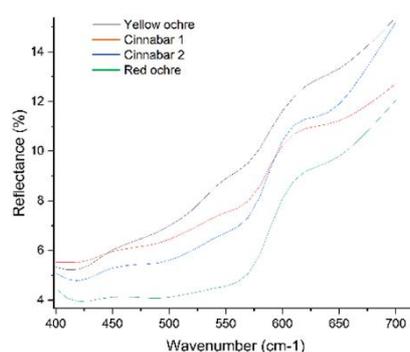


Figure 26—Spectra of red and orange

The analysis of green dyes and green pigments reveals a reflectance minimum between 640 and 650 nm, indicative of the presence of a green dye. Additionally, malachite is identified by a reflectance maximum occurring between 545 and 550 nm.

In the case of red, and orange, mixtures of yellow ochre and cinnabar were probably used, since the complex reflectance spectra showed inflection points at approximately 530 nm and maxima near 600 nm (yellow ochre), with often a second inflection point between 590 and 600 nm (cinnabar). Darker red areas were obtained from red ochre according to the inflection point around 580 nm.

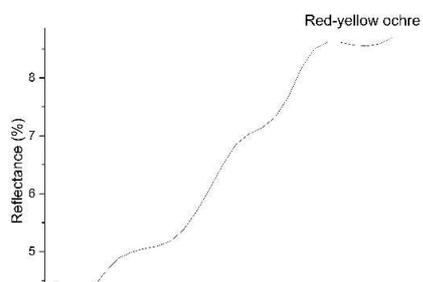


Figure 27—Spectra of red-yellow ochre

Yellow pigments are represented by red-yellow ochre, with inflection points observed at approximately 530 nm and 580 nm. Black pigments, in contrast, display no significant reflectance, consistent with their absorptive properties.

3) Wat Chong Nonsi

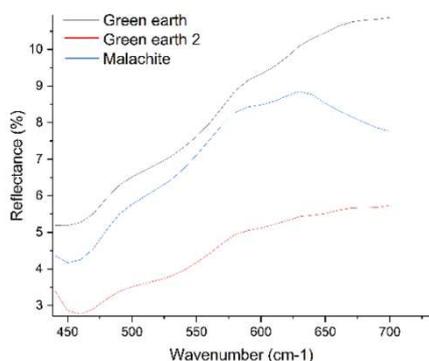


Figure 28–Spectra of green pigments

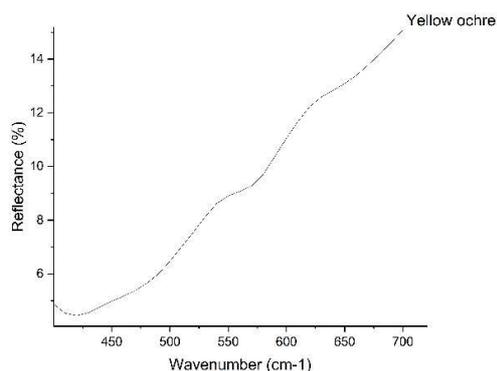


Figure 29–Spectra of yellow

The green pigments identified include green earth, characterized by a reflectance maximum at approximately 550 nm, and malachite, which exhibits a maximum around 545 nm.

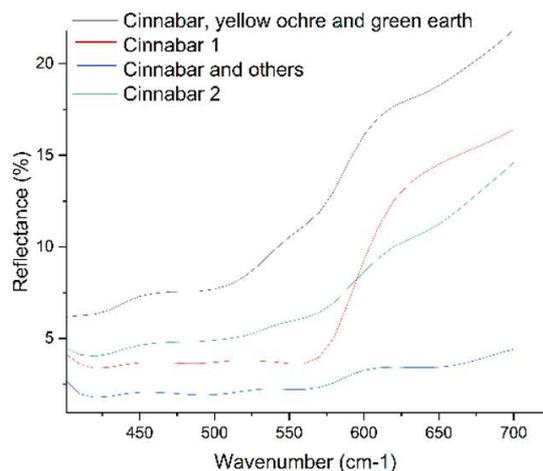


Figure 30–Spectra of red pigments

Among the yellow pigments, yellow ochre was identified an inflection point at approximately 530 nm. For the red pigments, cinnabar was consistently found, with an inflection point near 600 nm, while an additional inflection point around 545 nm suggests the presence of yellow ochre. Another instance of cinnabar is marked by an inflection point at approximately 590 nm, accompanied by a mixture that includes pink-toned areas. The identification of white and black pigments remains inconclusive due to

insufficient spectral clarity.

In some cases, the presence of Paraloid B-72 appears to influence pigment mixing. This effect can be observed in black pigment found at crematorium number 5, where interaction with yellow ochre and green earth are evident.

4.1.2 MICROINVASIVE CHARACTERIZATION OF PIGMENTS IN THE FOUR FRAGMENTS FROM WAT CHAIWATTHANARAM

Raman Spectroscopy

Raman spectroscopy is a non-destructive technique used to study the chemical composition of materials within the context of qualitative analysis. The vibration modes of the sample's molecules interact with the photons of the laser light, scattering anelastic photons (Raman photons), which are collected and analysed to provide a characteristic spectrum (Raman spectrum). The Raman spectrum

is characterized by sharp peaks, is very reproducible, and is like a fingerprint for most of the chemical substances. On the other hand, the acquisition of a Raman spectrum is not always possible, since patinas, dirt, degradation by-products can hamper the detection of Raman lines. For the microRaman characterization, we used a Renishaw *InVia* Raman instrument equipped with a Leica microscope. The NIR laser line at 785 nm was used, since this line reduces effects due to fluorescence and patinas, expected on degraded artifacts.

Raman spectroscopy analysis of the fragments from the green sample of Wat Chaiwatthanaram (WCGreen) was carried out on the front (pictorial layer) of the sample. The analysis indicated distinct mineral compositions in different areas. The white area of green sample exhibited characteristic peaks at 277 cm^{-1} corresponding to calcium oxalates, 1007 cm^{-1} indicating the presence of calcium sulphate, and peaks at 1087 and 1463 cm^{-1} associated with calcium carbonate. In contrast, the green area in the cross-section showed calcium oxalate signals at 196 , 1025 , 1489 and 1642 cm^{-1} , suggesting distribution and possible different crystalline phases of the compound within the sample. (Fig.31)

No green pigment identification was possible, since no Raman spectra on the green areas were matching any of the expected Raman peaks for typical green pigments (green, earth, malachite, etc.)

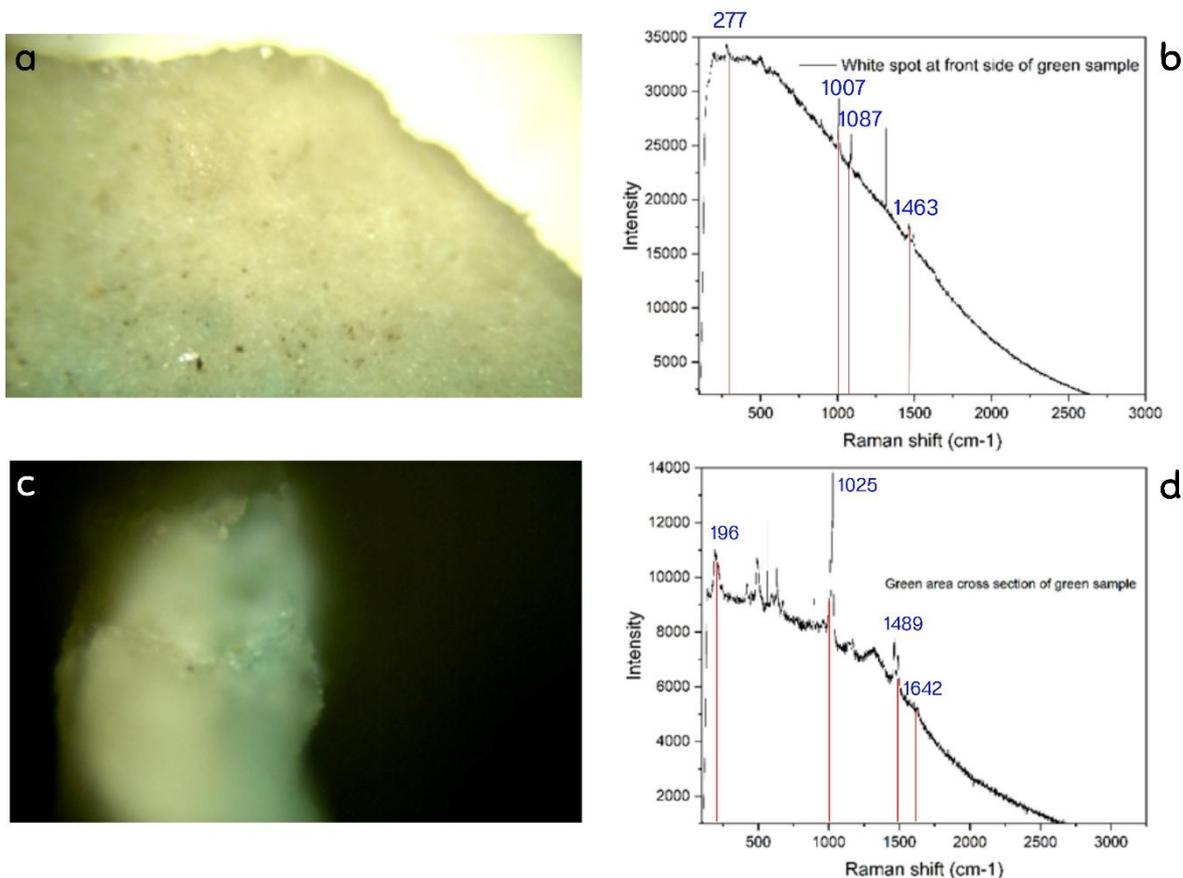


Figure 31– (a) White spot on a fragment from WCGreen and (b) Raman spectrum (785nm 10% 10X 10sec) with peak position from this spot; (c) Green area in the cross section and (d) Raman spectrum (785nm 10% 20X 10sec) with peak position from green area

Raman spectroscopy of fragments from the black sample (WCBlack) revealed, on the front side, the presence of amorphous carbon black, with characteristic peaks observed at 1325, 1375, and 1583 cm^{-1} . Additionally, a phosphate peak at 962 cm^{-1} was detected, indicating that the overall composition of the black spot is consistent with a bone black or ivory black. In the white area of the same sample, peaks at 1308 and 1588 cm^{-1} suggests the presence of minor amount of carbon black, while a phosphate signal at 960 cm^{-1} supports the identification of similar inorganic components. It is therefore possible that the white area is dominated by a calcium phosphate, with minor amount of carbon black (Fig.32)

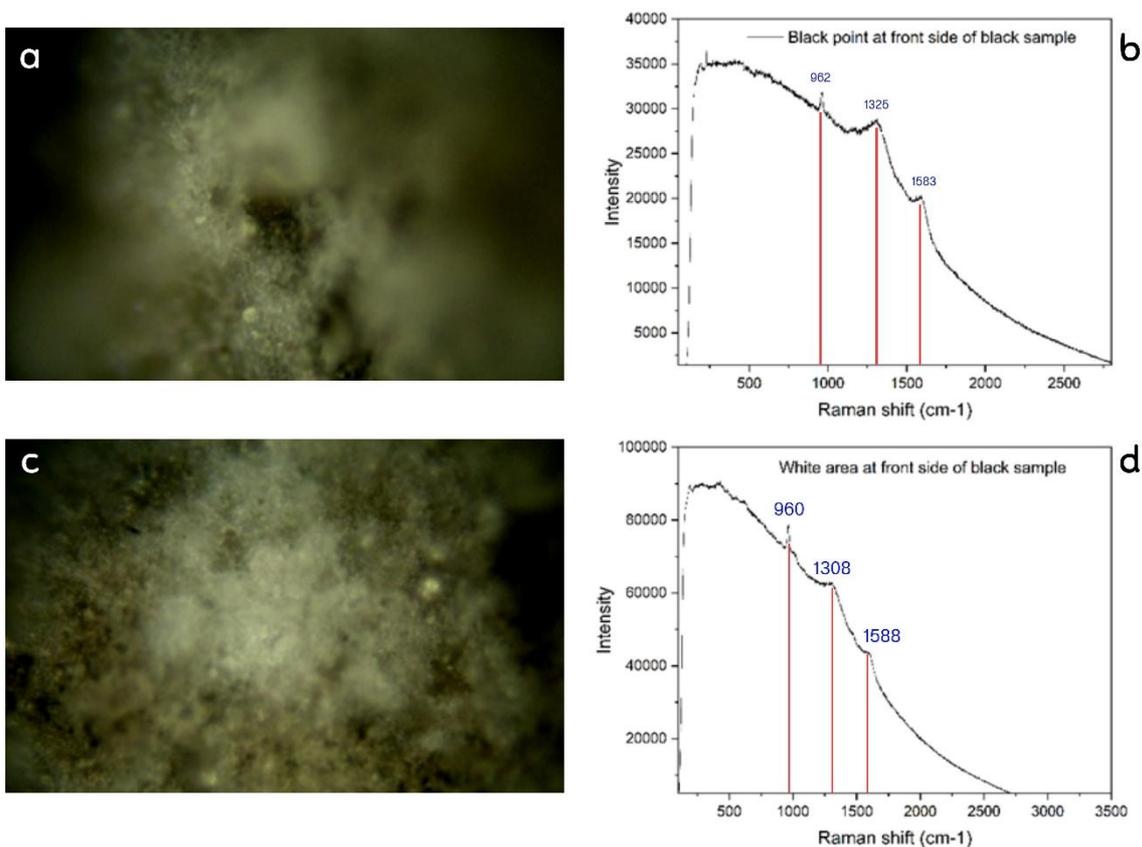


Figure 32– (a) Black spot in WCBlack and (b) Raman spectrum (785nm 10% 50X 10sec) with peak position from this spot; (c) White area and (d) Raman spectrum (785nm 10% 50X 10sec) with peak position from this area

Raman spectroscopy of fragments from the red sample (WCRed) revealed a combination of mineral pigments and binders. The presence of calcium carbonate was identified by a peak at 1086 cm^{-1} , while a signal at 1007 cm^{-1} corresponds to calcium sulphate dihydrate (gypsum). Peaks at 221,

292, and 400 cm^{-1} were characteristic of hematite (red ochre), indicating the use of iron oxide-based pigments for the red color. In the red area of the sample, additional peaks at 252 cm^{-1} suggested the presence of some amount of cinnabar. Calcium carbonate was present in the red layer, as attested by a peak at 1085 cm^{-1} , together with gypsum (peaks at 492 and 1007 cm^{-1}), supporting the identification of a layered or mixed pigment composition in the red region. (Fig.33)

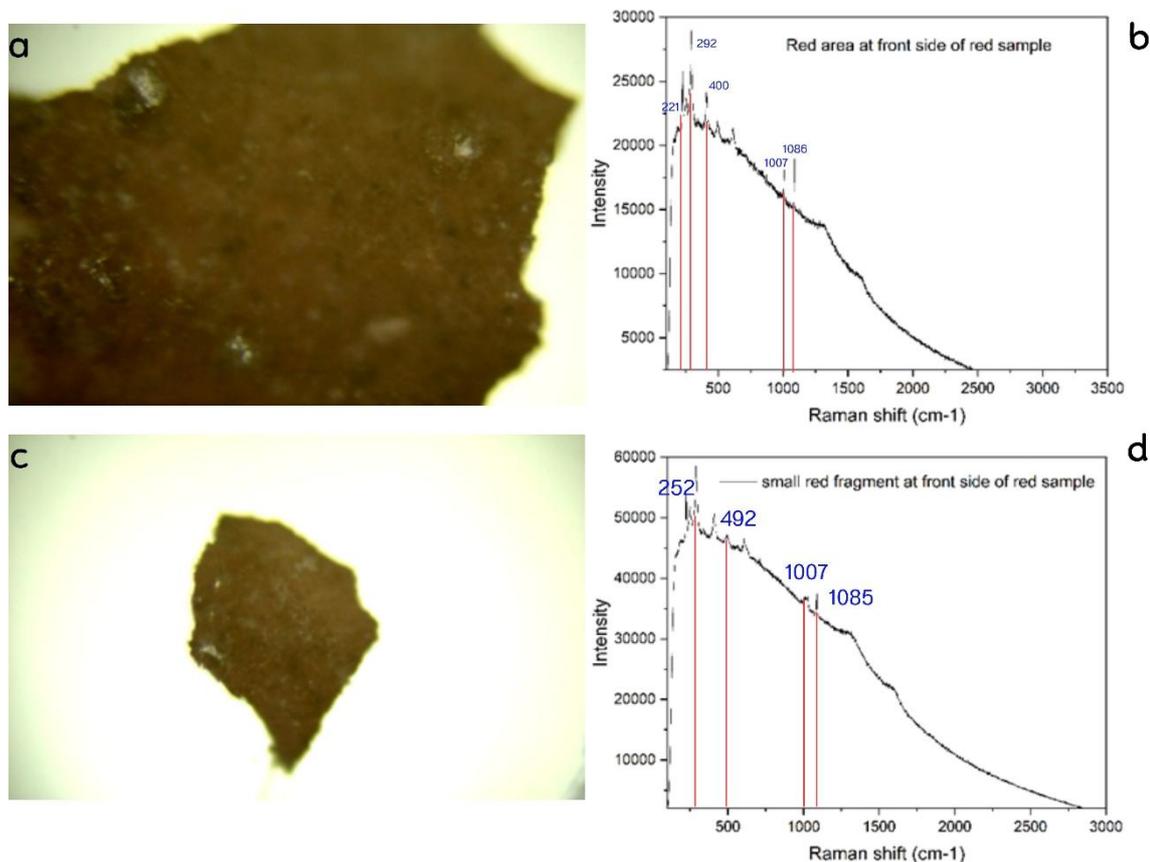


Figure 33– (a) Red area of WCRed and (b) Raman spectrum (785nm 10% 10X 10sec) with peak position from this area; (c) A different red area and (d) Raman spectrum (785nm 10% 10X 10sec) with peak position from this area

Scanning Electron Microscopy–Energy Dispersive X-ray Spectroscopy (SEM-EDS)

The Scanning Electron Microscope (SEM) is an advanced imaging tool that allows researchers to visualize surface details beyond the capability of the naked eye or conventional light microscopes. It offers significantly higher resolution and magnification, with the ability to enlarge image up to 200,000 times. The SEM operates by directing a focused electron beam across the surface of a specimen, producing high-resolution, three-dimensional-like images that reveal topographical, morphological, and compositional details.

In addition to imaging, SEMs are equipped with detectors for analytical capabilities. For example, Electron Backscatter Diffraction (EBSD) can be used to analyze the crystallographic orientation of materials, while Energy Dispersive X-ray Spectroscopy (EDS or EDX) enables

elemental analysis by detecting X-rays emitted from the sample when it is bombarded with the electron beam. These features allow researchers to investigate both biological and physical samples, assess surface conditions, and detect microstructural changes due to stress, deformation, or damage.

The SE image of a fragment from WCgreen revealed a very irregular surface (Fig. 35a), characterized by many crystals of different morphology. SEM-EDS (Fig. 35b,c) indicated high concentrations of calcium and sulfur, along with trace amounts of copper. In addition, elements such as carbon, oxygen, phosphorus, silicon, and chlorine were detected throughout the sample in varying amounts. In Fig. 36, it is reported the SE image of a particle, whose aspect is typical of a small bone fragment. Actually, the EDS spectrum of an area of the fragment (Fig. 36b) indicates a high concentration of calcium and phosphorus, consistently with the mineral apatite or the mineral hydroxyapatite, along with carbon and oxygen. In fig. 37a it is reported, with a higher magnification, another area of the bone fragment, and the EDS spectrum on this area (Fig. 37b): also in this case, Ca and P are dominating, although Ca peaks is higher, probably suggesting that other calcium compounds, together with apatite/hydroxyapatite, are present. Other green areas of WCgreen were examined, but fundamentally Ca and S were detected, with variable amount of P. Just in some points, significant amounts of lead and arsenic were detected (Fig.38)

As a whole, these results suggest that calcium sulphate is present throughout the sample, probably as alteration by-product and the identified mineral phases contain copper, but are not consistent with malachite or other copper-based mineral pigments (Fig.34b). The presence of phosphorous in many points, with the presence of a small fragment looking as a bone fragment, supports the possible presence of a bone glue as a binder.

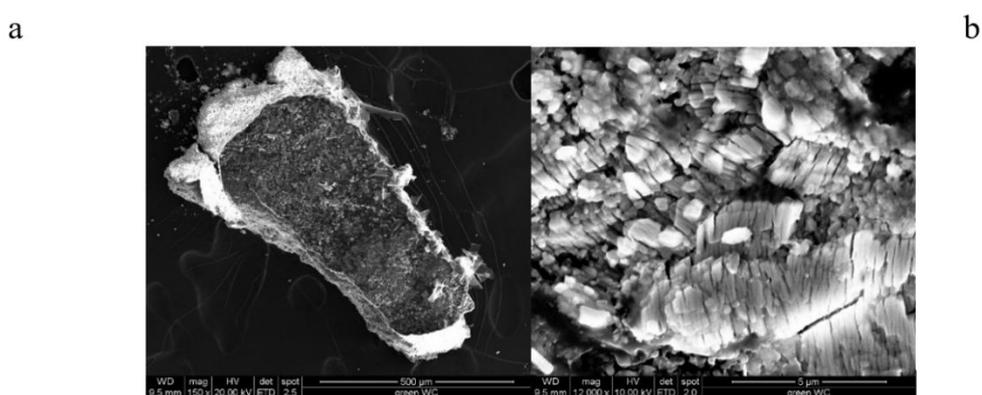


Figure 34 – SEM image of calcium sulphate on green sample (a)overall sample (b)surface contains crystal and calcium sulphate

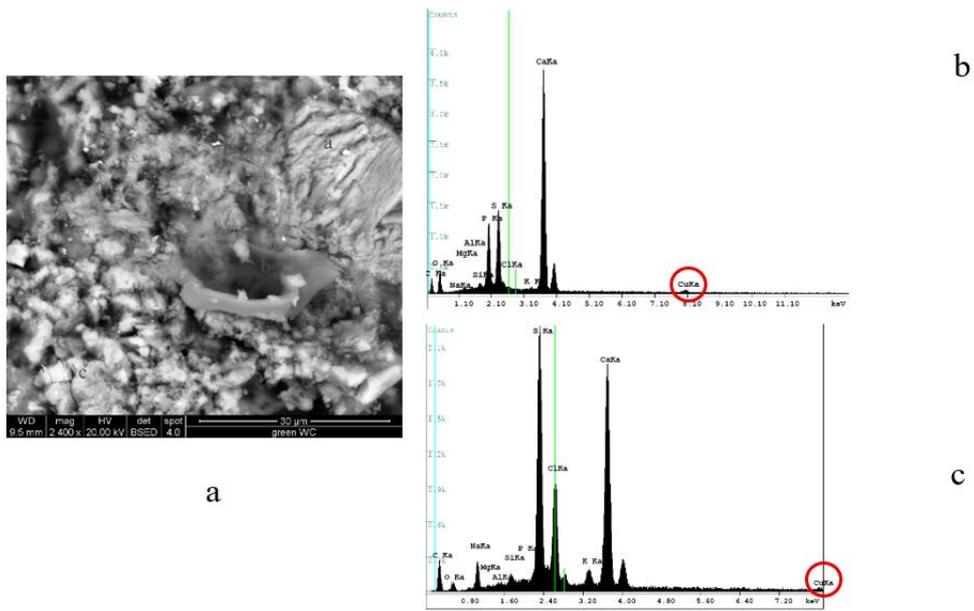


Figure 35 –SE image (a) and EDS spectra (b,c) on the surface of WCGreen. The red circle indicates the position of the Cu signal.

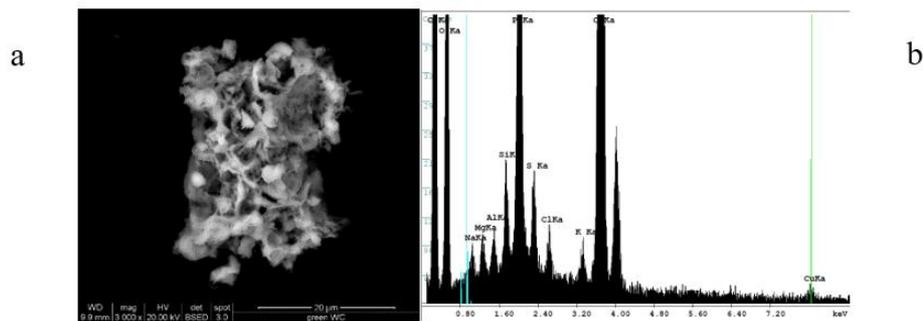


Figure 36–SE image (a) and EDS spectrum (b) of a bone fragment in the WCGreen sample

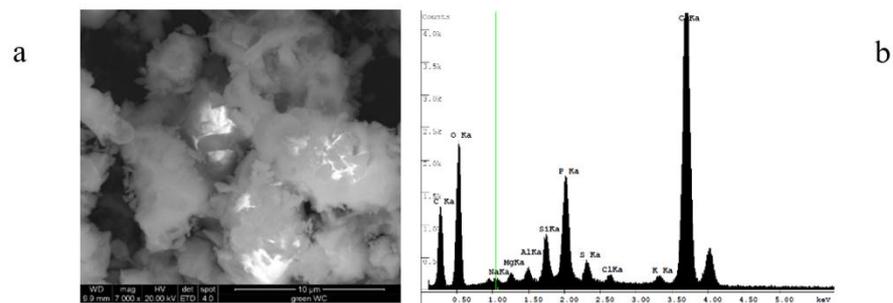


Figure 37–SE image (a) and EDS spectrum (b) of another area of the bone fragment.

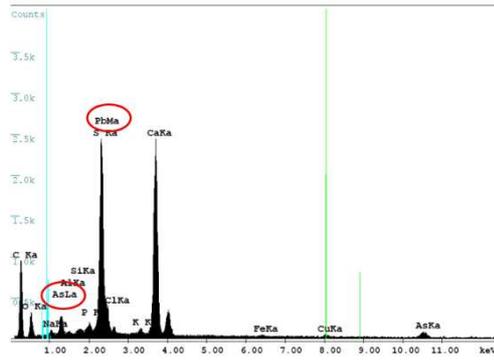


Figure 38–EDS spectrum in an area of WCGreen, showing peaks related to As and Pb.

The SE images of WCBlack indicated again a rough surface, with many crystals, possibly of calcium sulphate (Fig.39a). Actually, EDS spectra in various points (Fig. 39b,c,d) revealed high concentrations of calcium, carbon, oxygen, sulfur, and phosphorus. Additionally, mercury was detected in variable amounts within the same region. (Fig.40b). Notably, gold flakes were also identified in an area of the black sample (Fig.41). Copper was not detected in the sample. The presence of phosphate compounds, along with elevated levels of calcium and phosphorus, may suggest the use of bone-based adhesives, such as bone glue.

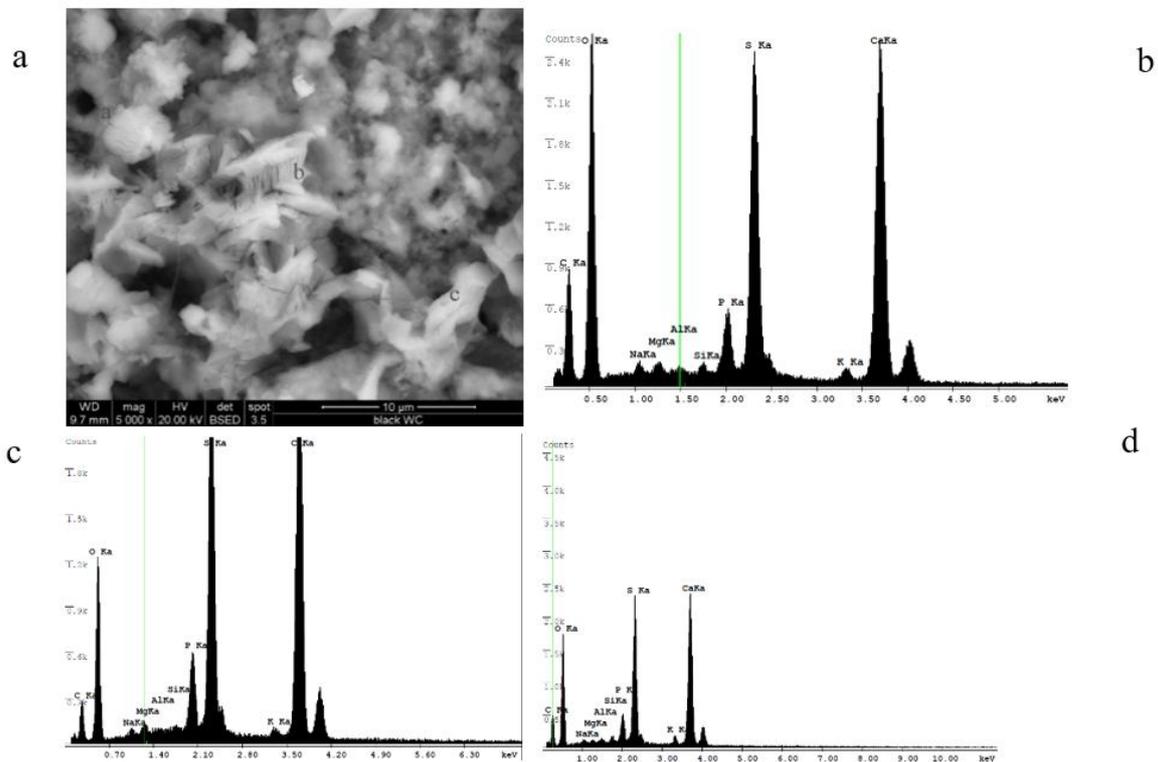


Figure 39– SE image (a) and EDS spectra (b,c,d) of an area in WCBlack. EDS spectra indicate high concentrations of carbon, oxygen, calcium, sulfur, and phosphorus.

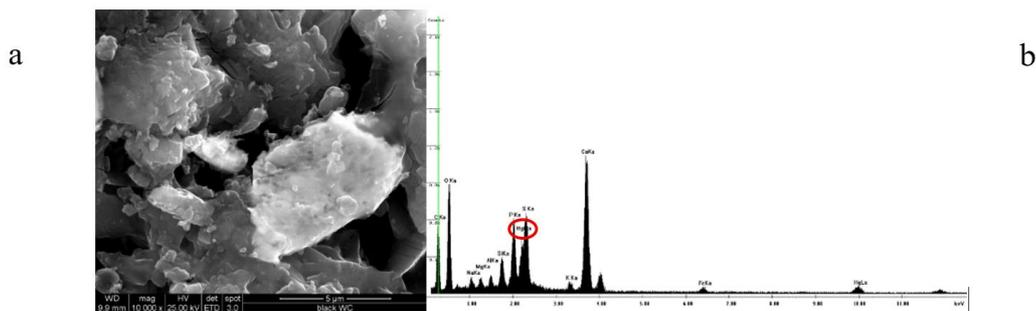


Figure 40– SE image of another area in WCBlack (a) and EDS spectrum in this area (b) indicating the presence of mercury

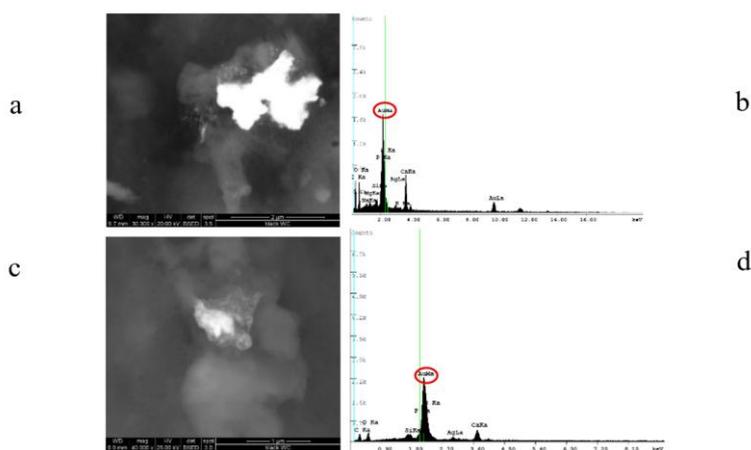
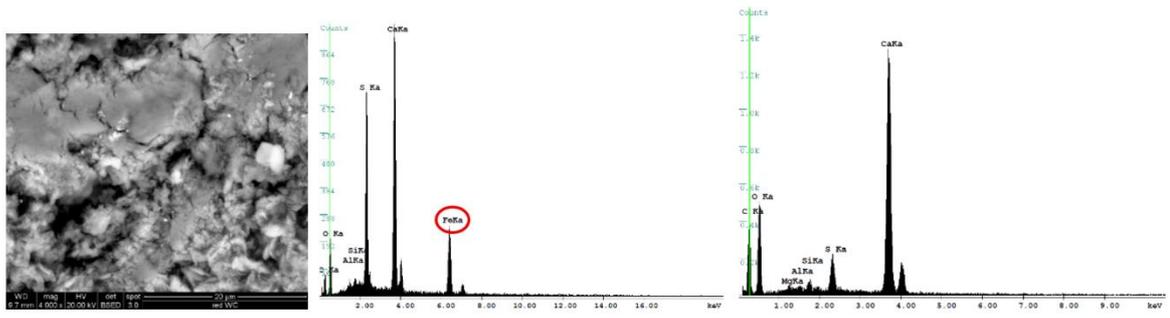


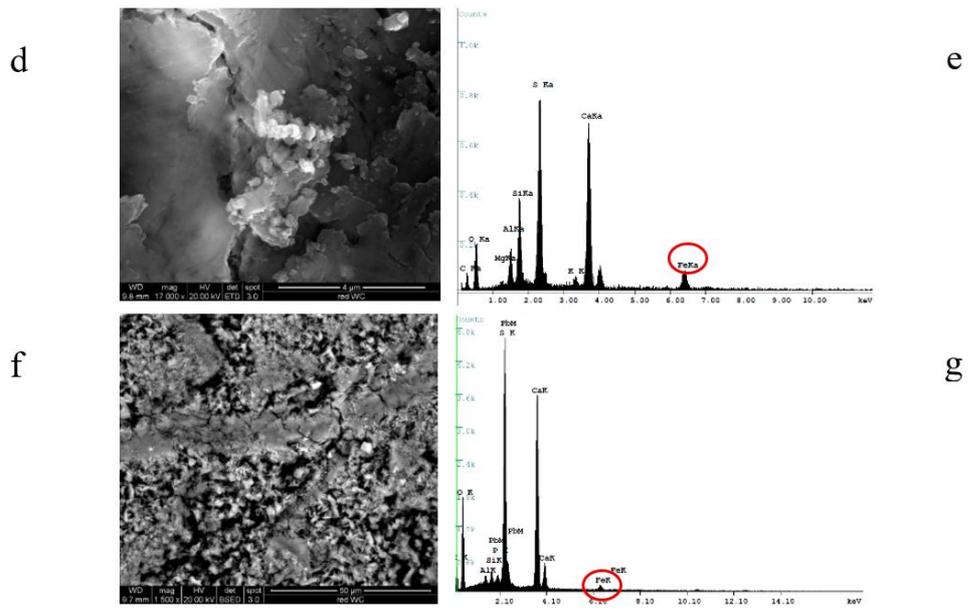
Figure 41– SE image of a “flake” in WCBlack, and corresponding EDS spectrum (b) with indicated the Au peak; (c) another “flake” and corresponding EDS spectrum (d).

The SE image of a fragment from the WCRed sample has a similar morphology as the previous samples: a rough surface with various crystals and aggregates, with other areas more homogeneous (Fig.42a). The EDS spectra (Fig.b,c) analysis of the red sample revealed the presence of calcium, sulfur, and iron, this latter not present in the other compounds, confirming the presence of iron oxide compounds, like hematite (Fe_2O_3), detected in Raman spectra, and confirming the use of red ochre for the red coloration. The amount of iron was variable: in other points, the top painted layer was absent, or thin, and the corresponding iron signal was low (Point images in Fig.42d,f and corresponding EDS spectra in Fig.42e,g). Again, sulphur and calcium were detected all over the sample, indicating the diffused presence of gypsum.

Some specific spots (looking bright in the BSE images) were analysed (SE image in fig. 43a) and mercury was detected in these areas (Fig.43b).



a b c



d e f g

Figure 42– SE images (a,d,f) and EDS spectra (b,c,e,g) of a fragment from WCRed

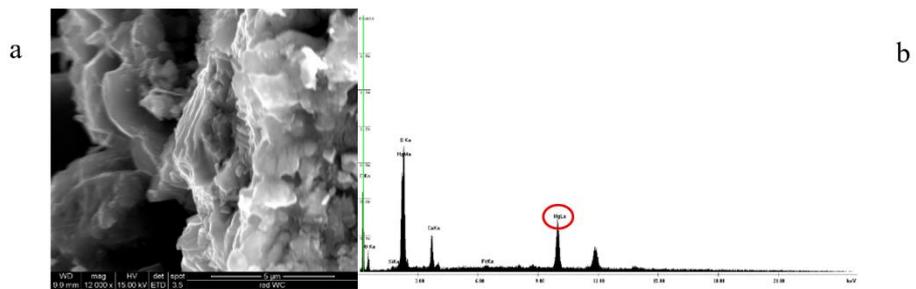


Figure 43– SE image (a) and EDS spectrum of a “bright” area in WCRed

The EDS analysis of the mortar sample indicates the presence of calcium, sulfur, oxygen, and carbon in varying amount (Fig.44b,c). These results are consistent with the presence of a calcium carbonate and calcium sulfate compounds.

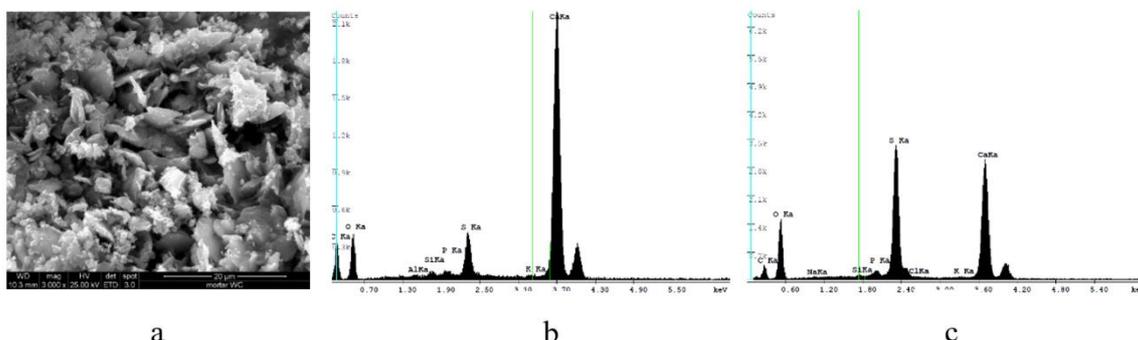


Figure 44 – SE image of an area in the WCMortar (a) and EDS spectra (b) and (c).

Electron Paramagnetic Resonance (EPR)

Due to the undefined nature of the green areas in the WCGreen sample, Electron Paramagnetic Resonance spectroscopy (EPR) was applied on this sample to detect the possible presence of Cu^{2+} in a dispersed, amorphous form. EPR spectroscopy is able to detect paramagnetic species, i.e., species having unpaired electrons. These species encompass organic molecules (radicals) as well as very common transition metal ions, like Cu^{2+} , Fe^{3+} , Mn^{2+} . EPR is very sensitive to Cu^{2+} ion, which is a chromophore giving a blue or green color to the matrix embedding it, even when it is not specifically present in a crystalline mineral phase (like malachite, verdigris, azurite, etc.), but is present in smaller amount in a dispersed form. Considering the absence of a specific Raman spectrum attributable to a pigment, but the detection in the EDS spectra of minimal amount of copper, not present in the other samples, a possible explanation is that the green colour derives from sporadic copper ions embedded in an inorganic hosting matrix. In Fig.45 it is shown the CW-EPR spectrum of a WCGreen fragment. The spectrum appears as the sum of a Cu^{2+} signal and a Mn^{2+} signal. The green interpolating line shows how the Cu^{2+} EPR signal appears in the experimental spectrum, while the overlapped, six-line Mn^{2+} signal is represented as a stick-plot (in black).

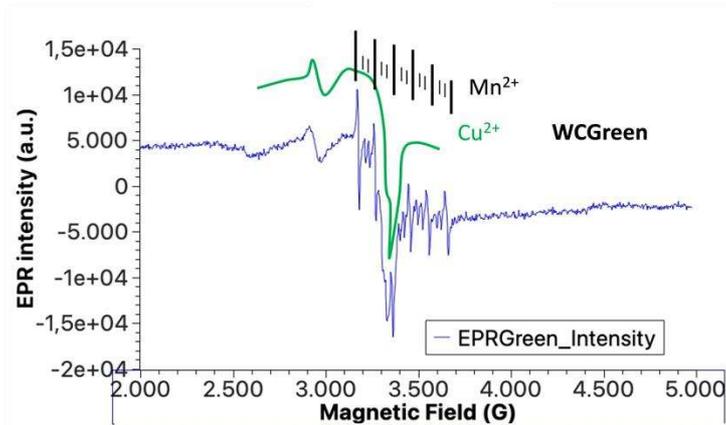


Figure 45– CW-EPR spectrum of a fragment from WCGreen (in blue); in green, the interpolated signal for the Cu^{2+} species, while in black the line sextet due to the Mn^{2+} species.

Mn^{2+} is a paramagnetic ion commonly replacing Ca^{2+} in calcium or calcium-magnesium carbonates. Therefore, it is associated to the calcite present everywhere in the sample (and in the mortar, particularly).

In order to verify the possible presence of Cu^{2+} also in the other samples, CW-EPR spectra of WCBlack and WCRed fragments were acquired (Fig. 46 and Fig. 47). The black sample presents just a broad, weak signal of dispersed Fe^{3+} , with overlapped the signal of Mn^{2+} . Carbon black is normally EPR-silent, besides minor signals possible due to carbon dangling bonds present in carbon black. Consistently with the EDS spectra, no Cu^{2+} signal was detected (in the limit of EPR sensitivity).

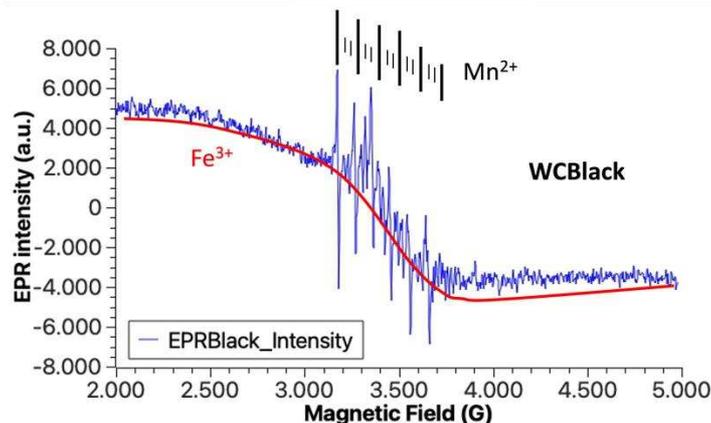


Figure 46– CW-EPR spectrum of a fragment from WCBlack (in blue); in red, the interpolated signal for Fe^{3+} species, while in black the line sextet due to the Mn^{2+} species.

The CW-EPR spectrum of WCRed, consistently with the presence of hematite observed in Raman and Fe in SEM-EDS, shows a clear signal of Fe^{3+} , whose asymmetrical features are typical for Fe^{3+} oxides. A weak signal of Mn^{2+} is also present.

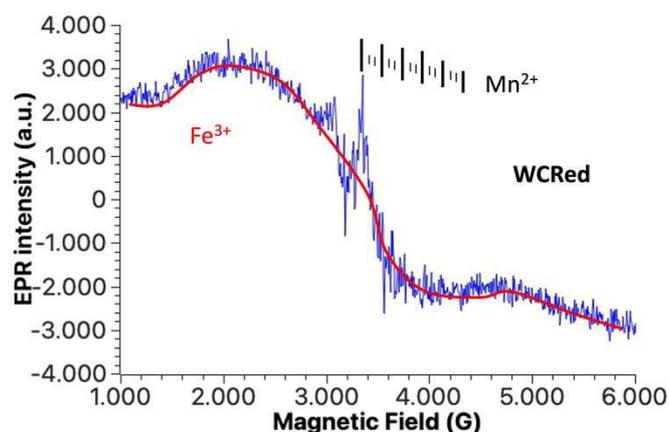


Figure 47– CW-EPR spectrum of a fragment from WCRed (in blue); in red, the interpolated signal for a Fe^{3+} oxide, while in black the line sextet due to the Mn^{2+} species.

No Cu^{2+} signal was detected also for WCRed. Based on the presence of a clear signal of Cu^{2+} dispersed in WCGreen, which is absent in WCRed and WCRBlack, the hypothesis that the green areas in WCGreen are due to this chromophore is strongly supported. We can therefore speculate that the original green pigment (maybe a malachite), dispersed in a binder, is slowly degraded, dispersing the Cu^{2+} ion.

4.2 IDENTIFICATION OF BINDER

4.2.1 MICROINVASIVE CHARACTERIZATION OF BINDERS IN THE FOUR FRAGMENTS FROM WAT CHAIWATTHANARAM: MICROFTIR

Fourier Transform Infrared Spectroscopy (FTIR) is an analytical technique used to determine the composition of substances through the interaction of infrared (IR) radiation with matter. It is particularly effective for identifying organic compounds and polymers. In FTIR analysis, infrared radiation is directed at a sample, where it is selectively absorbed by vibrational modes within the molecular structure of the constituent substances. This absorption generates a characteristic spectrum—often referred to as a molecular “fingerprint”—that is unique to each compound. The resulting spectrum, which plots the intensity of absorbed light against wavenumber, provides detailed information about the functional groups and overall chemical composition of the sample. By comparing the obtained spectrum with reference spectra from established databases, the identity of the substance can be accurately determined.

The IR characterization was carried out in External Reflectance mode, which rules out any contact with the sample. The microFTIR instrument was a Bruker Lumos II equipped with a LN-MCT detector for maximum sensitivity. A gold mirror was used as a reference, and a total of 128 scans were acquired

The IR characterization of the WCGreen sample considered three distinct regions on the front and the back side. The analysis of the first back-side spot, slightly greenish (Fig.48) shows signals corresponding to silicate minerals, with prominent peaks at 778 cm^{-1} and 1084 cm^{-1} , indicative of common silicate structures. Organic oil components are evidenced by characteristic peaks at 1134 cm^{-1} , 1684 cm^{-1} and 1749 cm^{-1} (these latter indicative, respectively, of carboxylic and carbonylic groups). A peak at 1907 cm^{-1} is consistent with a minor presence of iron oxide (overtone peak), while another overtone band of iron oxides is observed at 2336 cm^{-1} . The sample also contain possible overtone bands of copper carbonate (maybe malachite or azurite) at 2518 cm^{-1} , 2565 cm^{-1} , and 2568 cm^{-1} , but other peaks attributable to copper carbonates (1384 , 1414 , 1480 cm^{-1}) are not present, or clearly visible, making not reliable this assignment. The broad band at 3228 cm^{-1} is related to OH stretching modes, and its low-wavenumber position suggest that is related to OH groups in a hydrogen-bonding network, as typical for organic compounds. A second spot on the front side reveals a slightly different composition. The IR peak at 674 cm^{-1} can be attributed to sulphate, while peaks at 1314 cm^{-1} (C-O stretching), 1353 cm^{-1} (OH bending) and 1397 cm^{-1} (carbonate asymmetric stretching) correspond to organic compounds and carbonates.. Calcium sulphate (gypsum) is identified through overtones at 2564 cm^{-1} and an “upside down”band at 3419 cm^{-1} (“restrahlen effect”, often observed in External Reflectance IR spectra) associated with OH groups in gypsum(Fig.49). Other points on the back side of WCGreen exhibit a spectrum showing strong Amide I (1650 cm^{-1}) and Amide II (1550 cm^{-1}) bands, related to proteins, indicating the use of a protein based-binder. In addition, carbonyl stretching vibrations are present, further supporting the presence of other complex organic materials such as aged oils or natural resins.(Fig.50)

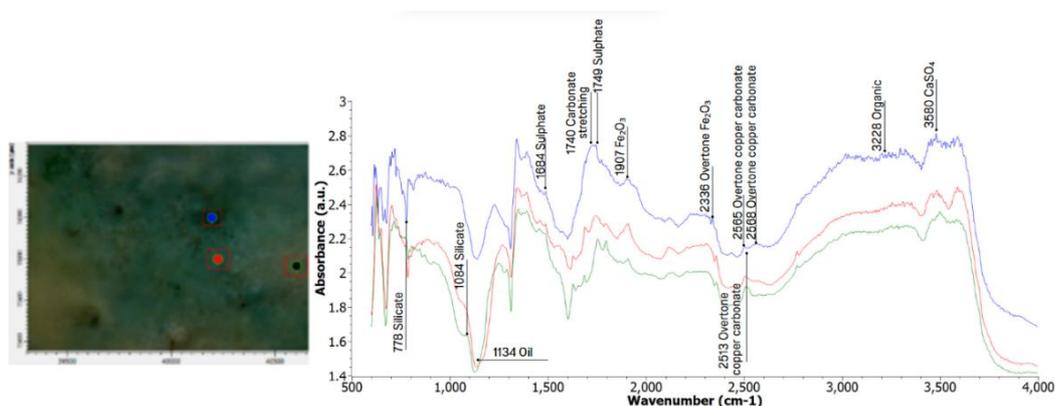


Figure 48– Microscopic image and IR spectrum on a greenish spot at the back side of a fragment from WCGreen

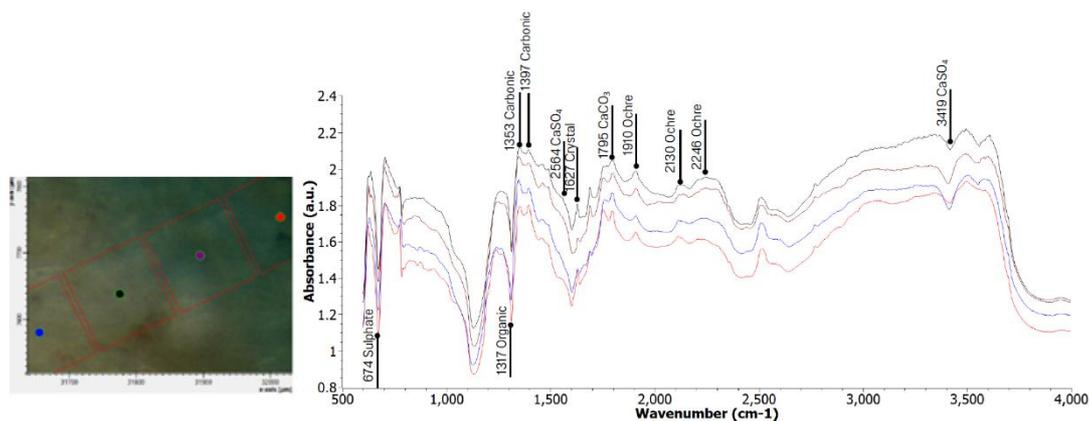


Figure 49– microscopic image and IR spectrum of a greenish part at the front side of WCR

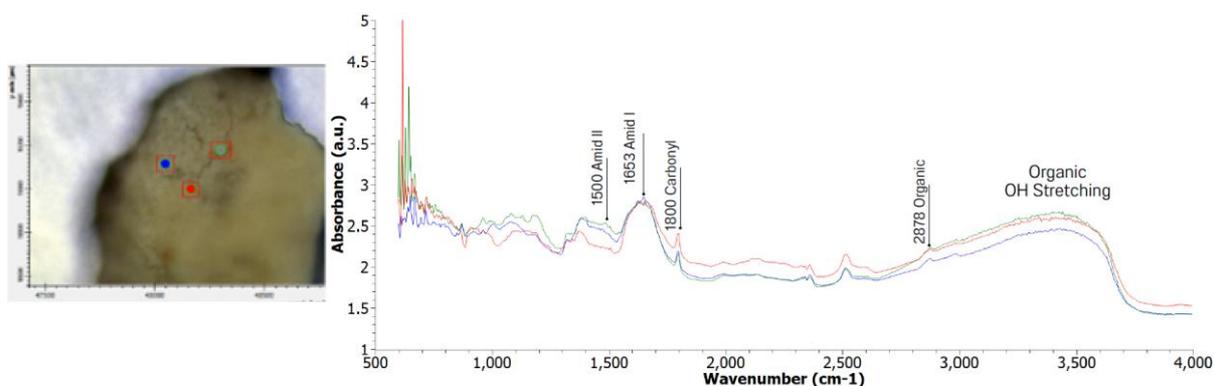


Figure 50– Microscopic image and IR spectrum of a greenish part at back side of green sample

The IR spectra from WCBlack highlight often the presence of oil-based binders, protein materials, and inorganic components such as calcite, suggesting a complex mixture likely used in historical painting or coating applications. The IR spectrum from the front side of WCBlack (Fig.51) reveals a composition rich in organic materials, consistent with oil-based binding media: a prominent band at 1164 cm^{-1} corresponds likely to an ester C-O – stretching, frequently observed in oils/fats. A peak at 1240 cm^{-1} could be assigned to Amide III band, suggesting the presence of protein materials. Additionally, carbonyl-containing compounds, like oils, fats, resins, could be inferred by the bands at 1737 cm^{-1} , 1742 cm^{-1} , and 1745 cm^{-1} (carbonyl (C=O) stretching modes of various organic compounds). However, very weak bands around 3000 cm^{-1} (C-H stretching) are not consistent with resins, fats or oils, which present normally strong sharp peaks in this region, but these bands can almost disappear in very degraded organic compounds, where CH groups are oxidized to COH groups. The presence of a broad feature in the higher region suggests overlapping O–H stretching vibrations, potentially from moisture or hydroxyl-containing degradation products.

Spectra collected from two separate areas on the back side of the sample (Fig.52 and Fig.53) show multiple peaks associated with organic components. In Fig.52, notably, C=O stretching bands are observed at 1719 cm^{-1} and 1724 cm^{-1} , together with a C-O stretching band at 1165 cm^{-1}

(“inverted”), confirming the presence of ester compounds, like the ones present in oils. In some regions, IR bands consistent with Amide I and Amide II vibrations (typically found near 1650 cm^{-1} and 1550 cm^{-1} , respectively) can be guessed, although their broadening makes unsure their presence. Their presence would suggest a protein component (Fig.53). In addition, overtone bands of calcite are detected in various areas on the back side, as evidenced by characteristic IR bands typically around 2511 and 2515 cm^{-1} .

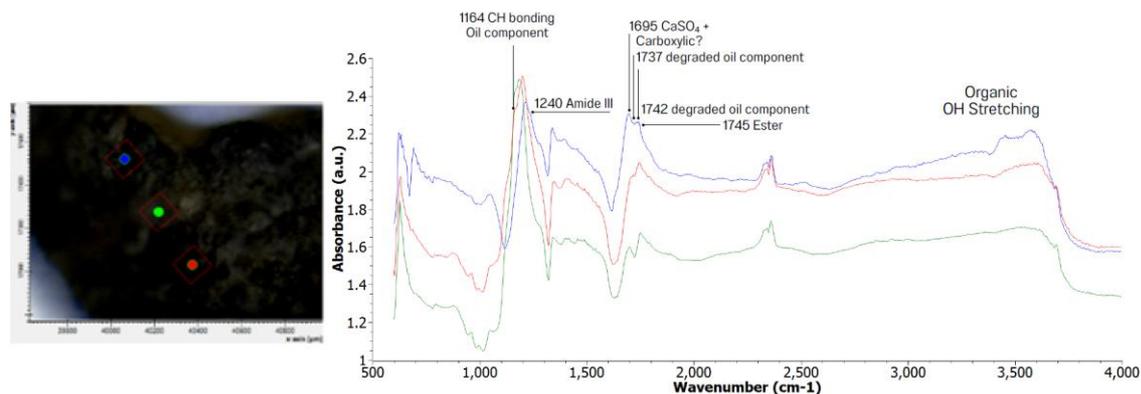


Figure 51– Microscopic image and IR spectrum of a black part at front side of WCBlack

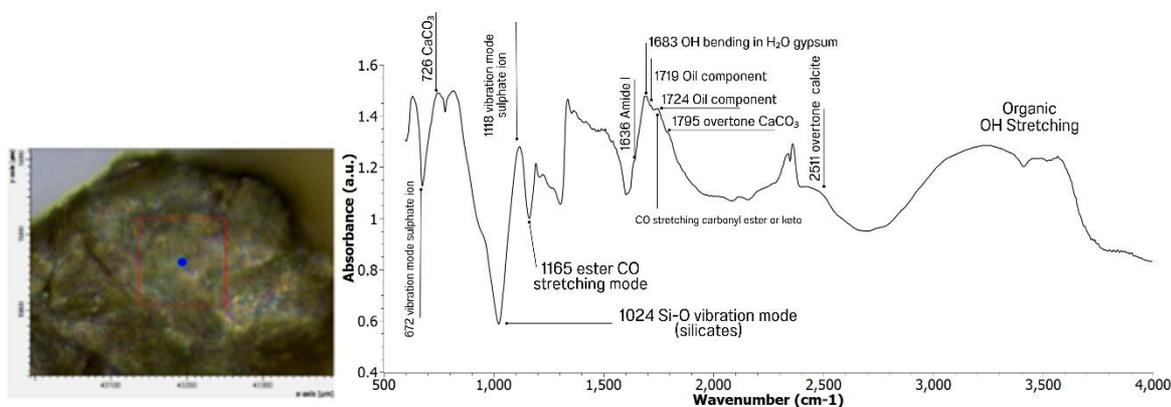


Figure 52– Microscopic image and IR spectrum of a grey spot at back side of WCBlack.

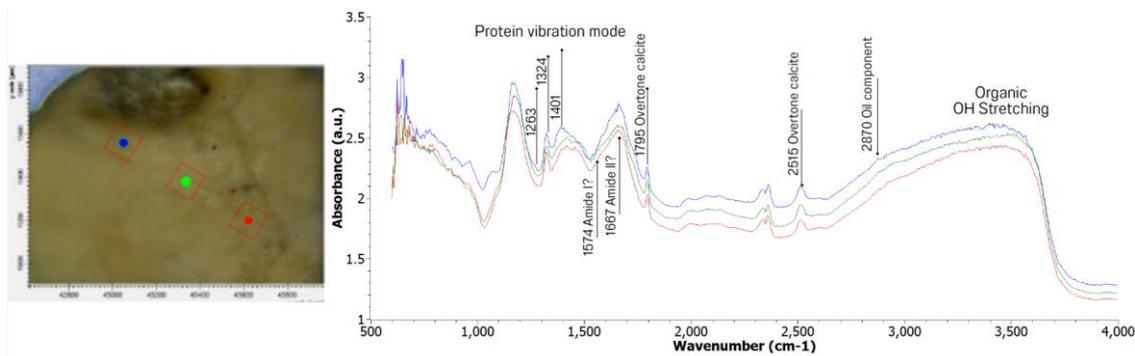


Figure 53– Microscopic image and IR spectrum at the back side of WCBlack

In Fig. 54 and 55 the IR spectra on red spots at the front side of two fragments from the WCRed sample are reported. Characteristic peaks at 2137 cm^{-1} and 2243 cm^{-1} (Fig.54), and 2129 cm^{-1} , 2234 cm^{-1} , and 2359 cm^{-1} (Fig.55), are assigned to ochres. These peaks represent overtones or combination bands of Fe–O stretching vibrations typical in hematite and other oxhydroxide iron compounds. In both areas, strong IR bands are observed around 2914 cm^{-1} , indicative of C–H stretching vibrations associated with organic substances, such as drying oils or natural resins, used as binders. Additional weaker bands around 1730 cm^{-1} suggest the presence of carbonyl (C=O) functional groups, likely originating from oxidized oils or ester-containing organic media, confirming aged organic binders. In this case, the copresence of CH stretching peaks and C=O stretching bands strongly support some type of fat/oil binder. Furthermore, spectral features consistent with calcium carbonate (CaCO_3), calcium sulphate (CaSO_4), and calcite were observed, suggesting the use of these minerals either as pigment extenders, substrate coatings, or as part of a ground layer beneath the red pigment.

The back side of the red sample also exhibits strong evidence of organic materials, as indicated by the CH stretching bands around 3000 cm^{-1} and a peak at 1680 cm^{-1} possibly related to carbonylic/carboxylic compounds. (Fig.56)

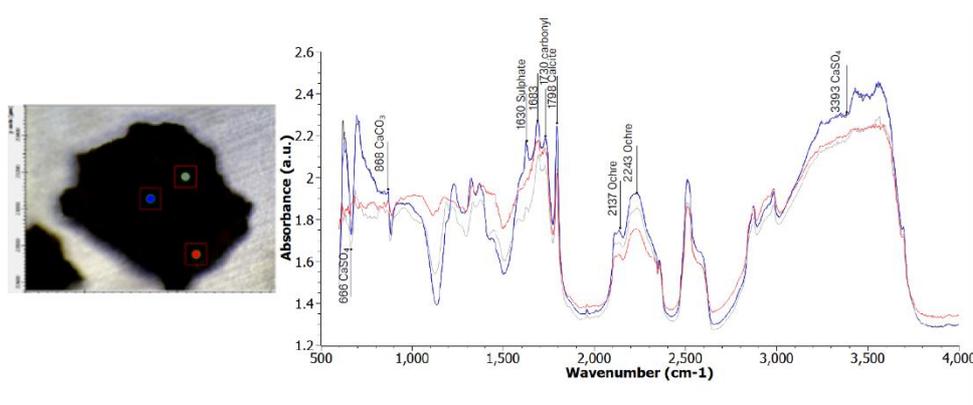


Figure 54– Microscopic image and IR spectrum at the front side of WCRed

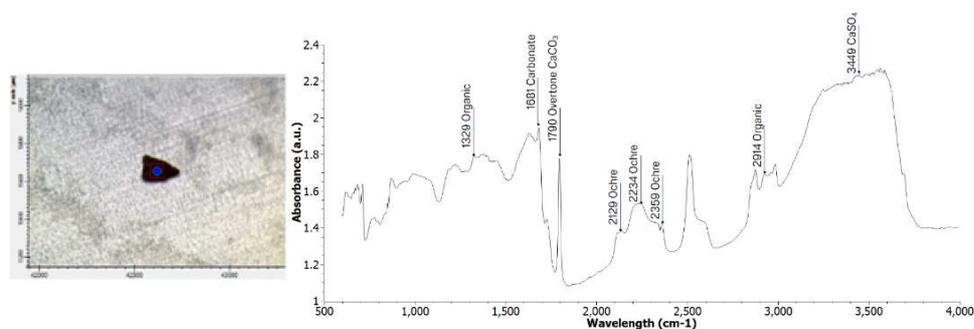


Figure 55– Microscopic image and IR spectrum at the front side of a small fragment from WCRed

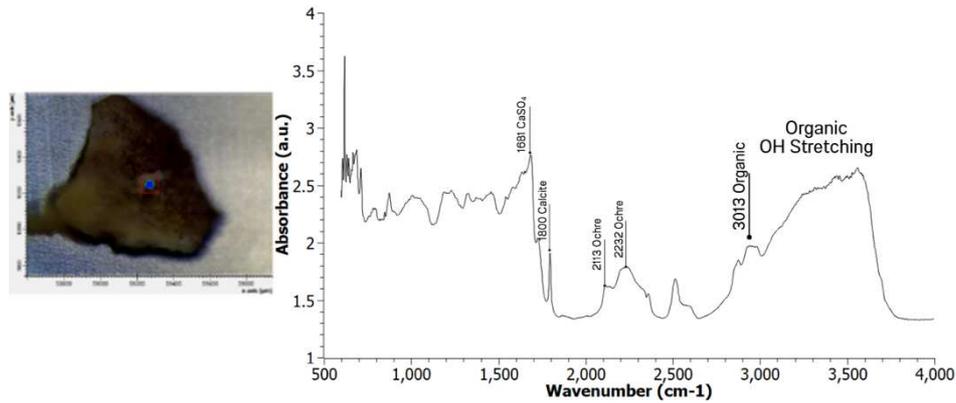


Figure 56– Microscopic image and IR spectrum at back side of WCRed

For mortar samples, two areas were examined, white and red. Strong IR bands in the 2870–2983 cm^{-1} region, characteristic of C–H stretching vibrations associated with organic components, are present in the white area (Fig.57) suggesting the use of a binder in the mortar, although the absence, or no clear presence, of other peaks, attributable to specific organic functional groups, in the region 1600-1800 cm^{-1} , makes unclear the type of organic binder. In addition, broad O–H stretching bands were detected, indicating the presence of moisture, hydroxyl groups, or hydrogen bonded compounds, likely from organic degradation products or residual water in hydrated phases.

Other strong overtone bands (1798 cm^{-1} 2500-2600 cm^{-1}) are safely attributable to calcite, together with the sharp peak at 875 cm^{-1} .

In contrast to the general white color of mortar, a specific red-colored spot within one of the samples showed additional peaks at 2135 cm^{-1} and 2235 cm^{-1} , which are attributed to the overtone bands of iron oxides, likely from hematite or related ochre pigments. This indicates localized pigment application or contamination, possibly from adjacent painted surfaces or decorative elements. (Fig.58)

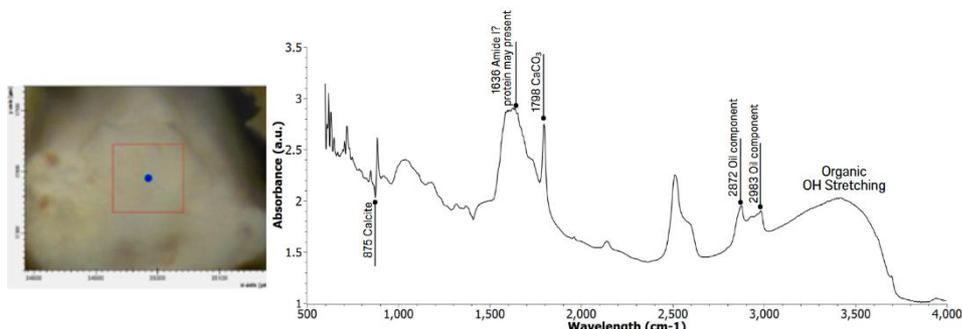


Figure 57– Microscopic image and IR spectrum at whitish spot of mortar sample

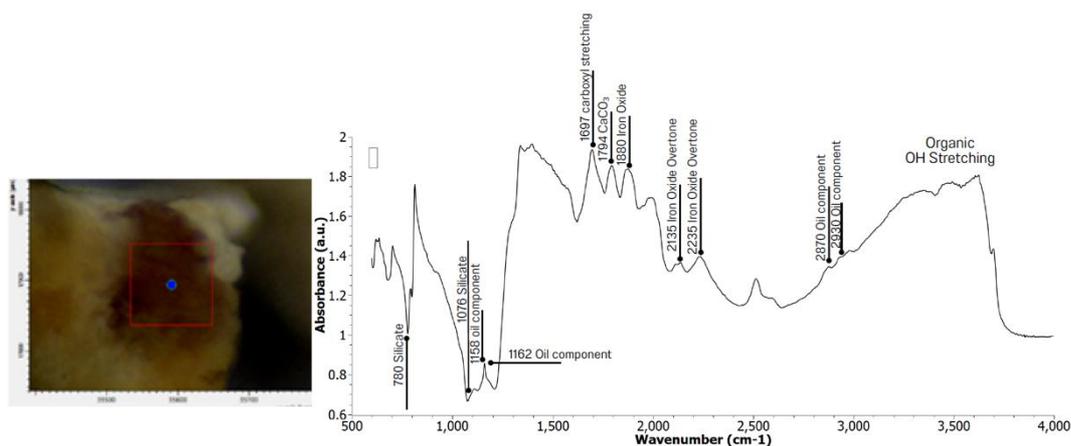


Figure 58– Microscopic image and IR spectrum at reddish spot of mortar sample

Chapter 5 Discussion

In this work of thesis, Thai mural paintings have been examined in situ in Wat Chaiwatthanaram (UNESCO site), Wat Chong Nonsi and Residential Building of Somdet Phra Phutthakosajarn using a non-invasive approach based on a colorimeter, which provided a trace of reflectance spectrum in the visible region. This was a first overview to possibly identify the dyes and the pigments applied on the surface of the mural painting. Although only limited traces of the original artwork remain today, primarily due to environmental factors and humidity, which have significantly contributed to the deterioration of mural, it was possible to identify colored areas well preserved. The color palette included green mint, green sage, green moss, green pine, green pickle, green dark jungle, green seaweed, orange tangerine, orange tiger, yellow dijon, red blush, red wine, red purple, red crimson, red scarlet, red blood, pink, black, white and grey.

The colorimetric investigation provided useful first indications on the type of pigments, albeit limited to the visible region of the spectrum: orange and yellow areas investigated on Residential Building of Somdet Phra Phutthakosajarn presented the typical profile for ochres and were the result of a mixture of hematite and goethite minerals. Black and grey areas were inconclusive about the type of pigments, as expected for colorimetric measurements, although a “background” of yellow ochre was always present. Some red spots were indicative of the presence of cinnabar while green areas were attributable to earth green in some areas and to a copper-based pigment in other areas. Red areas in Wat Chaiwatthanaram were generally attributable to cinnabar, bright green areas to malachite (albeit degraded), dark green to a green earth, or to a mixture of yellow ochre and some blue dye. In Wat Chong Nonsi, red areas were cinnabar, yellow areas were ochres, the only green

area was likely a green earth, and a pink area was probably due to some organic dye. As a whole, the investigation suggested a rich color palette, with probable more overpaintings on the original pictures.

As second step, small fragments from green, black, red and mortar in Wat Chaiwattanaram were taken, and spectroscopic (Raman, FTIR SEM-EDS) and microscopic (SEM, optical microscopy) investigations were carried out to characterize the materials.

Microscopic and spectroscopic investigations on the four samples from Wat Chaiwattanaram contributed to a deeper insight. The main results are here discussed, crossing the various techniques.

- 1) *WCGreen*. Pale green spots on a white background were evident in green fragment micropictures (see Fig.15 and Fig.16 in Chapter 3). Raman investigations on the green spots did not provide any indication about possible common green pigments, like malachite, brochantite, atacamite or verdigris. From Raman, a green earth could be not ruled out as a pigment, since green earth gives often broad and unclear bands in Raman spectra. However, SEM-EDS investigations suggested the presence of a small amount of copper on the green areas of the green fragment (Fig.35 and Fig.36 in Chapter 4). Albeit very low, the presence of copper was indicative, since copper was completely undetected in SEM-EDS investigations in the other three samples (WCBlack, WCRed, and Mortar fragment). CW-EPR on the green fragment showed the clear presence of Cu^{2+} in a dispersed form, suggesting that the green areas are likely due to an amorphous phase, where Cu^{2+} ions are dispersed providing the observed pale green coloration. Likely, this is due to a significant degradation from an original painted layer were the original copper-based pigment (malachite?) degraded to the present amorphous form, likely due to a reaction with the binder, humidity and chemical interaction with sulfates and chlorides. This is consistent also with the presence of calcium oxalates, attested by Raman, which are often the degradation oxidative byproducts of organic binders, especially in presence of copper-based pigments, which are efficient catalysts for these oxidation reactions. MicroFTIR investigations supported further this assumption, showing the presence of organic binders, which could be related to a degraded oil, or possible to some plant sap rich in carbonyl compounds, although deeper investigations are required to characterize better this aspect.
- 2) *WCBlack*. The microscopic images show a thin black layer overlapped to a white preparatory layer. According to Raman, the black layer is essentially amorphous carbon black. The presence of a phosphate peak in any black point explored by Raman suggests the possible use of a bone black, or ivory black. SEM-EDS investigations support this assumption, showing ^{31}P peaks everywhere in the black. Pretty interesting, some small flakes of gold on the painted layer were detected in SEM-EDS. This is a rare finding, as

gold leaf was typically applied using sap from *Ficus carica L.* as an adhesive. Due to environmental factors, such as humidity and degradation over time, gold leaves are generally no longer preserved after 500 years. This is consistent with the expectations of art historians, who suggest that gold leaf may have been applied over black pigment to enhance visual contrast and make the color appear more vibrant. The gold may have become embedded in the pictorial layer over time as a result of degradation. According to Ms.Kiriya Chayakul Sitthiwang, Thai Academic Artist noted that gold was likely reserved for application over black pigment, as it created a striking visual effect and symbolized the wealth and grandeur of the Siamese or Ayutthaya Kingdom. She more clarified that, 'It is extremely rare to find scientific evidence of gold leaf on mural paintings. In this case, the only remaining evidence in present found by archaeologists is a tiny flake of gold applied to the lacquered surface of wooden ceiling.' Apart from that, MicroFTIR provided evidence of the presence of organic binders and degraded oil components where they all appear both front and back side of green, black, red and mortar fragment.

- 3) *WCRed*. The red fragment optical microscopy images allowed one to estimate the presence of at least four different layer, from top to bottom, red, black, red, and mortar (Fig.20 in Chapter 3). Raman investigations on the red spots provided evidence of red ochre (Fig. 33 Chapter 4), with some small red areas where cinnabar was clearly detected. MicroFTIR suggested the presence of ochres in various fragments (Fig.54; Fig55 and Fig.56). SEM-EDS investigation confirmed the presence of ochre, with Fe signals in the red layer higher than observed on the other samples. Also, small bright areas in BSE images gave SEM-EDS spectra showing the presence of Hg, consistently with the presence of cinnabar detected via Raman. SEM images suggested that the cinnabar was probably a layer, no more present, overpainted on an original red ochre layer. Probably, this cinnabar/vermillion layer was painted already in Ayutthaya period. (Fig.43 in Chapter 4)
- 4) The optical microscopy images of the mortar fragment showed brownish, yellowish and orange spots on the surface (Fig.21 in Chapter 3). Micro FTIR on mortar provided the evidence of calcium carbonate and sulphate which corresponded to SEM-EDS investigations, which assured the presence of calcium carbonate and calcium sulphate compounds quite ubiquitous. According to this, they may come from shell white produced by roasting and grinding shells into a fine powder, or from calcite which Thai craftsman typically used as a primer.

As a whole, SEM-EDS investigations indicated the everywhere presence of Ca and S, as a layer immediately beneath the pictorial layer. Actually, Raman detected often the presence of peaks related to gypsum, although Raman is a technique more focused on the pictorial surface, and often

the calcium sulphate crystals were just beneath the main pictorial layer. MicroFTIR, which has a higher penetration depth, detected actually the presence of calcium sulphate bands (1683 cm^{-1} , 1620 cm^{-1} , 667 cm^{-1}) in most samples. The presence of calcium sulphate could be related to a preparatory layer, but from the SEM images it looks often at the same level, or even above the pictorial layer (Fig.34 in Chapter 4). Therefore, possible assumption is that calcium sulphate crystals were formed beneath the pigment layer, due to degradation phenomena, pushing in some points the pictorial layer away. Protein-based or oil-based binders were often detected by microFTIR. The presence of protein binders, together with the everywhere presence of ^{13}P peaks in SEM-EDS, and the presence of phosphate peaks in Raman spectra, could be indicative of the use of a bone glue.

Compared to art historian expectations, although the traditional technique of Thai mural painting is based primarily on the *secco* technique, it is characterized by smooth color transition, precise outlines, and a deliberate selection of pigments — often derived from locally available natural materials such as ochre, cinnabar, copper, bone black and binders from plants and animals. Craftsmen historically relied on familiar and accessible substances, reflecting both cultural practices and environmental adaptation. Therefore, it is essential to scientifically identify the materials and techniques employed in these historical artworks to understand the choices made by ancient artisans. Such characterization allows them to confirm the presence of traditional materials or, alternatively, to recognize the use of substitute substances with similar properties. This information is crucial not only for historical and art historical interpretation but also for guiding appropriate conservation strategies. In particular, identifying original materials helps avoid the use of incompatible or damaging substances in restoration, ensuring that any conservation intervention respect the integrity of the artwork.

Chapter 6 Conclusion

The characterization of Thai mural paintings from three case studies, particularly the murals at Wat Chaiwatthanaram and Residential Building of Somdet Phra Phutthakosajarn have been carried out using scientific analytical techniques for the first time. This study focused on the identification of both pigments and binder materials through a range of non-invasive and micro-invasive methods so as to be able to generate accurate and detailed information about the materials used in the mural paintings. These findings not only enhance our understanding of traditional Thai painting techniques and material selection but also provide a valuable reference for future conservation efforts and scientific investigation of Southeast Asian mural arts.

The findings from such studies are especially valuable when mural paintings face threats from environmental factors, including fluctuations in temperature and humidity (physical deterioration), microbial or insect infestations (biological damage), and chemical interactions that may lead to the fading, corrosion, or delamination of materials. A comprehensive understanding of both the original materials and deterioration mechanisms supports the development of sustainable conservation plans, including controlled environmental conditions, the selection of compatible consolidation agents, and the avoidance of irreversible treatments.

Ultimately, these insights contribute not only to the preservation of Thailand's mural heritage but also to the broader field of conservation science by providing models for the care of wall paintings in similar climatic and cultural contexts.

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Appendix

Vocabulary

Term in italics are listed as separated entries in this appendix.

Aimui Vermilion	Highest quality of vermilion and originated from the city of Xiamen, China
Bodhisattvas	An enlightened beings who have put off entering paradise in order to help others attain enlightenment in Buddhism.
Calamus draco	A tropical species of rattan plant predominantly found in Southeast Asia serves as the source of red seeds that produce a red substance known as iron pyrites, which is sometimes referred to as “dragon’s blood”.
Cassia siamea	Siamese cassia, a member of subfamily Caesalpinioideae, has glossy dark green leaves with a paler underside. The leaves possess acidic properties and are traditionally used to reduce the alkalinity of walls prior to painting.



Figure 59 – *Cassia siamea*

Source : <https://indiabiodiversity.org>

Celadonite A mica group mineral formed through low-grade hydrothermal or diagenetic alteration of other minerals or volcanic glass, resulting in an earthy green to blue-green appearance.

Champaca A large evergreen tree known for its fragrant flowers, which range in color from cream to yellow-orange and are rich in essential oils commonly used in perfumery.



Figure 60 – Champaca

Source : <https://pacifichorticulture.org/articles/>

Ch'ien Tan Orange red lead from China

Cho Sae Vermillion Name of vermilion from Xiamen, China

Curma domestica A flowering plant in the ginger family Zingiberaceae, turmeric is a herbaceous species native to the Indian subcontinent and Southeast Asia. It is widely used as a natural indicator to test the alkalinity of the wall surfaces in preparation for traditional Thai painting. If the color of the turmeric remained dark orange-red, it indicates the continued presence of alkalinity. Conversely, if the turmeric turns bright yellow, it signified that the alkalinity has been sufficiently neutralized, typically through the application of Cassia leaves.

Dai Ochre Red pigment from Yanmen region in Chanxi province, China

Dharma It comes from Sanskrit, meaning to hold or to support, thus referring to law that sustains things from one's life to society, and to the universe at large.

Dharmic paradox Messages or images that convey hidden meanings related to the Dharma require wisdom and discernment to fully comprehend their underlying significance.

Dvaravati

The name of an ancient kingdom primarily located in central Thailand, with archaeological evidence increasingly indicating its presence in northern, northeastern, eastern, and southern regions of the country. Dvaravati flourished approximately between the 12th and 16th Buddhist centuries (circa 1200 – 1600 B.E.), with major centers in regions such as Nakhon Pathom, Rachaburi, Suphan Buri, and Lop Buri.

Feronia limonia Swingle

It belongs to a family of plant native to Asia, particularly the South and Southeast Asian regions, including countries such as India, Sri Lanka, Bangladesh, Myanmar, Thailand, and Laos. This plant has diverse applications, serving both culinary and medical purposes. All parts of the tree are utilized in traditional herbal medicine. The resin extracted from its trunk possesses astringent properties, making it effective in treating diarrhea and stopping bleeding. Due to its high viscosity and adhesive qualities, the resin is also used as a natural glue for bonding materials and serves as an ingredient in traditional Thai paints and coloring agents.



Figure 61 – *Feronia limonia* Swingle

Source : <https://medthai.com>

Ficus glomerata

It is native to Sri Lanka, Southern China, South Asia, and Southeast Asia. In traditional Thai medicine, it is valued for its various medical properties, particularly its resin, which is commonly used as a base material in the process of gilding.

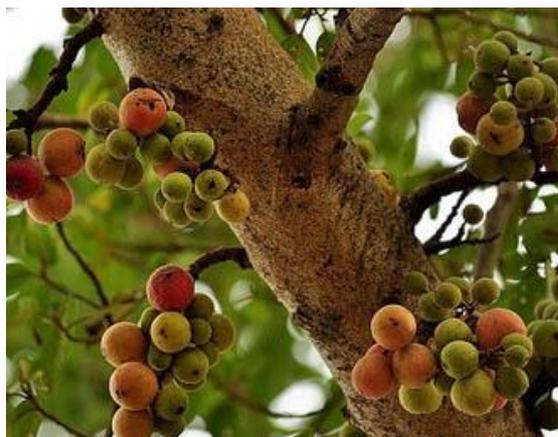


Figure 62 – *Ficus glomerata*

Source : <https://www.planetayurveda.com/library/>

Khao Sumonakut

A sacred mountain in Sri Lanka is believed by Buddhists to bear a footprint of the Buddha, said to have been left during his third visit to the island.

Lu Chhing

Other Chinese name for malachite

Garcinia hanburyi

The plant species is predominantly found in Sri Lanka, Cambodia, and Thailand, particularly in the Chantaburi province. In Thai, its yellow resin is known as *rong*, and it bears a hue comparable to that of the moon or the traditional gamboge tint. The resin is extracted by making incisions in the trunk with a knife, after which the sap is filtered for impurities and gently boiled. It is then poured into bamboo tubes and roasted over a fire, in a method similar to the preparation of bamboo stick rice.

Care must be taken during this process: if the heat is too intense, the resin turns a dark orange color and becomes unsuitable for painting, as it reverts to the dark tone upon drying. Therefore, a low and controlled flame is essential. Once the resin solidifies into a lump, the bamboo is split open, revealing the resin preserved in the shape of the bamboo tube.

This natural pigment possesses unique adhesive properties, enabling it to bind effectively to wall surfaces without the need for additional binders such as glue or other liquids.

Glauconite

Green mineral which contains high concentration of iron which has very low weathering resistance.

Gum Arabic

A natural compound classified as a hydrocolloid and is widely utilized in the food industry. It is derived from the natural resin exuded from the bark of trees in the *Acacia* genus, particularly *Acacia Senegal*. This resin coagulates upon exposure to sunlight, eventually drying and hardening into a clear, glass-like substance that adheres to the tree. Gum Arabic varies in color, ranging from transparent to amber, and typically forms in drop-like shapes. These may appear round, oval, or irregularly angled, depending on natural conditions. In contemporary Thai painting, artists often mix Gum Arabic with naturally derived pigments to enhance the adhesion of color to the painting surface.



Figure 63 – Gum Arabic

Source : <https://lairodnamart.blogspot.com/>

Indigofera tinctoria

This plant is found in tropical regions and is widely distributed throughout Southeast Asia, including countries such as Thailand, Myanmar, and Laos. It thrives in open natural environments. During the rainy season, fallen seeds germinate and grow into new plants, while seed maturation typically occurs in the winter. When the fresh plants are fermented in water, they can be used to produce natural dyes for fabrics, as well as inks and pigments for painting.



Figure 64 – *Indigofera tinctoria*

Source : <https://www.rhs.org.uk/plants>

Indigotin	A chemical compound responsible for the characteristic deep blue color extracted from <i>Indigofera tinctoria</i> .
Ivory Black	A deep black pigment, denser than soot and regarded as the highest quality of black, derived from carbonized bone or ivory of animals.
Jataka tales	The life story of Lord Buddha, encompassing events from before his birth to his passing (Parinirvana), generally includes key milestones such as his birth, early life, renunciation, enlightenment, the dissemination of his teachings, and his final passing.
Javanese	Evidence from Indian, Arab, Greek, and later Portuguese sources suggests that the term “Java” originally had a broad meaning, encompassing many islands in the western part of what is now Indonesia. For instances, Sumatra was once referred to as “Big Java,” while Java itself was known as “Little Java.” At times, the term “Java” may have specifically referred to Sumatra. In contemporary culture and ethnology, however, the term “Java” has a more defined meaning, primarily referring to the language and way of life of the people on the island of Java, excluding the western part, which is home to the Sudanese people.
Khao Kabang	The whitish Thai tonal color derived from burning kaolin until it is well-cooked, then grinding it into fine dust and filtering it to obtain a pure white color.

Karma	The term originates from the Pali language and refers to action, specifically intentional or volitional action.
Ling Sha.	An orange-red pigment synthesized in China
Lopburi	According to historical chronicles, the Lavo Kingdom was established in 1002 CE, with <i>Lopburi</i> as its capital. Situated in the central region of the Chao Phraya River basin, the kingdom's territory extended from Chainat to Prachuap Khiri Khan province in the west. <i>Lopburi</i> had previously been a significant city within the <i>Dvaravati</i> Kingdom and had long been a center of Buddhist influence and cultural development.
Mara	Derived from Sanskrit and Pali, the term <i>Mara</i> means “destroyer” or “bringer of death.” In Buddhist philosophy, <i>Mara</i> refers to a being or force that hinders sentient beings from escaping the cycle of rebirth and obstructs practitioners from attaining enlightenment.
Naga	In the belief of many Asian religions, the Naha in Sanskrit is a large, crested serpent that resides in the underworld. This mythical creature holds significant symbolic and mythological importance across the traditions of South and Southeast Asia.



Figure 65 – *Naga*

Source : <https://www.ennxo.com/article/>

Nammatha River	According to the <i>Tripitaka</i> , the location of the Buddha's footprint in India is associated with an event in which the Buddha travelled to the bank of Nammatha River, the dwelling place of the <i>Naga</i> kings. The <i>Naga</i> kings invited the Buddha to descend into their underwater and paid homage to him. Before departing, the Buddha delivered a sermon on the Dharma. In gratitude, the <i>Naga</i> king requested that the Buddha leave his footprint on the riverbank as a sacred relic.
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Persea kurzii

A small to medium-sized evergreen species, typically reaching heights of approximately 10-15 meters. It is commonly found in dry evergreen forests and dry dipterocarp forests. The tree produces a clear, white, milky resin with adhesive properties, which is particularly effective for sealing. The resin is stored within specialized cells in the tree's inner tissues.



Figure 66– Persea kurzii

Source : <http://www.qsbg.org/database/>

Phyllocarpus septentrionalis

A tree species native to Guatemala and other regions of Central and South America

Rong

A clear yellow hue obtained from the resin of gamboge

Sattabappa

The sacred mountain, located in Saraburi Province, is the site of the Buddha's footprint and is recognized as one of the five most significant Buddha footprints in Thailand.

Secco

In painting technique, the artist mixes pigments with a binding agent—such as egg, glue, or oil—to ensure the paint adheres effectively to the wall surface.

Siam

The term was historically used by foreign powers and monarchs to refer to the territory now known as Thailand. It often encompassed the Siamese people—an early ethnonym for the Thai population in the region—although it was not the name these people originally used to identify themselves. According to the Thai Royal Institute Dictionary, Siam referred both to the land and to the various groups who had inhabited it since ancient times. Thai monarchs employed the name *Siam* in diplomatic treaties with foreign nations for several centuries. Given the kingdom's diverse ethnic composition—including Tai, Lao, Mon, Vietnamese, Khmer, Indian, Chinese, French, and Malay

communities—Thai rulers adopted the term *Siam* as a unifying identity for the population. *Siam* remained the official name of the country from the reign of King Mongkut until it was formally changed to Thailand on June 24, 1939.

Sintao

Zigzag lines dividing the wall paintings into section

Srivijaya

the kingdom emerged as the first major center of maritime trade in Southeast Asia by exerting control over the strait of Malacca. This development occurred in the early 6th century, following the decline of the Funan Kingdom, which paved the way for the rise of new powers in the Indonesia archipelago, particularly in Java and Sumatra. In Sumatra, Srivijaya became a significant maritime trading power due to its strategic location near both the strait of Malacca and the Sunda strait, with its political and economic center based in the city of Palembang.

Sukhothai

Established over 700 years ago in the lower northern region of present-day Thailand, the first Thai kingdom served as the birthplace of the Thai alphabet and the earliest Thai literature work. It also marked the beginning of nation's first industry, the production of ceramics.

Tabebuia argentea Britton

The medium-sized deciduous tree, characterized by its yellow flowers, belongs to the Bignoniaceae family. It is an exotic species native to South America, specially found in regions such as Paraguay, Argentina, and Brazil. The tree typically flowers in the summer, with blooming occurring between March and April each year. The trunk is brown with rough, fissured bark. The tree is classified as a softwood species, with brittle branches that are prone to break.



Figure 67 – *Tabebuia argentea* Britton

Source : <https://kps.ku.ac.th>

Tamarindus indica

The tropical tree, belonging to the Fabaceae family, is native to parts of Africa, including Sudan, Cameroon, Nigeria, Kenya, Zambia, and Tanzania. It was later introduced to tropical regions of Asia and Latin America. The adhesive extracted from tamarind seeds is traditionally used as a binder in the primer for the conservation of Thai mural paintings. However, a key limitation is the seasonal availability of tamarind seeds, as they are difficult to source out of season and have limited storage longevity.



Figure 68– Tamarindus indica

Source : <https://www.agrinewsthai.com>

Tempera

A permanent, dry painting medium composed of pigment mixed with a liquid binder, typically a gluten-based substance such as egg yolk or other binders. The term tempera may also refer to artworks created using this technique. This method of painting is valued for its durability and is traditionally employed to ensure the long-term preservation of the artwork.

Tinospora crispa

The plant is native to dry evergreen and mixed deciduous forests in Southeast Asia. It is commonly found in countries such as Thailand, Myanmar, and Laos, as well as in parts of South Asia, including India and Sri Lanka. In Thailand, the plant has long been recognized for its traditional uses. Historically, it was employed in herbal medicine for the treatment of various sickness and served as an ingredient in the preparation of surface for traditional Thai paintings.



Figure 69– *Tinospora crispa*

Source : <https://arit.kpru.ac.th>

Traibhumi

Religious and cosmological concepts in Buddhism describe a tripartite structure of existence comprising *Kamabhumi* (Sensuous plane), *Rupabhumi* (Form plane), and *Arupabhumi* (Formless plane). This framework serves as a central theme in traditional Thai painting, particularly during the early Ayutthaya and Rattanakosin periods. Such visual representations function as a medium for conveying Buddhist teachings, emphasizing the impermanence of life, the workings of *karma*, and the continual cycle of existence within cycle of rebirth.

Tripitaka

A scriptural text that compiles the teachings of the Lord Buddha

Tratteggio

The technique involves restoring paintings by applying continuous vertical lines over damaged areas, thereby enhancing the visibility of the original image without compromising its aesthetic integrity.

Tua Pia

It may refer to high-quality red pigment originating from China, characterized by a color similar to red soil but with a finer powdery texture, or to red pigments derived from lac or cochineal insects.

Vihara

Monastery in the context of Buddhism

Vinaya

The rule of discipline in Buddhism

Ylang Ylang tree

A plant native to tropical regions of Asia, particularly the Philippines and Indonesia. It is a medium-sized, open-climbing vine that flowers year-round. The flowers typically appear in clusters at the leaf axils, with each cluster containing four to six blossoms. The petals are yellowish-green and emit a subtle, pleasant fragrance.



Figure 70– Ylang Ylang flowers

Source : <https://home.kapook.com>

Zhang Red

The red pigment originated in Hangzhou, Fujian Province, China