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A Technical Examination of 7 Thai Manuscripts in the 18th, 19th, and 20th Centuries

Abstract

The ideology of Buddhism was taught through various art forms such as architecture, sculptures, murals, and manuscripts on both palm leaves and papers. Little has been studied on the materials and techniques of Thai manuscripts on paper (*Samut khoi*). A total of seven Thai manuscripts were selected from the Philip Hofer Collection in the Asian Department of the Harvard University Art Museums for technical examination and art historical research. The project focuses on an 18th century manuscript, *Illustrated Tales from Jataka*; six other manuscripts from the 18th, 19th, and 20th centuries (2 each) were selected for comparison. The scope of the project includes researching historical information on Thai manuscripts and how political movement and commerce effected the artists' choice for painting materials. The techniques include visual examination, fiber analysis, ultraviolet and infrared light examination, non-destructive micro-x-ray fluorescence (XRF), Raman spectroscopy, Fourier transform infrared spectrometry (FTIR), and scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM-EDS). The analyses indicate the presence of huntite, lead white, calcite, indigo, red lead, vermilion, gamboge, ultramarine, and red earth in the 18th century manuscripts. In the 19th and 20th century manuscripts, the analyses indicate lead white, calcite, red lead, vermilion, gamboges, chrome yellow, emerald green and Prussian blue, as well as possible barium sulfate, titanium white, and viridian. Lead white, gold leaf, and vermilion were found consistently in all seven manuscripts. The results suggest that different blue pigments were used in different centuries: indigo in the 18th century, ultramarine and Prussian blue in the 19th century and Prussian blue alone in the 20th century. Further analyses and examination of additional manuscripts is planned to confirm these patterns.

1. Introduction

In 1984, Philip Hofer gave Harvard University Art Museums 55 South East Asian manuscripts including many Thai manuscripts and a few manuscripts from Burma, Sumatra, and Bali. The Thai manuscript collection has received little attention in the past, and only a small number of scholars have studied them. In 2005, several Thai manuscripts from the Hofer collection were loaned for an Exhibit, *The Kingdom of Siam: The Art of Central Thailand, 1350-1800*, in Asian Art Museum of San Francisco in 2005. One particular manuscript, *Illustrated Jataka Tales* (1984.511), was singled out and highlighted in the catalogue (see

figure 1). Scholars found one of the images in this manuscript resembled a banner in the San Francisco's collection, which had interesting implications for workshop practices. Thus, a technical study on those manuscript and banner was planned at both institutions to investigate and compare the artists' materials and techniques. Unfortunately, further investigation in San Francisco discovered that their banner was a copy of the Hofer collection manuscript made by a Buddhist monk in the 1960s. However, the discussions about the manuscripts highlighted the need for an in-depth technical study of the materials and artists of Thai manuscripts. Based on the hand written museum record, a total of seven Thai manuscripts from 18th, 19th, and 20th centuries were selected from the Hofer Collection (figure 1 to 7). One aim of the study was to evaluate the accuracy of the record found in the museum.

The seven manuscripts are listed as below:

1. **18th century**, Illustrated Jataka Tales, HUAM 1984.511
2. **18th century**, Illustrated Manuscript, HUAM 1984.512
3. **18th century**, Illustrated Ten Jataka Tales, HUAM 1984.508 (reassigned to 19th century)*
4. **18th-19th century**, Illustrated Dharma Quotes/ Ten Jataka Tales, HUAM 1984.501
5. **19th century**, Illustrated Text on Cosmology, HUAM 1984.517
6. **19th century**, Illustrated Phra Malai Manuscript, HUAM 1984.524 (reassigned to late 19th century)*
7. **20th century**, Illustrated Phra Malai Manuscript, HUAM 1984.510

* The dates for these two manuscripts were subjected to change after the analysis of the blue and green pigments

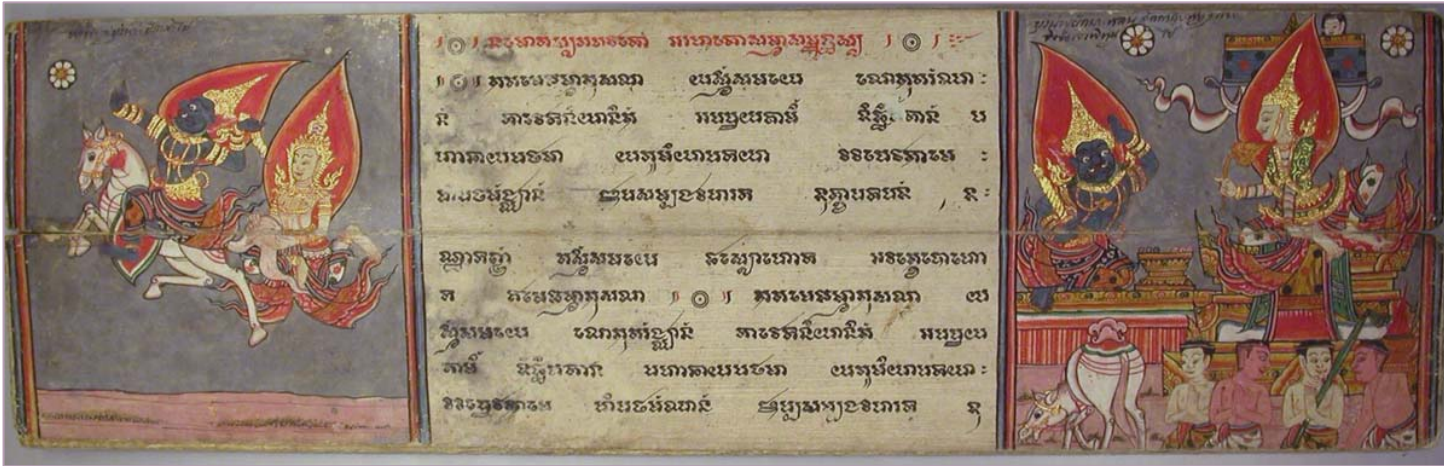


Figure 1 Illustrated Jataka Tales, HUAM 1984.511, 10.1 x 63.5 x 3.7 cm

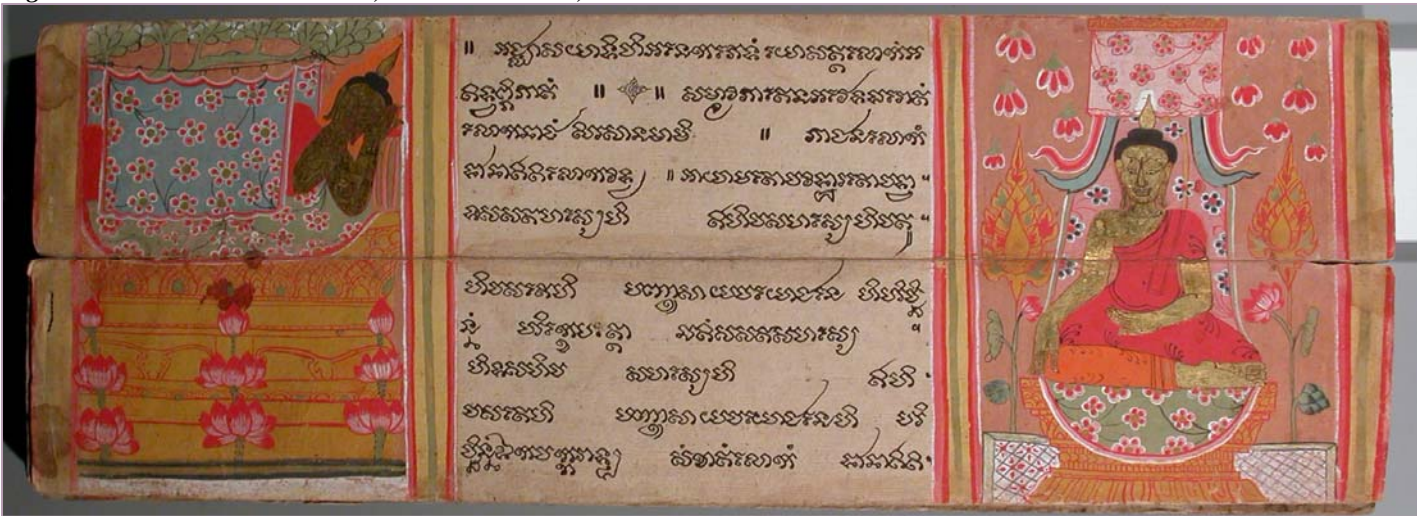


Figure 2 Illustrated Manuscript, HUAM 1984.512, 11.0 x 59.6 x 4.0 cm

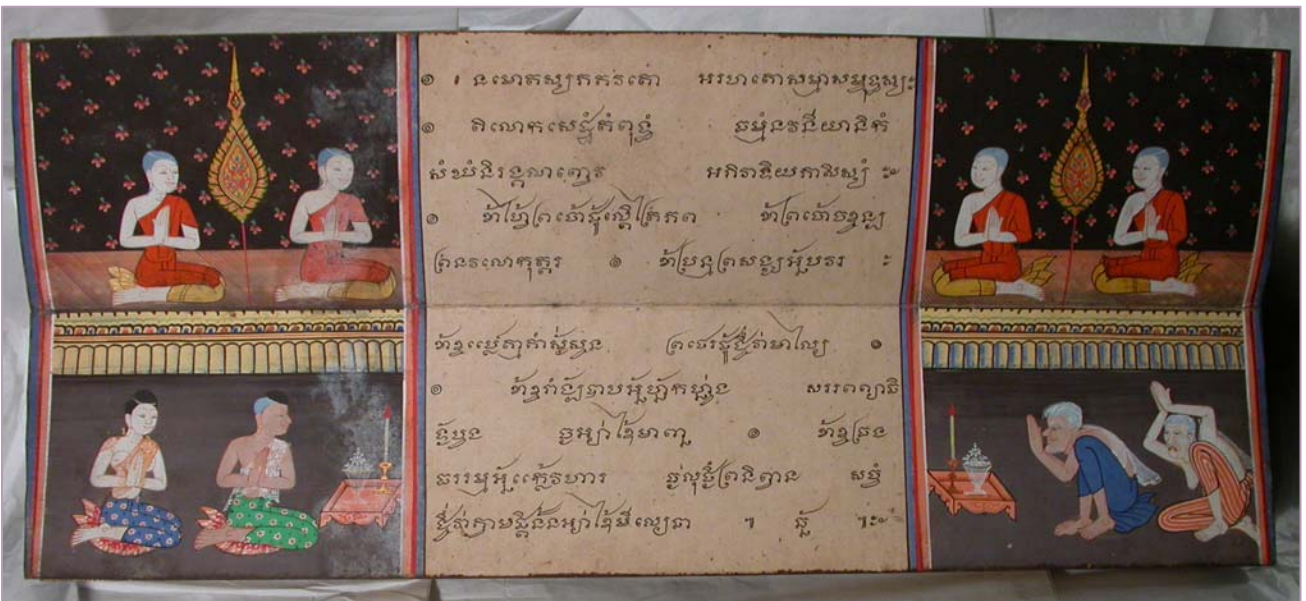


Figure 3 Illustrated Ten Jataka Tales, HUAM 1984.508, 14.5 x 65.5 x 10.0 cm

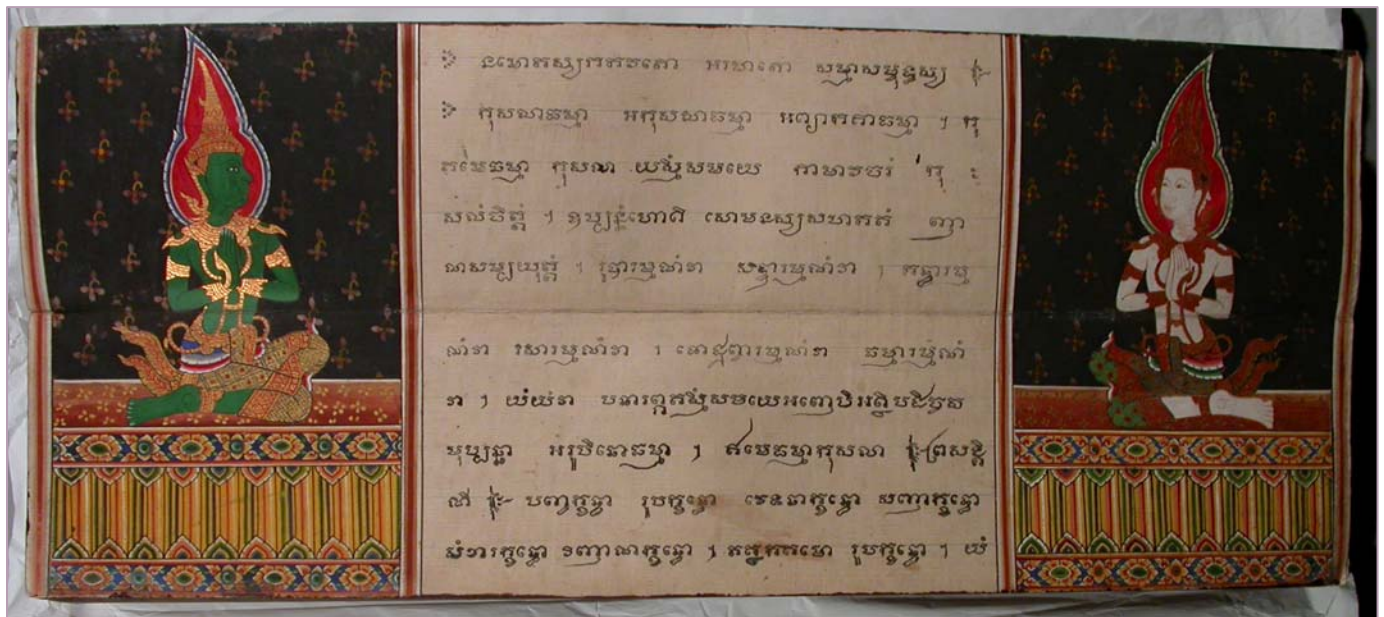


Figure 5 Illustrated Text on Cosmology, HUAM 1984.517, 20.1 x 65.0 x 9.0 cm

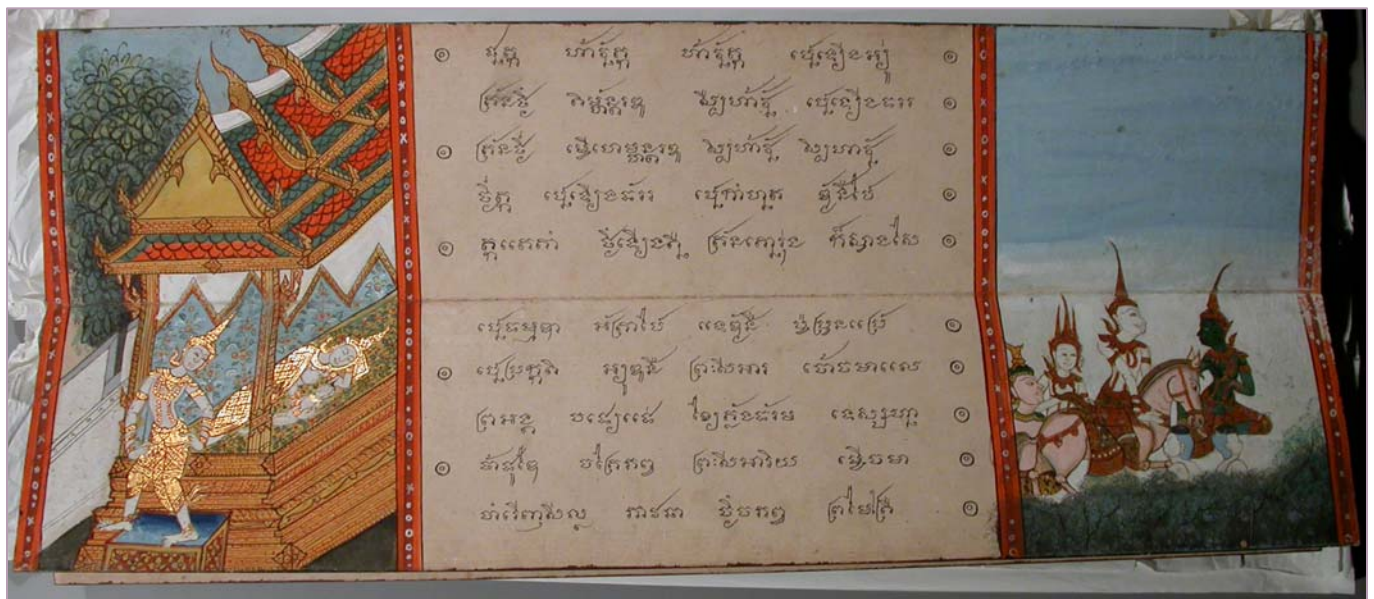


Figure 6 Illustrated Phra Malai Manuscript, HUAM 1984.524, 15.0 x 68.6 x 8.5 cm

Figure 7 Illustrated Phra Malai Manuscript, HUAM 1984.510, 14.3 x 67.0 x 9.7 cm

Between 18th and 20th centuries, Thailand lived through various changes due to internal political changes, foreign invasion, trades, and modernization. During this time, the country underwent the end of Golden age Ayutthaya period (1350-1767), the Burmese invasion (1876-1767), the re-establishment of Bangkok period (1768-1932), and the militray government (na Pombejra, 2005). The name, Siam, often refers to the period that the country was ruled by a monarch. In 1939, the country was officially named Thailand.

International trade had been an important driving force for the economy of Siam in the 18th, 19th and 20th centuries. The royal court and the elite society were active in the junk ship trade with Western countries such as Portugal, the Netherlands, England, France, and Italy. China and Siam had been trading since the ancient time. The maritime trade had existed since the 13th century (Yuan Dynasty). After the 1680s, trading between Chinese merchants and Siam intensified and gradually monopolized Siam's economy in both the long and short distance trades (Viraphol, 1977; Cushman, 1993). By the 17th and 18th century, Siam was not involved in major trade route.

From the ruins of the city of Ayutthaya, it was clear that art and architecture must have had strong financial support and patronage. In addition, trading with other countries would inevitably introduce new materials (eg. pigments) and encourage new industry (eg. ship building) in Thailand.

2. Background

2.1 Thai Manuscript

In a Buddhist society in Thailand, Thai manuscripts were used to inspire and to educate the public. Two types of Thai manuscripts survived today: palm leaves and paper accordion-style folding book (Ginsburg, 1989). The oldest surviving Thai Manuscript on paper is dated back to the 17th century. Similar to palm leaf manuscripts, Thai Manuscripts are elongated in width and narrow in height, and they are meant to be viewed one page at a time. Manuscripts on paper are usually larger than palm leaf manuscripts. They are made into accordion format; which means the papers are often joined together along the width and can stretch to several yards if they are unfolded completely. Thai manuscripts on paper, also named *Samut Khoi*, typically consisted of two components: paintings and scripts. During the Ayudhaya period (1350-1767), scholar found painted illustration occupying both pages. In the Bangkok period (1768-1932), smaller illustrations were found on either end of the manuscript with text in between (Jermsawatdi, 1979).

Lankavong Theravada Buddhism, spread from India to Thailand towards the 13th century, was the largest religious sect in Thailand to modern times. During the late 13th century, Lankavong monks used Pali language and the king Rama Kamheng adapted the Cambodian and Khmers alphabet (Jermsawatdi, 1979). The scripts recite stories from religion as well as secular events. The artists often drew inspiration from those stories. *Jataka*, also known as previous lives of Buddha, have been repeatedly used in manuscript paintings as an instructive tool for the Buddhist teaching. *Jataka* stories were initially believed to be oral stories later turned into written common folk tales. In 5th century, first *Jataka* stories in Pali were written. The English version of the stories was translated from Pali in 1906 by the Pali Text Society of London. Among the 547 *Jataka* stories, the last 10 are the most popular (Wray and Rosenfield, 1996).

Another subject of monk Phra Malai became gradually popular in the early 19th century. The stories,

originated from Sri Lanka, depicted vivid tales of heaven and hell, which were told through the central figure of the monk Phra Malai.

The Thai manuscripts from the Hofer collections included Jataka tales, tales of monk Phra Malai, and secular subjects. Jataka stories were depicted well into the 20th century. The story of monk Phra Malai appeared only in 19th and 20th century manuscripts.

2.2 Khoi Papermaking

Thai manuscripts were often made from the inner bark of khoi tree (*streblus aspera*). (see figure 9) The earliest use of khoi paper was unclear; however, according to a 1912 source, papers made from fibers of bark were already employed in Thailand in 1504. Khoi paper had been strictly used for manuscripts. It was not until 1911, blank folding book made from khoi fibers were publicized as merchandize in the International Exhibition of Industry and Labour held in Turin, Italy. Domestically, the blank folding books were sold in the Chinese quarter in Sampeng, Bangkok (Ministry of Commerce and Communication, Bangkok, 1930).

The khoi trees grew wild in northern Thailand that were harvested and ship to Bangkok for papermaking. Apart from khoi fiber paper, other materials such as cotton, rages, and paper mulberry (*Broussonetia papyrifera*) were also used for making paper.

The bark was striped off the tree, dried, and sent to Bangkok. Various qualities of bark were sorted into groups. The barks were soaked in limewater for 2 to 3 days followed by steaming which also took approximately 2 days. The processed fibers were washed extensively and sorted again from any remaining outer bark. The fibers were refined into pulp by pounding with a wooden mallet. The pulp was gathered and formed into balls ready to be made into paper (Gerini, 1912).

The khoi papers were made in a rigid mould that was usually 2 feet by 7 feet (or 2 by 0.4 meters). The mould is made from four flat pieces of wood or bamboo with a cloth (either fine or coarse) on the bottom. Traditionally, papermakers would make papers by the bank of river. The mould was submerged in water and formed a temporary open vat within which the ball of pulp could be distributed. A stirring rod was used to evenly agitate and distribute the pulp. The sheet of paper was formed when the mould was removed from the water. A smooth roller was then rolled over the surface of the wet sheet to squeeze out excess water and leave a smooth surface on the paper. The papers were dried on the mould and then removed with a wooden spatula. The finer grade papers were treated with rice starch and lime and then burnished with a stone. The finished papers have a slight sheen on the surface with striated embossed lines from the burnishing stone. To make the manuscripts, the shorter edges of the khoi papers were trimmed and joined with an overlap of about 1cm. The literature cites five full sheets of paper to make a book of manuscripts (Ministry of

Commerce and Communication, Bangkok, 1930).

2.3 Commerce

Thailand, equipped with rich natural resources, began trading with outside countries in the Ayutthaya period (1361-1767). Portuguese merchants first traded with Thailand in 1511. Nearly a hundred years later (1612), the English East India Company also became active trading partners. The Thai monarch monopolized international trade. Some of the noted exports included deerskin, ray skin, Sapen wood, tin, lead, benzoin (gum Benjamin), and stick lac (na Pombejra, 2005). In 1852 B.C.E., an employee of the British East India Company, D. E. Mulloch, compiled a detailed list of imports and exports to Thailand. The information provides a glance of what Thailand consumed and produced yearly in the mid-19th century. In his book, he categorized the lists into four parts: *Production of Siam Annually*, *British imports*, *Imports of India Goods to Siam*, and *China goods imported into Siam*. As table 1 suggested (see below), the artists could choose materials from local products and foreign imports. A few specific foreign imports include verdigris, red and yellow ochre, and white and yellow arsenic. Frederic Arthur Neal, a local resident in Siam, stated that merchants imported boxes of watercolors, cakes of finest Indian ink, gum, and glue from Canton and Macao to Bangkok in 1850s (Neal, 1850).

Table 1. Selected items from D.E. Mulloch’s record on Siam

Siam local resources	Dragon’s blood, gamboges, gold dust (for local temple), indigo (local use only), lead white and black
Siam’s import from India	Arsenic (white and yellow), red and yellow ochre, turpentine, gum tragacanth (or gum dragon from Turkey), gum Arabic, and verdigris.
Siam’s import from China	Gold leave (large quantity for temples), glue, varnish, paint (red, blue, black, white, and green)
British Imports	Paints (green, blue, black, and red)

At the end of Ayutthaya kingdom (1767), China became Thailand’s biggest trade partner and gradually became a major market place for countries in South East Asian and Europe.

2.4 Artists

Traditional Thai painters were Buddhist monks who produced murals and manuscripts as an act of devotion and instructive tools to communicate Buddhist ideology to the public. Devoted layman were trained by the monks and worked within temples and local communities. The provincial cities often had more influence

over artists' community than the central government (McGill, 2005).

In 1967 Acharn Lert, allegedly the last artist who was trained in the traditional painting style, was interviewed by Helen Duncan. He stated that one of the unique components in Thai manuscripts was their textual appearance, which relied solely on the brushes used. In the interview, Acharn Lert revealed the technique of making paintbrushes. The paintbrushes are unique because they are made from the bark of *khra-dung-nga tree* or root of *lum jiak* trees. The bark is straightened by soaking in water for several days and nailing to wooden boards to dry. To make the bristles, the end of the bark is soaked in water and splits into fine fibers. The larger brushes are made for painting murals, the smaller ones are used for manuscripts. For painting finer details, the artist would make brushes from animal hair, preferably using hair from the inner ear of cattle.

2.5 Previous Analytical Research on Thai Manuscripts and Murals

There has only been one scientific analysis conducted on the subject of Thai manuscripts on paper, by Burgio, Clark, and Gibbs in 1999. They used Raman microscopy to study four Thai manuscripts from the British Library Oriental Department. Three additional scientific analyses of Thai mural were found and thought to be helpful to this study. In 1990, Chompunut Prasartset analyzed an early Ayutthaya period mural using chemical tests, SEM/EDX, XRD, and TLC, HPLC, and mass spectroscopy. Prasartset identified mineral pigments and organic blue and yellow. In addition, most of the pigments were mixed with gypsum, kaolinite, and lead white (hydrocerussite). In 1996, Prasartset compared analytical results from 14th, 15th, early and late 19th century murals. He believed that Prussian blue was used due to the Western influence. Later in the 19th century mural, ultramarine was found consistently in mixture with barium sulphate. An abstract of a study by Ryuitiro Suigisita in 1983 suggested the artists used lead white, calcium carbonate, silica (SiO₂), vermilion, and green verditer.

Although the later three studies were of paints on murals, a connection can be made based on art historians' claims of the parallel relationship between the murals, sculptures, banners, and manuscripts in the history of Thai art. Among the four referred studies, the result suggested the paints applied were usually not homogeneous in composition. Various transparent whites such as gypsum, kaolin, or calcite were mixed into all of the colors. It is possible that the artists for the murals and manuscripts shared similar techniques in paint preparation.

Table 2. Previous researches and their results

	C. Prasartset, (1996)	C. Prasartset, (1990)	Burgio, Clark, and Gibbs, (1999)	R. Sugisita, (1983)
Analytical Techniques	SEM-EDX, XRD, CHN analyzer, and microchemical tests	SEM-EDX, XRD, mass spectrometry, TLC, HPLC, and microchemical tests	Raman Microscopy	XRF, XRD, and IR Spectroscopic methods
Binder for paint	“plant products”	“tempera”	Animal glue	
White	Clay and gypsum and calcite-14 th to mid-17 th centuries Hydrocerussite- 18 th century Barium sulphat-late 19 th century	Hydrocerussite	Chalk and white lead- 1800s and 1880 Anhydrite, barite, gypsum, and white lead- 1900s	Lead white, calcium carbonate, and SiO ₂
Black	Carbon black	Carbon black	Carbon	
Blue	Azurite- 17 th century Indigo and cumengeite-18 th century Prussian blue- early 19 th century Ultramarine blue- late 19 th century	Indigo	Indigo-1800s Ultramarine blue- 1880 and 1900	
Green	Malachite- 17 th and 18 th centuries Emerald green- late 19 th century	Malachite	Not identified	Green verditer
Red	Cinnabar and minium –red lead and red ochre and hematite	Cinnabar, minium, hematite	Red lead and red ochre and vermilion- 1780 Litharge and red lead and vermilion-1800 Red lead and vermilion- 1880 Red lead-1900	Vermilion
Yellow	Gamboge- 14-early 19 th century. Lead pigment mixture showed in late 19 th century	Gamboge (found under gold leaf)	Orpiment and massicot-1800 Chrome yellow and chrome orange and orpiment- 1900	
Others	Cross-section included	Analysis based on an 18 th century mural. Gypsum was found in the majority of the results.	The study was based on four manuscripts from 1800, 1880, 1900, and 1780.	

3. Analytical Techniques

A total of 8 techniques were selected for this study. In prioritizing among the techniques, the preliminary study involved non-destructive methods such as visual examination, x-ray fluorescence, and ultraviolet and infrared light examination. The other techniques required very small samples. The locations of the samples were clearly noted on the black and white photographs and approved by Curator of Asian Art, Robert D. Mowry, before proceeding.

3.1 Visual examination

The manuscripts were examined under low power binocular microscopes for studying the paper support and the paints. Raking light was used to show the paper treatment and exaggerating the appearance of three-dimensional qualities of the paints; even lighting from both sides were used most frequently for preliminary investigation of under drawings and layers structures.

3.2 Polarized light microscopy (PLM)

Polarized light microscopy can be used to identify pigments using available pigment references base on their physical appearance, and optical properties. The samples were placed on the microscope slide under the cover slide. The end of the pencil eraser was used to compress and to disperse the sample. Cargill Melt Mount with refractive index of 1.69 was used to mount the sample. PLM was conducted by Narayan Khandekar (Senior Conservation Scientist).

The Polarized light microscope was also used for fiber microscopy to examine the seldom studied Khoi papermaking fibers. To prepare the sample, the paper support was dampened with a brush; a few strains of paper fibers were tweezed out and placed on a glass slide with a cover slide on top. The glass slides were studied in transmitted light using polarized light microscope. This technique reveals fiber morphology and characteristic, existing filler, and sizing.

3.3 & 3.4 Ultraviolet light examination and Infrared light examination

The paintings and paper support were examined under ultraviolet and infrared light using Foster & Freeman Video Spectral Comparator (VSC) 5000. Infrared light (1100 nm) was helpful in revealing any carbon-based underdrawing. Long wave ultraviolet light (365 nm) was used to observed any fluorescence that could be identified in either a coating or specific paint.

3.5 Energy dispersive x-ray fluorescence (XRF)

XRF was used to detect any element in the paint and no sample was required for this technique. The manuscripts were analyzed with an ARTAX micro XRF spectrometer with molybdenum tube. Through out the analysis, the points of interests were consistently analyzed at 50 Kv and 600 μ Amperes for 150 seconds acquisition time. The acquired information was processed by Roentec software and compared with references. The XRF analysis was carried out by Kathy Eremin (Conservation Scientist) and Narayan Khandekar (Senior Conservation Scientist).

3.6 Fourier transformed infrared spectrometry (FTIR)

FTIR was used to analyze organic lakes, binder, and inorganic pigments. Very small samples were taken under binocular microscope with a scalpel. The sample was placed on top and center of a diamond cell, 2mm x 2mm, and rolled flat. The sample was placed on the stage of Spectra-tech IR-plan infrared microscope. Nicolet 510 Infrared Spectrometer analyzed the samples from 4000 to 500 wavenumbers in an absorbance mode. The spectra were compared with references library in the Straus Center for Conservation.

3.7 Scanning electron microscope coupled with energy dispersive x-ray spectroscopy (SEM-EDS)

SEM was conducted in the Museum of Fine Arts, Boston, operated by Richard Newman, Senior Conservation Scientist. This technique would provide information on layer structure base on the elements identified in each point of interest under high magnification. The sample was analyzed in low vacuum with Inca X-sight Oxford Instrument, Jeol JSM-6460 LV Scanning Electron Microscope.

3.8 Raman Spectroscopy

Raman spectroscopy is a potentially non-destructive technique that can provide molecular information of the samples. The analysis was carried out by Kathy Eremin (Conservation Scientist) and Jens Stenger (Andrew W. Mellon Fellow in Conservation Science) in two places: Massachusetts Institute of Technology (MIT) and the Museum of Fine Arts, Boston. The samples on microscope slides were analyzed at MIT using Keiser Optical Systems Hololab 5000R Modular Research Raman Spectrometer; the microprobe used was 785 nm. The samples analyzed at Museum of Fine Arts, Boston, using Bruker-Senterra Spectrometer with laser source of 532 nm and Olympus objective (100x). Each sample was ran for 20 or 40 second in 5 mV. The data was collected between 100 to 2700 nm by Infinity 1 camera and analyzed by OPUS software.

4. Results and Discussion

4.1 Artist's techniques

In the 18th century manuscripts, the artists appeared to use red or brown outline (Fig. 8). Olive green and graphite under-drawing was found in the 19th and 20th century manuscripts (Fig. 9). The XRF analysis of the green underdrawing showed both copper and iron peaks. This was consistent with FTIR, which suggested a mixture of gamboge and Prussian blue. The artist appeared to work freehand following no specific order of how and when the color should be applied. The brush stroke produced by brushes made from tree roots or barks were distinctive and easy to identify. If gold was used in the design, a leaf was usually laid to block out an area, and finer details were later placed on top.

4.2 Paper support

Under raking light, the paper shows linear striated indent from burnishing (Fig. 10). The paper supports also bear criss- cross mark from the cloth. Although very little was known about khoi fibers, fiber microscopy of seven manuscripts suggested the use of the same type of fiber, likely to be khoi. A known khoi fiber sample given by Eliane Koretsky was used to make comparison. All of the samples have very close physical appearances (Fig. 11). Under the microscope, Khoi fibers appear long, even in width. In some section, the fibers are slightly narrow. The cuticles can be easily detected especially in the larger fibers. All of the samples have a coating of starch sizing confirmed by the potassium iodide test; some of the granules in the starch were still apparent. The modern khoi fiber sample showed larger particles and uniformly shaped filler; in comparison, the fillers in the manuscripts were irregular in shape and size.



Figure 8. Detail of 1984.511. Red underdrawing



Figure 9. Detail of 1984.517. (Left) Graphite underdrawing (Right) Green underdrawing

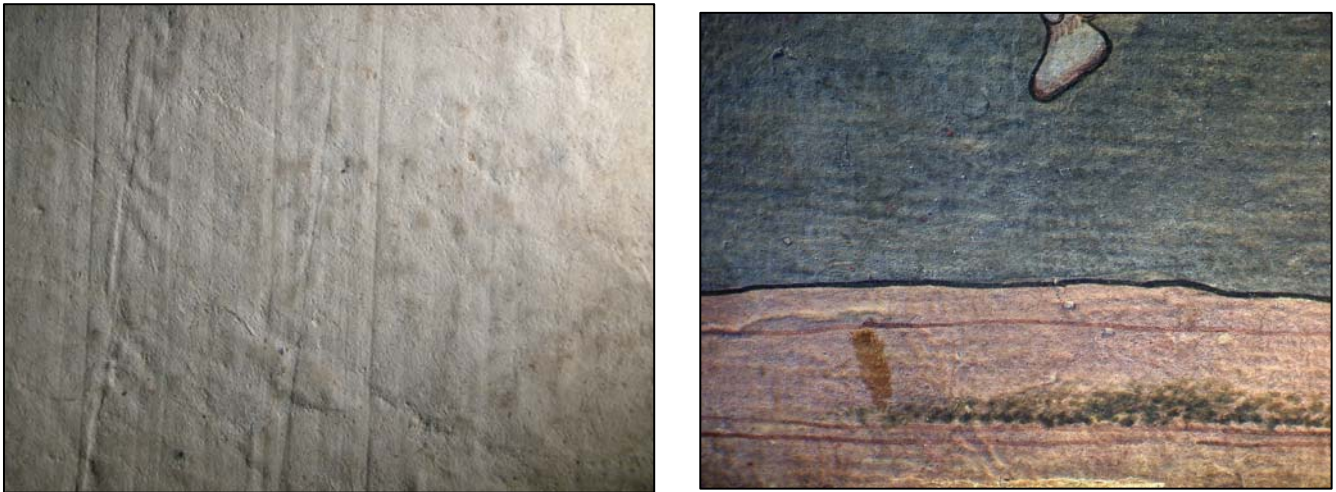
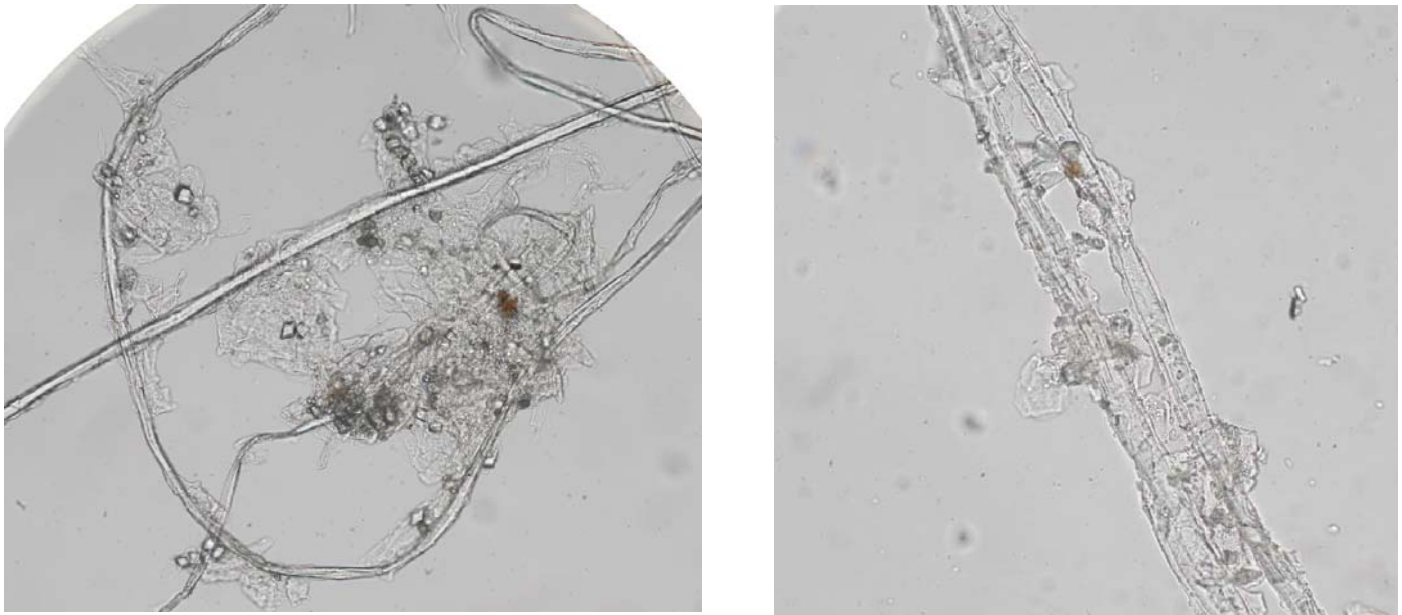


Figure 10. Detail of 1984.511. (Left) brunish mark, (Right) embossed from the woven screen



**Figure 11. (Left) modern khoi paper fibers with larger mineral filler
(Right) sample from 1984.508. Small fillers and starch paste sizing**

4.3 Paints (see table 3-6)

a. White- XRF analysis of all seven manuscripts suggested the presence of lead with other trace elements such as calcium. The presence of the lead white was confirmed in 1984.511 by FTIR and Raman and in mixtures with other colors in 1984.508, 1984.510 and 1984.517. From previous Thai mural and manuscripts studies, all of the paints including white were often found in mixtures with calcite, gypsum, or kaolin. The trace of calcium in these seven manuscripts may indicate the presence of calcite or gypsum in

addition to lead white.

The white sample from 1984.512 (dated 18th century), was found to be huntite by FTIR and Raman. Huntite, $Mg_3Ca(CO_3)_4$, was also found to be present in other colors in 1984.512. Barite was only found in 1984.524, dated to the 19th century.

b. Yellow- FTIR and Raman identified gamboge in the yellow areas in 6 of 7 manuscripts. The 20th century manuscripts, 1984.517, had no yellow paint to be analyzed but gamboge was found mixed with Prussian blue in the green underdrawing. The analytical results were consistent with D.E. Mulloch's record, which clearly stated that gamboge was used within the country. The Raman and FTIR also showed that the gamboge was mixed with a white or clear material, as found in previous studies, in most cases. This varied between manuscript: huntite (in .512), kaolin (in .501 and .511), lead white (in .508, .510) and gypsum (.524). Raman spectroscopy indicated chrome yellow in one sample from .524, indicating both chrome yellow and gamboge were used in this manuscript.

c. Red- Vermilion and red lead were often found in separate areas of the same painting. This finding is consistent with previous studies. Traces of iron in the XRF may suggest the presence of red iron oxide (hematite) mixed with the red lead or vermilion. In a 19th century manuscript, 1984.517, Raman spectroscopy showed that vermilion was mixed with ultramarine to make purple or dark blue. Vermilion was found mixed with gamboge in both 1984.511 and 1984.512 from the 18th century; this mixture was not present in the later manuscripts. Red lead was found with gamboge in 1984.501, also dated to the 18th century.

d. Black- Only two black samples were analyzed using FTIR and Raman Spectroscopy, from 1984.510 (dated to the 20th century) and 1984.524 (dated to the 19th century). Both techniques gave little clue to the composition of the black paint. Using PLM, the sample from 1984.510, the 20th century manuscript, contained red lead, colorless minerals, and carbon black. In 1984.524, the 19th century manuscript, the black paint consisted of ultramarine, lead white, colorless minerals, and un-identified yellow and green particles.

e. Green- Using XRF, copper was found in 6 of the 7 manuscripts, with the exception of 1984.524 (originally dated to the 19th century). The 1984.511, 1984.512, and 1984.501 manuscripts remained undetermined using XRF. PLM suggested the green sample from 1984.512 is consisted of yellow mass dye, red particles ($n > 1.66$) and small green particles ($n > 1.66$).

XRF indicated copper and arsenic in 1984.508 and 1984.517, suggesting the presence of emerald green. FTIR and Raman showed that emerald green was present in the light green sample from 1984.517. However no emerald green was found in 1984.508. FTIR and Raman indicated a mixture of Prussian blue and gamboges in both 1984.508 and 1984.517 in the samples from the dark green and green underdrawing. Manuscript 1984.517 hence contains two different types of green. It is possible that two different types of green are also present in 1984.508 and more analysis is required.

Emerald green dates from 1822 but was probably not imported into China until after 1855. If emerald green is present in 1984.508, it is likely that the manuscript post-dates 1855, hence dates from the later 19th century rather than the 18th century, which is suggested by the museum record (Wise, 1997).

The XRF indicated chromium in the green areas of 1984.524. However, FTIR showed only gypsum and glue binder. The PLM indicated blue particles in the green sample. The chromium present in the XRF spectra may be due to a green chrome pigment such as viridian or to a yellow chrome pigment, such as chrome yellow. Further work is required to determine the pigments present in this green. Viridian would suggest that 1984.524 was made specifically in the late 19th century as it became commercially available in 1849. The cost of viridian was high compared to other available green pigments.

f. Blue- A number of blue pigments were found in these 7 manuscripts. Raman spectroscopy suggested indigo in 1984.511 and 1984.512, FTIR spectra from these two manuscripts did not match the reference spectra of indigo. The FTIR spectra obtain from the blue of 1984.511 and 1984.501 were identical.

Ultramarine and Prussian blue were found in the later manuscripts, similar to the results obtained by Burgio, Clark, and Gibbs's study (1996). Prussian blue occurs in blue and green in 1984.510 and in the green only in 1984.517 and 1984.508. Ultramarine was used for blue in 1984.508, 1984.517 and 1984.524.

Table 3. 1984.511, *Illustrated Jataka Tales*, 18th century

XRF		XRF	
Red flower	Pb, Hg, Fe, Ca	Green shirt	Cu (L), Pb
Orange rim	Pb, Fe, Ca	Green leaf	Pb, Ca
Blue-gray	Pb, Hg, Fe, Ca	Red petal	Hg, Pb, Ca
Gold hat in red flam	Au, Fe, Ca, Pb	Blue face	Ca (L)
Red flam	Au, Hg, Pb, Fe, Ca	Gold hat	Au, Ca, Hg, Pb, Cu(vs)
Blue	No spectra	Red hat	Hg, Fe(s)
Pale pink area	Pb, Fe, Ca	White horse neck	Pb
White ribbon	Pb	Grey background	Ca (L), Fe, Pb (vs)
Black	No spectra	White face	Ca(L), Pb (vs)
Yellow	Ca, no spectra	Orange flower	Pb
Yellow orange	Same as the previous one	Red flower	Hg, Pb, Ca, Fe
Pink face	Hg, Pb	Purple background	Ca, Fe, Hg (vs)
Green curtain	Cu, Ca, Fe	Green leaf	Same as purple background.
White face	Ca, Fe, Pb (vs)	Black leaves	Ca (L), Pb (m), Fe(s)
Paper	Ca, Pb (vs)	Yellow spots	Ca (L), Fe(s)

Table 4. FTIR and Raman Spectroscopy on Thai manuscript, 1984.511:

Color	Raman	FTIR
Yellow	vermilion, gamboges	Gamboges, Kaolin
Blue-gray		Kaolin
Blue	indigo, calcite	Calcite
White (pink on rear)	calcite	Calcite
Green		No ID
Purple		Kaolin
White	lead white	Lead white, kaolin
Red	red lead, calcite	No ID
Red	vermilion	Gamboge
Yellow	gamboges	Gamboge, kaolin
Black with red		Bistre?
Green		No ID
Flesh	red lead	Lead white, kaolin
Yellow		No ID
Blue spatter*	ultramarine	
Blue-gray	calcite	calcite
Purple		
Red	red lead, lead white	

* The blue spatter is not original to the manuscript

Table 5. XRF results for 6 other Thai manuscripts: s- small peak; vs-very small peak

	18 th cen.	18 th -19 th cen.	20 th Cen.	19 th cen.*	19 th cen.	Late 19 th cen.*
	1984.512	1984.501	1984.510	1984.508	1984.517	1984.524
White	Hg, Pb, Ca, and Fe & Cu (s)	Pb	Pb, Ca (vs)	Pb, Ca	Pb	Pb, Ca, Fe
Black			Pb, Cu, Fe, Ca			Pb, Ba/Ti?, Ca, Fe, Mo. Cr, Sr(vs)
Yellow	Hg, Cu, Pb, Ca	Ca, Sr, Pb, Cu, Fe	Pb, Fe, Ca (vs)	Pb	Pb, Hg, As (vs)	Ca, Fe, Pb(vs), Ba/Ti?
Red	Hg, Pb	Hg, Pb, Cu, Ca, Fe	-Pb -Pb, Hg, Fe, Cu	Hg, Fe (s)	Hg	-Pb, Hg, Fe, Ba, Ca, Cr (vs) -Pb, Ca, Fe, Hg, Ba, Mn, Zn
Green	Cu, Hg &Ca &Pb (s)	-Cu, Ca, Fe, Pb, Hg -Cu, Pb, Fe, Ca, Hg -Cu, Pb, Ca, Fe	-Pb, Fe, Ca, As, Cu(vs) -Pb, Cu, Fe, Ca	-Cu, As, Pb (vs) -Cu, As, Pb, Fe(s), Ca (vs)	-Pb, Cu, Hg & As (vs) -Cu, As, Pb	-Pb, Ba/Ti?, Ca, Cr, Fe -Pb, Ba/Ti?, Ca, Fe
Light green					Pb, Cu, As	
Dark green					Underdrawing-Pb, Fe, Ca, Hg (vs)	Pb, Ca, Fe, Zn, Cr
Blue		Ca, Pb, Fe, Cu, K	-Pb, Fe, Ca -Fe, Pb, Ca	-Pb, Fe, Ca,(vs) -Pb	Pb, Ca, Fe, Cu (vs)	Pb, Ca, Ba, Cr, Fe
Light blue						Pb, Ca, Fe, Ba/Ti?(vs)
Brown				Pb, Fe, Ca (vs)	Pb, Hg	Pb, Fe, Ba/Ti?, Zn
Purple		Fe, Pb, Ca, Cu, Hg			Hg, Pb	Pb, Fe, Ca, Ba/Ti?, Zn, Cr
Orange				Pb, Fe(vs)	Pb, Hg, Ca	Pb, Ca, Cr, Ba/Ti?, Fe
Gray	Pb, Hg, Cu, Ca, Fe(vs)				Pb, Cu, Hg &As (vs)	
Pink	Hg, Pb, Ca, Fe, Cu (vs)		Pb, Ca	Pb, Fe, Ca (vs)		
Gold	Au, Hg, Cu, Pb, Ca, Fe	Au, Ca, Hg, Pb, Fe, Cu	Pb, Au, Fe, Ca	Pb, Au, Hg	Au, Hg (s), Pb, Ca, Fe	Pb, Au, Fe, Ca

*The dates are different from the museum records

Table 6 FTIR and Raman Spectroscopy of 6 other Thai manuscripts:

	1984.512 (18 th cen.)		1984.501 (18 th -19 th cen.)		1984.510 (20 th Cen.)		1984.508 (19 th cen.*)		1984.517 (19 th cen.)		1984.524 (Late 19 th cen.*)	
	FTIR	Raman	FTIR	Raman	FTIR	Raman	FITR	Raman	FITR	Raman	FITR	Raman
White	huntite	vermilion										
Yellow	huntite, gamboge	vermilion, gamboge	kaolin, gamboges	red lead	gamboge, lead white		lead white, gamboge	-lead white, gamboges			-gamboges, gypsum, animal glue -animal glue, barite	-Chrome yellow -gamboge
Blue			kaolin	indigo	Prussian blue		ultramarine , lead white		ultramarine, lead white	ultramarine , lead white, gypsum	ultramarine , ground gypsum	
Dark blue			kaolin, gamboge				ultramarine , lead white		ultramarine, gypsum	ultramarine , vermilion		
Green	huntite				Prussian blue, gamboges, lead white				Underdrawin g- gamboges with Prussian blue		gypsum, glue	
Light green									emerald green	emerald green		
Dark green					Prussian blue, gamboges		Prussian blue, gamboges, white lead		lead white, gamboges, Prussian blue		ultramarine , gypsum	
Black					glue						gypsum ultramarine	
Purple									gypsum, lead white, ultramarine	vermilion, ultramarine , lead white		
Gray	huntite, ochre	indigo										
Orange	vermilion											

*The dates are different from the museum records

6. Conclusion

The materials used in Thai manuscripts varied quite widely, perhaps determined by geography, artists' communities, and availability to new products. Among the seven manuscripts, a rough trend can be observed. Indigo was probably used in the 18th century, whilst ultramarine and Prussian blue were used in the 19th and 20th century manuscripts. The green color from the 18th century manuscripts has not yet been identified, while two different types of greens were used in the 19th and 20th century manuscripts, Emerald green and a mixture of Prussian blue and gamboge. The presence of emerald green in 1984.517 and probably in 1984.508 and of chromium pigments in 1984.524 suggests that these date to the late 19th century.

This study found some similarity with the previous studies; all the paints were inhomogeneous in composition, with various colorless minerals such as chalk, gypsum, kaolin, and barite added to the pigment. This technique appears to carry over to Thai mural painting as well. The consistent presence of lead white and gamboge may be an indication that the artists used locally abundant resources. However, with maritime trade with European and later Chinese merchants, the artists had more choices available, which may explain why earlier (local?) blue and green pigments were suddenly replaced by imported varieties in the 19th and 20th centuries.

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