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Supplementary issue paper

A technical analysis of paint media used in twentieth-century Vietnamese lacquer paintings

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Asiarta Foundation and the Getty Conservation Institute have collaborated in research to study Vietnamese lacquer paintings. The primary aim of the project is to gain a deeper understanding of the materials and techniques used in these unique lacquer paintings through technical analysis of various lacquer samples from paintings and from different sources in Vietnam complemented by in-depth interviews with Vietnamese lacquer artists. The origins and development of Vietnamese lacquer painting are outlined, followed by a description of the typical production processes involved in the manufacture of lacquer paintings. The analytical methods used for the analysis of lacquer samples as well as an outline of the methodology employed are briefly described. The results of the analyses are summarized and discussed. Samples were found to contain ingredients obtained from tree species indigenous to Vietnam and Cambodia, and interestingly some samples contained a combination of the less expensive cashew nut shell liquid lacquer, drying oils, tree resins, and drying additives. In addition, analysis indicated that some samples contained non-Asian lacquer-based ingredients.

Keywords: Lacquer, Vietnam, *Anacardiaceae*, *Toxicodendron succedaneum*, Laccol, Thitsiol, THM-Py-GC–MS, *Pinus latteri*

Introduction

Lacquer has a centuries-long history of use throughout Asia in the production of decorative panels, sculpture, temple decoration, objects of daily use and furniture. Although there are regional differences, lacquer has been employed in the decorative arts across the whole of Asia. Uniquely in Vietnam, artists adopted lacquer as a paint medium in the 1920s, as an alternative to traditional western oil painting.

Asiarta Foundation and the Getty Conservation Institute (GCI) have collaborated in research to study Vietnamese lacquer paintings with the aim of gaining a deeper understanding of the materials and techniques used in these works of art through comprehensive scientific research and artist interviews. One important aspect of the project was the development of a reference collection of artists' materials. This is a vital resource for accurate identification of material differences in samples from paintings, given the many variations of lacquer production and origin throughout Vietnam over the past century.

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Although much research on the identification of Asian lacquer has been undertaken (Derrick *et al.*, 1988; Kumanotani, 1995; Niimura & Miyakoshi, 2003; Heginbotham & Schilling, 2011; Rivers *et al.*, 2011; Wei *et al.*, 2011; Le Hô *et al.*, 2012), the use of Vietnamese lacquer as a painting medium has not been studied. Developing an understanding of the composition of Vietnamese lacquer paints will aid in undertaking investigations into stability and aging behavior, which will ultimately aid in formulating conservation treatment approaches for lacquer paintings.

Development of lacquer as painting medium

The use of lacquer for the creation of fine art paintings is unique to Vietnam, and was developed as a painting technique during the early twentieth century. Joseph Inguimberty, a French professor and head of the painting department at the École des Beaux-Arts de l'Indochine (EBAI)[1] in Hanoi, realized the potential

[1]The École des Beaux-Arts de l'Indochine (EBAI) was founded in Hanoi in October 1925. It was modeled on the École des Beaux-Arts in Paris and its first director was French artist Victor Tardieu, who remained in charge until his death in 1937. French artist Joseph Inguimberty arrived in Hanoi in 1925, having been hired by Tardieu to head the painting department of EBAI. He remained in charge of the painting department until 1945 when the college closed due to the overthrow of the French administrative government.

of lacquer, which had been previously used only in the decorative arts, as a paint medium. Anecdotal evidence suggests that he became interested in lacquer after seeing it used in temple decorations, admiring its longevity (Quang, 2005). According to Quang, Inguimberty and the artist Nam Son had been walking around the Temple of Literature in Hanoi when Inguimberty noticed the beautifully gilded and lacquered objects and architectural elements. These had lasted exceptionally well and had maintained their lustrous appearance despite the passage of time.

Inguimberty suggested to Victor Tardieu, the director of the EBAI, that they offer a course on traditional Vietnamese lacquer to students, and from the late 1920s Inguimberty urged his students to experiment with lacquer as a painting material as an alternative to the traditional western technique of oil painting. Subsequent generations of artists have used lacquer in the development of a uniquely Vietnamese esthetic. Tô Ngoc Vân was one of the earliest graduates of EBAI and continued to play a very important role in the Vietnamese art scene, returning to teach at the college after graduation. In 1948, he discussed lacquer painting at the Second National Cultural Conference in Hanoi, which was a meeting of artists, intellectuals and politicians (Scott, 2010). As Scott (2010) explains, Tô Ngoc Vân was of the opinion that western oil painting had reached a dead end globally, but that the characteristics of lacquer could act as a new source of inspiration for artists in Vietnam and further afield. Material properties associated with lacquer, such as its luminosity, complexity, and depth of color, could help to reinvigorate a stagnant global art scene.

Joseph Inguimberty, whom his students called 'Mr. I', is credited by the first generation of students of the EBAI as the person behind initial artistic experiments with lacquer as a painting medium. In Nguyễn Gia Trí's words, 'If there were no Mr. I and assistant Thành, [Đinh Văn Thành, craftsman and lacquerer] there would be no lacquered paintings produced by myself' (Nguyễn, 2009: 240). According to the painter Quang Phòng:

> In the development of lacquer painting, Mr. Joseph Inguimberty has quite a great deal of merit. He has made […] researches on 'the lacquer of Annam[2]' and was as well experienced as Mr. Phó Thành […], the man he's so close with throughout his 20 years of teaching in Hanoi. Being a […] teacher of oil painting, he had neglected his mission, as he was so infatuated with lacquer and continually watched for the students' lacquer works to guide them (Nguyễn, 2009: 241).

One of the artists who took up this new painting medium was Nguyễn Gia Trí, considered the greatest exponent of Vietnamese lacquer painting. During the early part of his career, his lacquer paintings accorded with the romantic colonial style and ideals, but he soon began experimenting successfully with abstraction. Specifically, Nguyễn Gia Trí credits his success in abstract painting to the material properties of lacquer; as Thái Bá Vân, one of Vietnam's most learned art critics, expressed this: 'with this kind of material he could free himself from imitation and dependence on objects' (Thái, 1993: 7). In a letter to his professor and friend Inguimberty, dated 27 December 1969, Nguyễn Gia Trí wrote:

> Instead of forcing lacquer into the rigid framework of my own personal ideas, I allow the lacquer to reveal itself in the best possible light. All I do is to give it a theme I think it might like to interpret … Instead of being an image of the real world, lacquer becomes a thing in itself with its own life and its own language which the artist is assumed to understand (Pentcheff, 2012: 66).

Context and production process of lacquer paintings

Traditionally, the three main types of lacquer used in the decorative and fine arts in Asia come from the exudates of trees in the *Anacardiaceae* (cashew or sumac) family. *Urushi* lacquer, prevalent in Japan and China, is obtained from the species *Toxicodendron vernicifluum*, *thitsi* lacquer in Burma, Thailand and Cambodia comes from *Melanorrhoea usitata*, while Vietnamese and Taiwanese lacquers come from *Toxicodendron succedaneum*. More recently, cashew nut shell liquid (CNSL) from *Anacardium occidentale* has been introduced as a less expensive material suitable for lacquers (Niimura & Miyakoshi, 2003). The main lacquer-producing region in Vietnam is Phú Thọ province in the north of the country. Raw lacquer used in the south of Vietnam often originated from Cambodia and would have been obtained from *Melanorrhoea usitata*.

Sap from lacquer-producing *Anacardiaceae* trees is a complex, water-in-oil emulsion of catechols, phenols, carbohydrates, glycoproteins, and laccase enzyme. The sap is harvested by making incisions through the bark of mature trees and into the sapwood, where the resin canals lie (Baer, 1977; Niimura & Miyakoshi, 2003). The color of the milky white sap changes to brown upon exposure to air. After harvesting, the sap is stored in containers to permit settling of debris and the resulting layers are graded according to quality and intended use (Nguyễn, 1995). Raw

[2]Annam was the name given to the French protectorate of central Vietnam. French Indochina was established in 1887 and initially consisted of the Vietnamese regions of Tonkin in the north, Annam in the central region, and Cochinchina in the south of Vietnam, as well as Cambodia. Laos subsequently also became a part of French Indochina.

lacquer, which is produced by heating and stirring the sap to reduce its water content, forms an oily liquid that is suitable for use. Unlike western lacquers or resin varnishes, which dry by solvent evaporation, Asian lacquers harden into intractable films through a two-step polymerization process. The first step is initiated by the laccase enzyme naturally present in the sap in the presence of high humidity, which is followed by a period of air-drying to achieve complete curing (Kumanotani, 1995). The exceptional durability and solvent resistance of lacquer are attributable to the extensively cross-linked polymer matrix. Lacquer suffers, however, from sensitivity to light exposure, which damages the surface and greatly increases its water solubility.

Lacquer is modified for use as painting medium by the addition of various substances. Drying oils are generally added to lacquer during manufacture to increase the gloss of the dry film, so that less final polishing is necessary to obtain the lustrous surface associated with lacquer. The predominant oils described in the literature on lacquer formulations are linseed (*Linum usitatissimum*), tung (*Vernicia fordii*), and perilla (*Perilla frutescens*), although oils such as sesame (*Sesamum indicum*) and rapeseed (*Brassica* spp.) are also mentioned (Webb, 2000).

Artists in Vietnam add drying oils and pine resin to modify the working properties and resulting film characteristics of the painted lacquer, and colored lacquers result from the addition of pigments and dyes. Black lacquer is obtained by stirring the lacquer with an iron rod, which causes chemical changes in the lacquer (Kumanotani, 1995). The raw and processed lacquer is sold to artists in small shops that also supply brushes, tools, and gold or silver leaf. Driers or curing agents are occasionally added to the paints in order to reduce the drying time of the lacquer film, although artists do not generally admit that they are used.

Initially, the traditional color palette consisted of blacks, browns, and reds. The blacks and browns are obtained through the use of lacquer processed to different degrees, while vermilion is traditionally used as a red pigment. Eggshell inlays are used to obtain a white color and to add patterns. Gold and silver leaf and powder are often incorporated into the painted lacquer. A green pigment that was compatible with lacquer was reportedly discovered in 1948 by artists Tô Ngoc Vân and Nguyễn Tu Nghiêm while experimenting with lacquer painting in Phú Thọ province (Quang, 2005).

In general, lacquer artists employ numerous assistants for lacquer painting, since it is such a labor-intensive process. The production of lacquer and lacquer painting replicates the traditional organization of artists' workshops as practiced in Europe during the Renaissance (Cole, 1983: 13), and lacquer painting is a lengthy and costly process.

The wooden supports for lacquer paintings are usually ordered from a family workshop that specializes solely in their preparation, although some artists still make their own. The process of support production involves many stages and takes about one month. A plywood substrate is coated in a layer of raw lacquer and covered with muslin. The panel is then given a thick coating of raw lacquer mixed with clay and sawdust, which is allowed to dry in the sun. Subsequent layers of lacquer are applied over this initial coat. Each layer is dried and smoothed with sandpaper until up to around 30 layers have been applied in this manner. The final layers are cured in a humidity chamber, after which they are carefully smoothed and polished by hand.

Two different methods of lacquer painting have developed in Vietnam. Carved lacquer paintings — sometimes called 'coromandel lacquer' — are known as *sơn khắc* in Vietnamese (literal translation 'color engraving') and usually consist of a black lacquer surface with the composition carved or engraved before subsequently being painted in.

The other, more common technique is called *sơn mài* in Vietnamese (which can be translated as 'rubbed/polished color') and involves the application of numerous colored layers of lacquer. Up to 100 different layers may be applied, which are subsequently sanded to reveal the composition beneath; this complex layering gives these lacquer paintings incredible depth. The depth and richness of color and design that is achievable with lacquer produced in this manner is unsurpassed by any other painting medium.

Commercial lacquer samples

Owing to the unique nature of Vietnamese painted lacquer, one of the first aims of the project was to analyze commercial lacquer products so as better to understand the materials and techniques used. Tubes of liquid lacquer were obtained from artists and suppliers, and samples from each were cured on glass slides prior to analysis.

Interviews with artists revealed interesting information about their choices of materials. Nguyễn Lâm, a lacquer artist working in Hồ Chí Minh City (HCMC), provided different samples of lacquer and a drying additive. He uses mainly Cambodian lacquer, which he obtains from the Foreign Trade Department in HCMC. Nguyễn Lâm's Vietnamese lacquer from Phú Thọ province was purchased from the main lacquer supplier in Hanoi (a shop called Toàn Lộc, located at 48 Hàng Hòm, Hanoi). He also provided mixtures of Cambodian and Vietnamese lacquer.

Several samples of raw and processed lacquer were obtained from Toàn Lộc. This lacquer, which originates from Phú Thọ province, is said to contain pine resin as an additive. Processed lacquer is known colloquially as 'cockroach wing' lacquer (*sơn cánh gián*) due to its translucent brown appearance. The same supplier also sells a different type of lacquer known as *sơn điều*, or cashew lacquer, from southern Vietnam.

Lacquer paintings in this study

To allow direct comparison with the test results from commercial lacquers, eight lacquer paintings were chosen for sampling and analysis during the second stage of the research project. These paintings, which belong to the Witness Collection of Vietnamese art, each exhibited some form of minor structural damage that allowed sampling from those areas. The paintings chosen represented different periods in Vietnamese art history and artists working in both the north and south of the country. The paintings studied in this research project are listed below in the 'Results and discussion' section.

Lacquer analysis

Research at the Getty Conservation Institute has led to the development of a systematic approach to material identification in Asian lacquers by means of a comprehensive marker compound database and specialized Excel workbooks for data interpretation and presentation.[3] The analytical methodology used to characterize the organic materials in the lacquer samples appears elsewhere in this volume (Schilling *et al.*, 2016), but a brief summary is included here for the sake of convenience. At present, the best analytical technique available for comprehensive chemical analysis of the organic materials used in Asian lacquer formulations is pyrolysis -gas chromatography –mass spectrometry using thermally assisted hydrolysis and methylation with tetramethylammonium hydroxide (THM-Py-GC–MS). Chemical compounds in the Py-GC–MS chromatograms are identified and listed in a report using AMDIS, a computer program developed by the National Institute for Science and Technology (NIST) to process GC–MS data and identify compounds against a user's library of mass spectra. Marker compounds are formed by specific materials or classes of materials present in the sample and are useful for material identification. Researchers have tabulated numerous marker compounds for identifying Anacards and other organic materials in Asian lacquer formulations (Chiavari & Mazzeo, 1999; Niimura & Miyakoshi, 2003; Frade *et al.*, 2009; Heginbotham & Schilling, 2011; Le Hô *et al.*, 2012; Schilling *et al.*, 2016). These include catechols (Anacard markers), fatty acids (oil markers), di- and triterpenes (natural resins) and numerous specific compounds formed by proteins and carbohydrates. A specialized Excel workbook was developed to process the AMDIS report, identify the organic materials in the samples and to present the test results in a standardized format.

[3]These research tools can be obtained at workshops on Asian lacquer analysis organized by the Getty Conservation Institute. The first in a series of workshops entitled 'Recent Advances in Characterizing Asian Lacquers' (RAdICAL) was held at The Getty Conservation Institute from 22 to 26 October 2012.

Analytical procedures

In the present study, THM-Py-GC–MS analyses were performed on a Frontier PY-2020D pyrolyzer interfaced to an Agilent 7890A GC/5975C inert MSD. A J&W DB-5MS-UI capillary column (30 m × 0.25 mm × 0.25 μm) attached to a Frontier vent-free adaptor was used, with the helium flow rate set to 1 ml per minute. The split injector was set to 320°C with a split ratio of 50:1. The GC oven temperature program was 40°C for two minutes, then 6°C per minute to 320°C with a nine minute isothermal hold. Samples placed into 50 μl stainless steel Eco-cups were treated with 3 μl of 25% tetramethyl ammonium hydroxide in methanol, then pyrolyzed at 550°C. This protocol has already been used to study seventeenth-century Asian and European lacquered furniture in the collections of the J. Paul Getty Museum (Heginbotham *et al.*, 2008; Heginbotham & Schilling, 2011).

Elemental analysis of the commercial product used as a lacquer drier was performed by X-ray fluorescence (XRF) spectrometry using a Bruker Keymaster handheld XRF (Re tube, 40 kV, 1.50 mA, Ti/Al filter, 60 second acquisition time). Organic marker compounds from the drier were identified using THM-Py-GC–MS.

Results and discussion

The oldest painting sampled is *Thủ Dầu Một Village* by Trần Hà (Fig. 1). The painting depicts a traditional scene with buffalo in the village of Thủ Dầu Một, where Trần Hà's lacquer workshop was located, in the south of Vietnam in Bình Dương province. The painting is thought to date from the 1940s to 1950s based on its composition and style, although the exact date is unknown. During the wartime partitioning of Vietnam between 1956 and 1975, Vietnamese lacquer from Phú Thọ province was not available in the south and lacquer was sourced from neighboring Cambodia. Thus, identifying the type of lacquer used could help to date the painting, since Cambodian lacquer contains thitsiol rather than laccol.

Laccol was indeed identified in the samples from this painting based on the distribution of marker compounds in their gestalt graphs (Fig. 2), with the C_{17}

Figure 1 Trần Hà, ***Thủ Dầu Một Village***, 1940–1950s, 90 × 60 cm, Witness Collection.

catechol, C_7 hydrocarbons, C_{10} arlenic acid (the most abundant acid catechol) and a small series of alkyl benzenes from C_3 to C_7. This same pattern appears in Fig. 3 for Phú Thọ raw lacquer and for every Phú Thọ reference sample, which implies that the lacquer trees growing in Phú Thọ province in northern Vietnam are of the species *Toxicodendron succedaneum*. The absence of thitsiol, which is typical of Cambodian lacquer, leads to the conclusion that this painting probably dates from before 1956.

In addition to laccol, the drying oils identified in every sample from this painting have higher molecular weight fatty acids that are not present in typical commercial artists' oil paints (Fig. 4). Traditionally, the primary diagnostic tool for differentiating oil types is the ratio between palmitic acid and stearic acid, or the P/S ratio (Shin & Kim, 1994; Schilling & Khanjian, 1996; Mills & White, 1999). As a result, the P/S ratio was thought to be an unreliable method for identifying the oil type in samples from this painting.

A small proportion of pine resin was also present in the samples from this painting, which was compared to the results for the commercial lacquer references (Table 1). The proportion of abietic acid relative to oxidized abietate compounds in the reference lacquers was fairly low but varied between the samples, suggesting that the resins received moderate heat treatment that altered the original resin composition (van den Berg *et al.*, 1996). Oxygen scavenging by the pine resin from heat treatment may have reduced the quantity of oxidized dicarboxylic fatty acids that formed in these lacquer samples.

The reference samples of Phú Thọ lacquer and the mixture of Cambodian and Phú Thọ 'cockroach

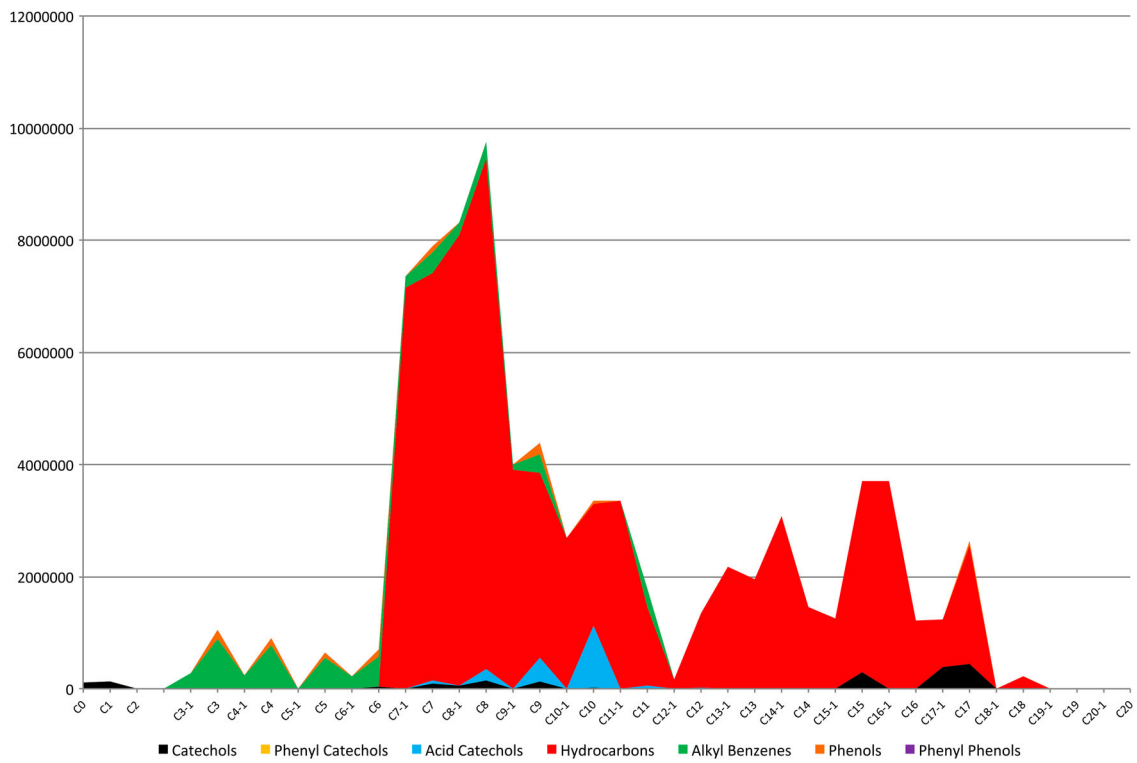

Figure 2 Gestalt graph of Anacard markers in sample 1 from ***Thủ Dầu Một Village*** by Trần Hà.

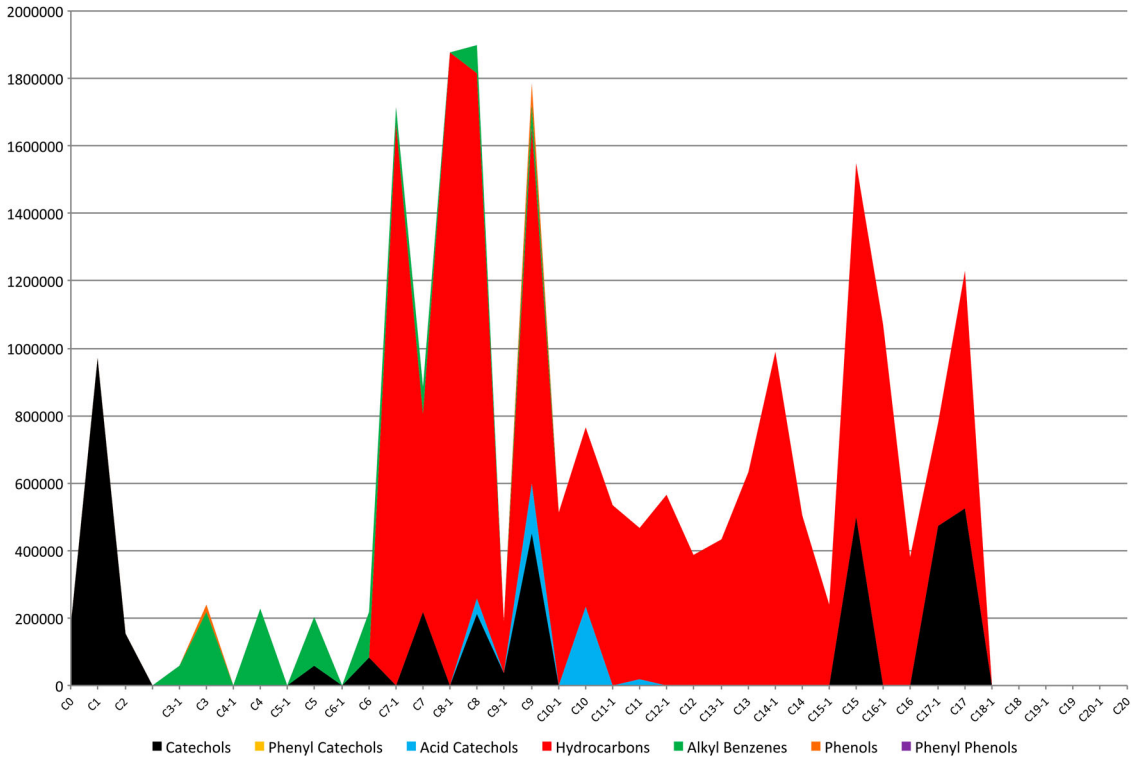

Figure 3 Gestalt graph of Anacard markers for Phú Thọ raw lacquer, which contains laccol.

wing' color contained a number of oxidized abietic acid compounds typical of *Pinaceae* resins used as artists' materials (van den Berg *et al.*, 1996), plus an unusual compound that provided more specific information about the species of pine tree. Mercusic acid (labd-8(20)-ene-15,18-dioic acid) has been identified in resins from two species of *Pinus* that grow in Southeast Asia. One is the Tenasserim Pine, *Pinus latteri*, which is native to the mountains of southeastern Burma, northern Thailand, Laos, Cambodia, Vietnam and Hainan Island (Wang, 2007; Wikipedia, 2013). The other is the Sumatran Pine, *Pinus merkusii*, which grows

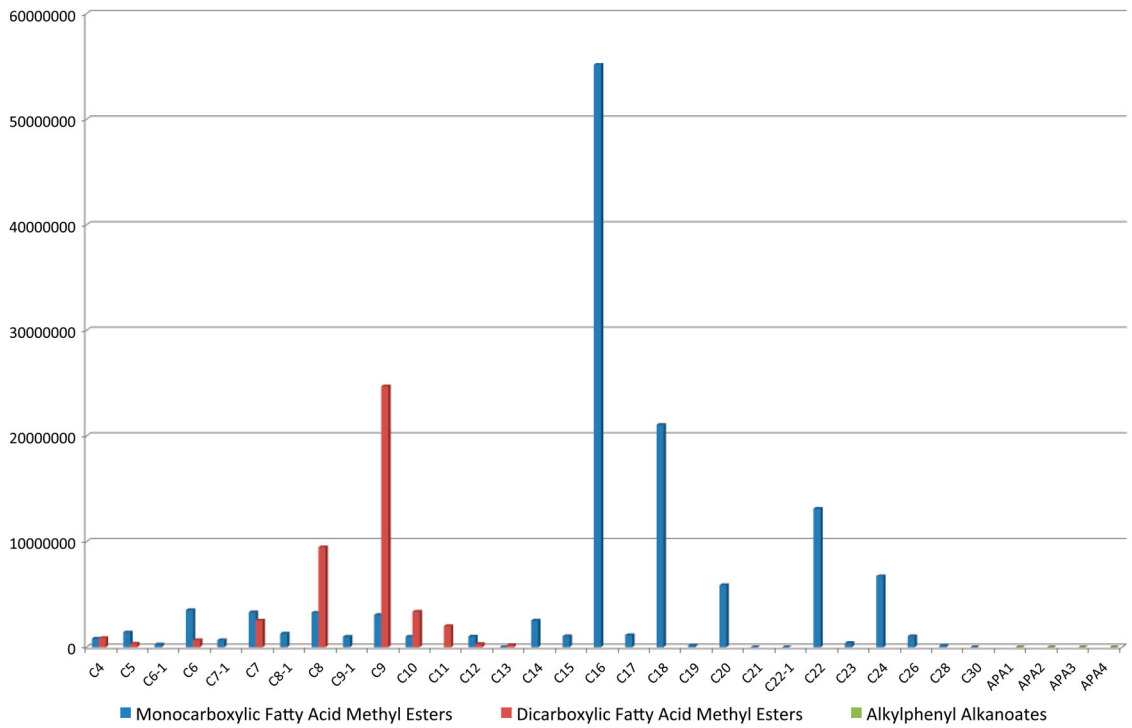

Figure 4 Fatty acid bar graph for the paint sample of red with thin black from *Thủ Dầu Một Village*, which contains unusual levels of high molecular weight fatty acids.

Table 1 THM-Py-GC–MS normalized peak area percentages for diterpene compounds present in lacquer samples that contain pine resin

Pinaceae compounds	Methyl isopimarate	Mercusic acid methyl ester	*Methyl dehydroabietate*	*Methyl-6-dehydrodehydroabietate*	Methyl abietate	Dimethyl-labd-8(20)-ene-15,18-dioate	*Methyl 7-oxodehydroabietate*	*Methyl 15-Hydroxy-7-oxodehydroabietate*	% Abietic acid/sum of oxidized abietates
70% Cambodian, 30% Phú Thọ 'cockroach wing' color	10	12	36	16	1.0	5.6	18	0.6	1
70% Cambodian, 30% Phú Thọ, blackened	13	12	27	6.7	16	20	5.5	0.3	39
Phú Thọ raw with pine resin	5.9	7.8	36	11	0.5	18	20	1.4	1
Phú Thọ with pine resin, blackened	11	12	40	11	2.1	16	8.0	0.3	3
Phú Thọ processed, 'cockroach wing' color	11	9	32	8.0	15	13	11	0.9	28
Phú Thọ blackened	12	10	44	7.9	6.6	14	4.6	0.2	12

Notes: All the compounds were detected in the form of the corresponding methyl esters. Oxidized abietic acid compounds appear in italics. The percentage of abietic acid relative to the sum of oxidized abietic acid compounds appears at the right side of the table.

Table 2 Peak area percentages for *Thủ Dầu Một Village* by Trần Hà

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
1 – red with thin black	27% laccol	66% drying oil	3% *Pinus latteri*	1%	1%
3 – red brown	23% laccol	65% drying oil	4% *Pinus latteri*	1%	5%
4 – red brown	45% laccol	47% drying oil		1%	3%
5 – red brown, thin black	22% laccol	64% drying oil	6% *Pinus latteri*	1%	3%
6 – red brown	39% laccol	53% drying oil	6% *Pinus latteri*	1%	1%

Figure 5 Xu Man, *Admiring the Flag*, 1960, 74 × 45 cm, Witness Collection.

further south in Sumatra and the Philippines (Wiyono *et al.*, 2006; Wikipedia, 2013). Another important observation was that the lacquer samples lack palustric acid, which is also absent in resin from *Pinus latteri* trees that grow in Cambodia, but is abundant in *Pinus merkusii* resin. Based on the similarity in composition, it was concluded that these samples likely contain *Pinus latteri* resin. Regarding the Trần Hà painting, the pine resin composition in the samples was consistent with *Pinus latteri*.

Finally, small quantities of markers for carbohydrates and proteins associated with gums and glycoproteins abundant in laccol were also identified in these samples. These markers have also been observed in Chinese and Ryukyuan laccol lacquers (Heginbotham *et al.*, 2016); the full results for this painting are listed in Table 2.

The next painting studied was *Admiring the Flag* by Xu Man, painted in 1960, possibly during his studies in Hanoi at the College of Fine Arts (Fig. 5). It depicts an ethnic minority woman proudly showing the Vietnamese flag to a group of women and children, while Hồ Chí Minh looks on from a portrait on the wall. Samples from this painting contained a high proportion of laccol (nearly 50%), *Pinus latteri* resin (36%), drying oil and traces of carbohydrates and proteins. Based on a P/S ratio of 1.6, linseed oil was identified as the drying oil (Table 3).

The painting by Phan Kế An in this study, *Woman and Lotus*, was painted during the 1970s, and portrays a seated woman reading by a table with a vase of lotus flowers (Fig. 6). Phan Kế An lives and works in Hanoi in the north of Vietnam. This painting represents traditional Vietnamese lacquer painting from Hanoi, where the technique originated during the 1920s. As listed in Table 4, samples taken from the edges of the painting contained variable proportions of laccol, *Pinus latteri* resin and perilla oil (P/S 2.2) based on peak area percentages. Interestingly, laccol carbohydrates were unusually high relative to the amount of laccol present in two samples, something that has also been observed in Chinese lacquers (Schilling *et al.*, 2016). Although the precise reason for this is unclear, the technique for tapping the laccol sap and the time of year at which the tree was tapped may both affect the carbohydrate content.

The painting *Friends* by Nguyễn Văn Bình examined in this study dates from 1971 (Fig. 7). The artist taught at the Hanoi College of Fine Arts until his retirement in 1979. The women depicted are wearing

Table 3 Peak area percentages for *Admiring the Flag* by Xu Man

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
3 – all layers	48% laccol	13% linseed oil	36% *Pinus latteri*	0.4%	1%

Figure 6 Phan Kế An, ***Woman and Lotus***, 1970s, 90 × 60 cm, Witness Collection.

Figure 7 Nguyễn Văn Bình, ***Friends***, 1971, 51 × 41 cm, Witness Collection.

clothes identifying them as members of Vietnam's ethnic minorities from the Central Highlands and the northwest. Thus, the painting is an allegory for unification of north and south. The two samples tested were very similar in composition: *Pinus latteri* resin with lesser amounts of laccol and drying oil. Interestingly, high molecular weight fatty acids were identified in only one sample, whereas the profile of the second sample was consistent with perilla oil (Table 5). The lacquer from this painting is similar to commercially available processed lacquer, which also has a high proportion of pine resin mixed with laccol.

Nguyễn Thế Vinh's work *Guerilla* from 1979 depicts scenes from the Tay Nguyen Central Highlands where the artist was based during the war (Fig. 8). This portrait of a female guerilla from an ethnic minority tribe includes a gun slung over her shoulder. A sample from this painting had a fairly traditional composition of *Pinus latteri* resin, laccol and perilla oil, also with significant levels of laccol carbohydrates (Table 6).

Two paintings with an abstract subject matter by Nguyễn Gia Trí, the master of Vietnamese lacquer painting, were sampled: *Abstract with Girls* (Fig. 9) and *Abstract Composition* (Fig. 10). The artist began his career in Hanoi, but moved to Saigon in the south in the 1950s after a brief period in Hong Kong from 1946 to 1951. Although undated, the paintings were probably made in the 1970s or 1980s. It should be noted that it was possible to take samples only from the verso of both paintings due to their pristine surfaces and the results for the recto of the paintings may, therefore, be quite different.

The full results for these paintings appear in Tables 7 and 8. Unexpected paint media were identified in the two paintings, with both samples from *Abstract with Girls* and one sample from *Abstract Composition* containing cashew nut shell liquid. The key feature in the gestalt graph for CNSL is the intense homologous series of phenols that has maxima at C_7 and C_{15}, with much smaller peaks for

Table 4 Peak area percentages for ***Woman and Lotus*** by Phan Kế An

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
1 – brown black	20% laccol	11% perilla oil	65% *Pinus latteri*	1%	3%
2 – black	53% laccol	21% perilla oil	5% *Pinus latteri*	1%	14%
4 – black and tan	32% laccol	14% perilla oil	45% *Pinus latteri*	1%	6%

Table 5 Peak area percentages for *Friends* by Nguyễn Văn Bình

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
1 – black	37% laccol	4% perilla oil	56% *Pinus latteri*	1%	nd*
2 – black and gold	35% laccol	8% drying oil	55% *Pinus latteri*	nd	2%

* nd = not detected.

Figure 8 Nguyễn Thế Vinh, *Guerilla*, 1979, 45 × 33 cm, Witness Collection.

Figure 9 Nguyễn Gia Trí, *Abstract with Girls*, 1970–1980s, 63 × 86 cm, Witness Collection.

hydrocarbons and alkyl benzenes. This is shown in Fig. 11 for sample 1c from *Abstract Composition* and in Fig. 12 for the sơn điều lacquer purchased in Hanoi and said to originate from southern Vietnam. An important CNSL marker not included in gestalt graphs is methyl 2-methoxy-6-(8-oxooctyl)benzoate,

Figure 10 Nguyễn Gia Trí, *Abstract Composition*, 1970s–1980s, 58 × 75 cm, Witness Collection.

an oxidation product unique to cashew lacquer not previously reported in the literature. The mass spectrum and molecular structure for this compound, named ebertic acid by one of the authors (MS), are shown in Fig. 13.

Lacquer from CNSL has a rapid curing time and is significantly cheaper than urushi and laccol lacquers. Many Vietnamese lacquer artists prefer cashew nut shell lacquer to Vietnamese lacquer due to its relative cost and curing speed, although this is not usually admitted. Another alternative to cashew lacquer that is frequently used in Vietnam is *sơn Nhật* (Japanese lacquer). This is not true *urushi*, but a synthetic industrialized alternative.

In addition to CNSL, alkyd resin composed of perilla oil, pentaerythritol and phthalic anhydride was identified in the three samples that contained CNSL. It is difficult to understand the source of alkyd resin in an Asian lacquer formulation. Synthetic nitrocellulose lacquers are occasionally used in Vietnam as an alternative to traditional lacquer, though no nitrocellulose was detected in either painting. There is the possibility that an alkyd-based enamel paint was mixed into the formulation or applied as an individual layer. Cardanol resin modified alkyds may also have been used, given that CNSL and alkyd are both present. Yet it is unlikely that these two materials were mixed together into a single paint formulation because the proportions of alkyd and CNSL varied from sample to sample and, moreover, large amounts of *Pinus latteri* resin were identified in

Table 6 Peak area percentages for *Guerilla* by Nguyễn Thế Vinh

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
3 – gold and black	31% laccol	20% perilla oil	41% *Pinus latteri*	1%	7%

Table 7 Peak area percentages for *Abstract with Girls* by Nguyễn Gia Trí

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
2 – all layers	4% cashew nut shell liquid	60% perilla oil/alkyd	36% *Pinus latteri*	nd	nd
6 – all layers	4% cashew nut shell liquid	63% perilla oil/alkyd	31% *Pinus latteri*	2%	nd

Table 8 Peak area percentages for *Abstract Composition* by Nguyễn Gia Trí

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
1b – red	67% laccol and thitsiol	20% perilla oil	5% *Pinus latteri* and *Dipterocarpus*	1%	3%
1c – red	27% cashew nut shell liquid	70% perilla or tallow tree oil/alkyd	2% *Pinus latteri*	1%	nd

the two samples from *Abstract with Girls*, whereas this resin was present at very low levels in *Abstract Composition*. Whatever the source, it would appear that Nguyễn Gia Trí, the master of Vietnamese lacquer painting, used a variety of materials including both alkyd and CNSL lacquer.

In the second sample from *Abstract Composition* (1b) a mixture of laccol, thitsi and perilla oil was identified, again with elevated levels of laccol carbohydrates. The main markers for these Anacards in the gestalt graph of this sample (Fig. 14) are also present in the sample of Cambodian lacquer obtained from the artist Nguyễn Lâm (Fig. 15). This suggests that, contrary to the artist's understanding, the reference sample actually consists of a mixture of Cambodian and Vietnamese lacquer rather than pure Cambodian lacquer. As *thitsi* lacquer was available in southern Vietnam and is occasionally incorporated in Vietnamese lacquer formulations, this does not come as too much of a surprise. There are also

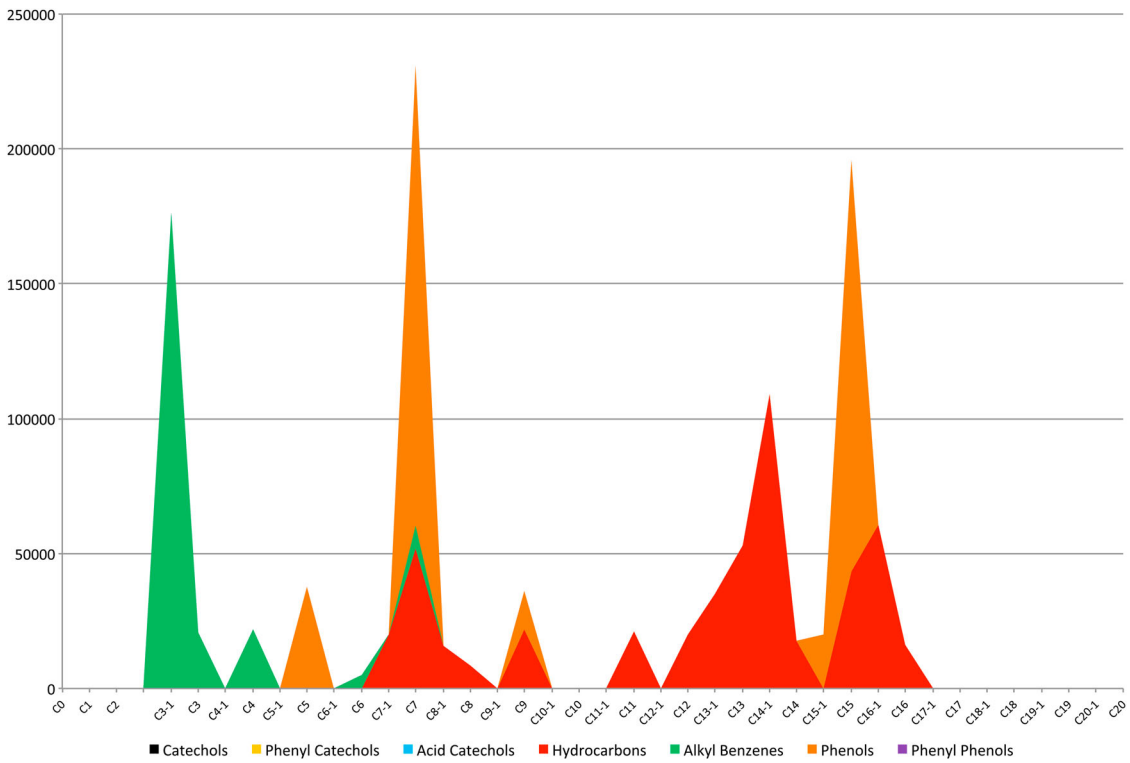

Figure 11 Gestalt graph of Anacard markers for sample 1c from Nguyễn Gia Trí's *Abstract Composition*, which contains CNSL.

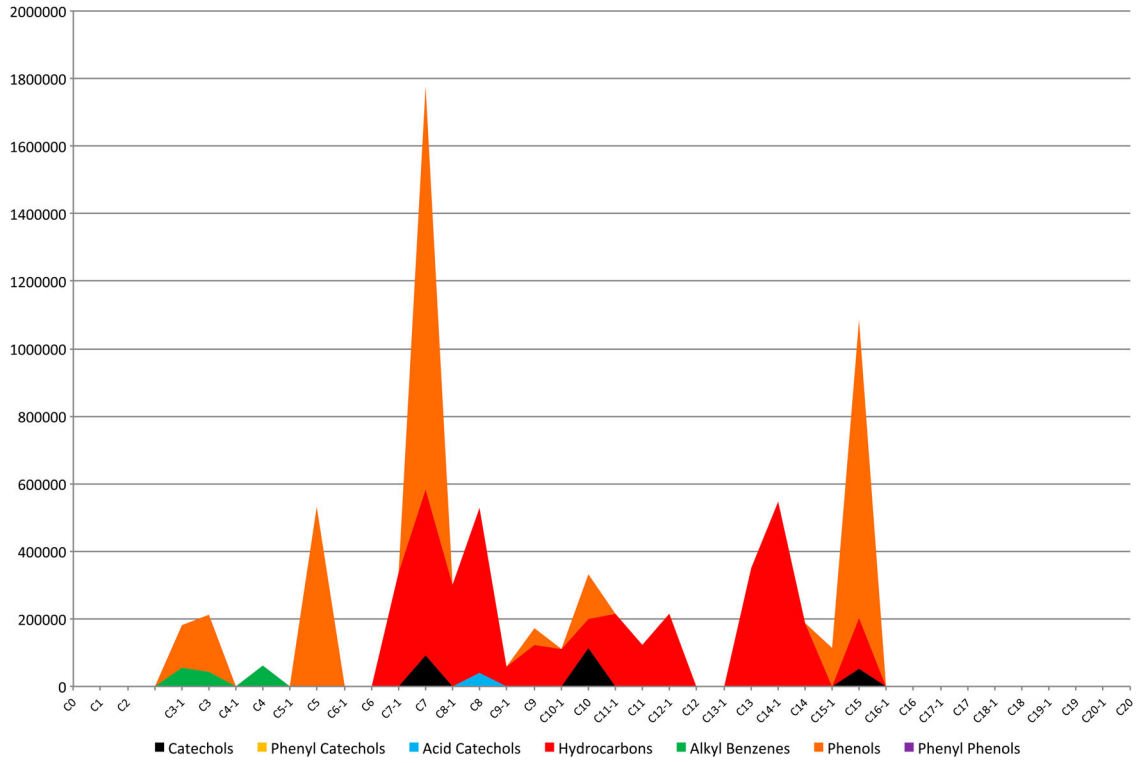

Figure 12 Gestalt graph of Anacard markers for sơn điều lacquer, composed of CNSL and linseed oil.

minor amounts of pine resin and *Dipterocarpus* markers typically associated with thitsiol and thought to indicate wood oil in Japanese export lacquer (Heginbotham & Schilling, 2011). These markers were also identified in the Cambodian raw lacquer and the mixture of Cambodian and Phú Thọ 'cockroach wing' color lacquer, both of which contained thitsiol.

Two samples from the verso of the painting *Abstract with Nude* by Nguyễn Xuàn Việt were studied (Fig. 16). It is an early abstract painting by a contemporary artist working in HCMC, who was a student of the artist Nguyễn Gia Trí. The painting has a slight concave warp, with a significant amount of cracking on the verso. The artist has previously repaired it by the addition of more layers of lacquer to the verso,

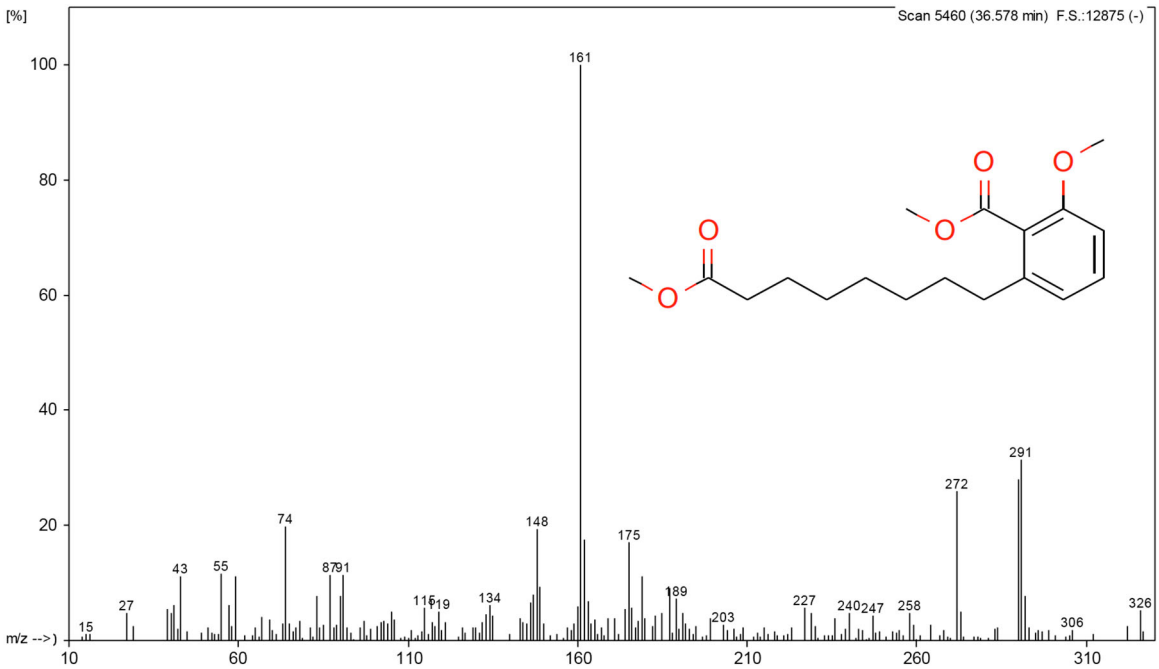

Figure 13 Mass spectrum and molecular structure for ebertic acid (methyl 2-methoxy-6-(8-oxooctyl)benzoate), an abundant marker in fully-cured CNSL.

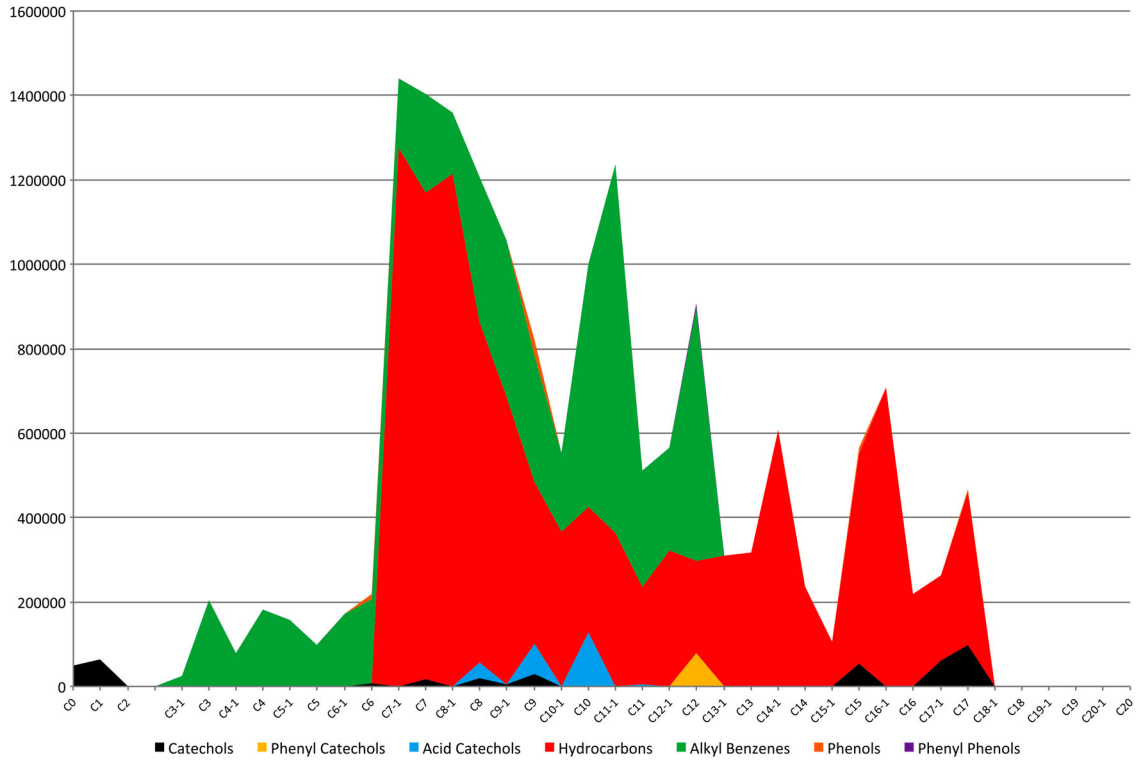

Figure 14 Gestalt graph of Anacard markers for sample 1b from *Abstract Composition* by Nguyễn Gia Trí, which contains laccol and thitsiol.

but the cracks reappeared subsequently. The artist believes this to be the result of poor preparation of the panel, as it is one of his early works.

The two samples from this painting exhibited variation in the proportions of components (Table 9). In the first sample, laccol makes up the majority, at almost 50% peak area composition, while there is a lesser amount (*c*. 29%) of pine resin and a small amount of drying oil present that is likely to be linseed oil based on its P/S ratio. The source of the

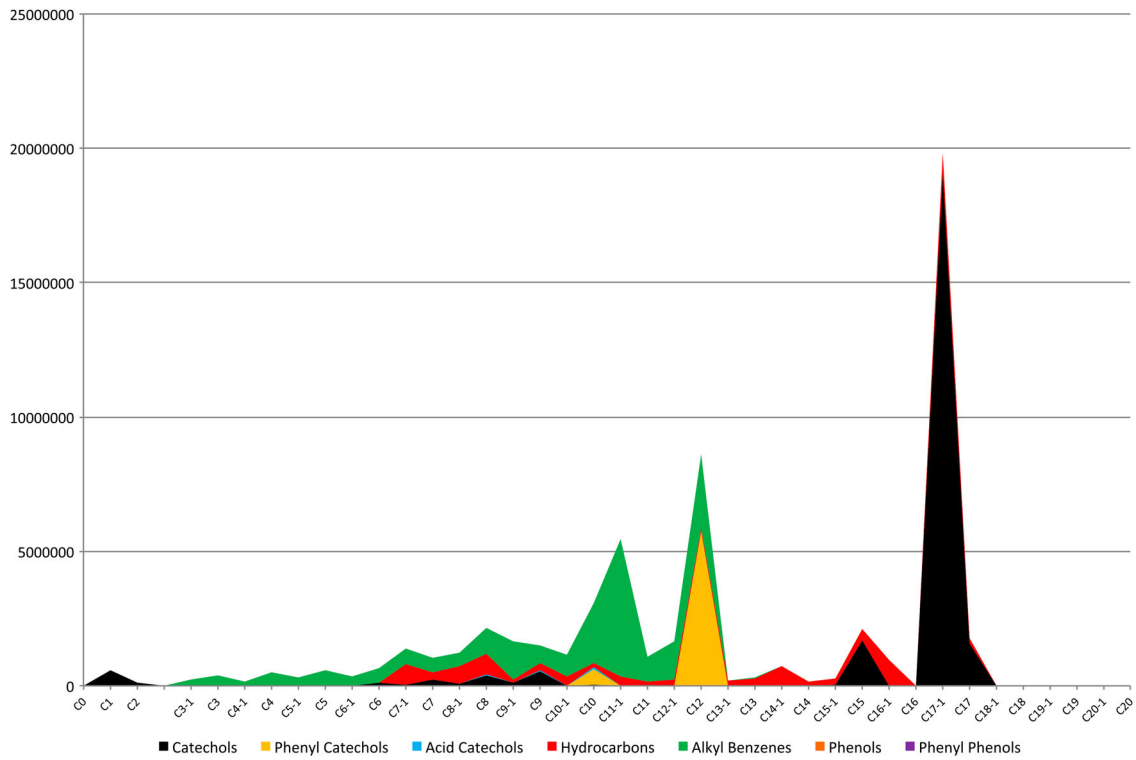

Figure 15 Gestalt graph of Anacard markers for 'Cambodian lacquer', which contains laccol and thitsiol.

Figure 16 Nguyễn Xuàn Việt, ***Abstract with Nude***, 1988, 30 × 40 cm, Witness Collection.

resin was once again identified as *Pinus latteri*, as in the previously considered paintings and commercial lacquer samples. The second sample contains a majority of *Pinus latteri* resin at 76%, followed by laccol (20%) and a small oil component. This variation in composition could indicate the two stages of lacquering the verso, one during the initial painting and the second during the attempted repair.

Commercial lacquer samples

Table 10 lists the test results for the commercial lacquer samples. In many samples, the fatty acid content was extremely low, which indicated that they were native fatty acids present in the tree sap itself. Tung oil was identified in the Phú Thọ raw lacquer on the basis of its low P/S ratio. Tung oil was also identified in the Phú Thọ processed blackened lacquer and the mixture of Cambodian and Phú Thọ 'cockroach wing' color lacquer samples, along with 'cyclic' fatty acids (ω-(*o*-alkylphenyl) alkanoic acids), which are common markers for oils rich in $C_{18\text{-}3}$ fatty acids (such as tung and linseed) that have been heat-bodied (Evershed *et al.*, 2008). It would appear that heat-bodied tung oil was added to 'further process' the Phú Thọ lacquer. Linseed oil was identified in the cashew (sơn điều) lacquer. Flax, the source of linseed oil, grows throughout central Asia, so the presence of linseed oil in these samples is reasonable. *Pinus latteri* resin was present in all of the Phú Thọ samples. Finally, *Dipterocarpus* markers were present in samples that contained thitsi lacquer.

Drier

Cobalt(II) 2-ethyl hexanoate drier was identified in all of the commercial lacquer samples based upon the combined results from XRF and THM-Py-GC–MS. Because the quantity of the drier in the lacquer products seemed to vary inversely with the content of natural resin, it could have been added to the lacquer prior to the addition of the resins. Presently, it is not known what effect the cobalt drier will have on the long-term aging behavior of the reference paints.

Conclusions

In this study, THM-Py-GC–MS was successfully applied to the identification of a wide range of materials in commercial Asian lacquers, such as Anacard tree saps, oils and resins. When the results from analysis of the lacquer paintings are compared with those from commercial lacquer samples, a correlation is noticeable that allows some conclusions to be drawn on the nature of the paint samples. Generally, the raw commercial lacquer samples contained a high proportion of laccol with a drying oil as the next most abundant component. In contrast, the processed commercial samples contained a higher proportion of pine resin. It is thus possible to conclude that the paint samples tested in this study, which contained a high proportion of pine resin, were possibly processed lacquer, while those with a higher laccol and drying oil component could be raw lacquer. Generally, raw lacquer is considered stronger and is used in base layers as well as for repairs, while processed lacquer is used during the painting stages.

In addition, some generalized conclusions can be drawn regarding more traditional Vietnamese lacquer paintings, particularly those by artists working in the north of Vietnam, including Xu Man, Phan Kế An, Nguyễn Văn Bình or Nguyễn Thế Vinh. These paintings often contain a large proportion of *Pinus latteri* pine resin, laccol and a drying oil component. It should, however, be noted that it is impossible to confirm the material makeup of Vietnamese lacquer paintings by visual inspection alone (i.e. without the aid of analysis), as can be seen from the variable results and unusual components identified in some of the paintings studied. In particular, the two paintings by Nguyễn Gia Trí defy categorization at present.

Table 9 Peak area percentages for ***Abstract with Nude*** by Nguyễn Xuàn Việt

Sample	Anacards	Oil	Resin	Protein	Carbohydrate
1 – red brown	49% laccol	13% linseed oil	29% *Pinus latteri*	1%	7%
2 – black and red	20% laccol	3% linseed oil	76% *Pinus latteri*	nd	1%

Table 10 Summary of THM-Py-GC–MS analysis results for lacquer references, expressed as normalized peak area percentages

Sample	Anacards	Oils/fatty acids	*Pinus latteri*	*Dipterocarpus*	Protein	Carbohydrate
Cambodian raw lacquer (*Sơn Nam Vang sống*)	91% thitsiol and laccol	2% native FAs	0.2%	6.8%	nd	nd
Phú Thọ raw lacquer (*Sơn Phú Thọ sống*)	57% laccol	28% drying oil	nd	nd	6%	3%
70% Cambodian, 30% Phú Thọ, transparent 'cockroach wing' color (*Sơn cánh gián*)	67% thitsiol and laccol	4% heat-bodied tung oil	20%	6.5	1	nd
Phú Thọ raw lacquer with pine resin (*Sơn Phú Thọ sống*)	8% laccol	1% native FAs	91%	nd	nd	nd
Phú Thọ lacquer with pine resin, blackened (*Sơn then*)	9% laccol	1% native FAs	90%	nd	nd	nd
Phú Thọ processed lacquer, 'cockroach wing' color (*Sơn cánh gián*)	18% laccol	2% native FAs	80%	nd	1%	nd
Phú Thọ blackened lacquer (*Sơn then*)	11% laccol	1% native FAs	88%	nd	nd	nd
Cashew lacquer (*Sơn điều*)	36% cashew nut shell liquid	48% linseed oil	nd	nd	nd	nd
Cashew lacquer, blackened (*Sơn điều then*)	45% cashew nut shell liquid	38% linseed oil	nd	nd	nd	nd

This research provides a basic overview of the complex nature of the raw and processed lacquers available in Vietnam, which has not been carried out previously. It is interesting that regional differences exist between the lacquer products that are available to artists in northern and southern Vietnam. These supply differences may have their origin in the Vietnam War, but persist to the present time.

None of the samples from the lacquer paintings contained the cobalt drier identified in the commercial lacquer samples. It is possible that this is a recent addition to commercial formulations and that analysis of contemporary lacquer paintings may reveal the presence of such a drier. The impact of the drier on stability and aging of the lacquer remains to be studied.

Analytical verification of materials should be carried out for products that are intended for use as standards in laboratory experiments as there are significant variations in the commercial lacquers available in Vietnam. This raises the broader concern of the need for securely classified botanical specimens to serve as analytical reference standards against which to identify the components of lacquers. Classified standards would be of inestimable benefit for clarifying the nature and sources of the triterpenes present in the Cambodian and 'cockroach wing' lacquers. Clearly, there is a significant role for botanists in the study of Asian lacquers.

Further steps in the research will involve additional painting analysis as well as artist interviews that should help to understand material preferences and differences in working processes. The next stage will involve investigations into the aging behavior of Vietnamese lacquer. In light of their vastly different compositions, the aging behaviors of laccol, thitsiol, and CNSL should also be quite different, thereby giving rise to long-term implications for the stability and conservation needs of paintings made within the different regions of the country. Ultimately, this research will aid in formulating conservation treatment approaches for Vietnamese lacquer paintings.

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