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Technical examination of Liu Kang's Paris and Shanghai painting supports (1929–1937)

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Abstract

This article presents an overview of Liu Kang's (1911–2004) canvas painting supports from his early artistic phases, Paris (1929–1932) and Shanghai (1932–1937). The research was conducted on 55 artworks from the collections of the National Gallery Singapore and Liu family. The technical examination of the paintings was supplemented with archival photographs of the artist at work to elucidate his practice of preparation of painting supports. The analyses conducted with light microscopy, SEM–EDS, and FTIR allowed us to characterise the structure of the canvases and identify the natural fibres and formulation of the grounds. In addition, references to contemporary colourmen catalogues, in relation to certain materials, were made. The obtained results suggest that, in both locations, Liu Kang employed commercially prepared canvases purchased by the roll or by the metre, together with bare strainers or stretchers of standard sizes. In Paris, the artist commonly used linen canvases, while in Shanghai he preferred cotton canvases, with linen used sporadically. The identified grounds from the Paris and Shanghai canvases are white and single-layered, but their formulations vary significantly between the two locations. Hence, grounds composed predominantly of lead white with extenders and drying oil as a binder are considered as exclusive to the Paris phase. However, semi-absorbent or absorbent grounds based on chalk are typical for Shanghai phase. This research contributes to the knowledge of Liu Kang's painting materials and working practices during the pre-war period in Paris and Shanghai.

Keywords: Liu Kang, Painting supports, Commercially prepared canvas, Metal soaps, SEM–EDS, FTIR

Introduction

Liu Kang (1911–2004) was one of Singapore's most prominent painters. He was born in Yongchun, Fujian province, China. In December 1928, after graduating from Xinhua Arts Academy in Shanghai, he moved to Paris, where immersed himself in the Western art. He returned to China in 1932 and in the following year he accepted the post of Professor at Shanghai Art Academy, the leading art training institution in China at the time. When the Second Sino-Japanese War (1937–1945) broke out, he moved to Malaya. In 1945, he came to Singapore, where he settled permanently and would contribute much to the development of art here.

The Paris period laid the foundation for Liu Kang's Western mode of expression while in Shanghai he tried to implement some elements of the Chinese ink technique. However, in Singapore, he recognised the need for the birth of a new style of painting that not only synthesises Eastern and Western art, but also captures the spirit of the tropics. The style come to be known as the Nanyang style, which focused on local scenes and aspects of the regional way of life [1, 2].

Despite Liu Kang's role in the development of modern art in Singapore, very little is known about his painting techniques and materials. Therefore, the ongoing research has involved an examination of the painting supports representative of his two artistic phases Paris (1929–1932) and Shanghai (1932–1937). The Paris phase also includes works that were painted during trips to Switzerland in 1929 and Belgium in 1930 [3].

Staying in two important cultural centres of the pre-war period exposed Liu Kang to an overwhelming

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variety of painting styles and techniques as well as a great range of painting materials from well-established artists' colourmen and small retailers. The advertisement sections of Le Salon's 1930 and 1932 exhibition catalogues give an insight into the manufacturers and retailers of art materials who were active in Paris at the time: Lefranc, Bourgeois Ainé, Robert Blanchet, Paris American Art Co., Paul Foinet Fils, J.M. Paillard, Morin & Janet, Merlin Denis, Tochon-Lepage, Sennelier, Tasset et L'Hôte, Hardy-Alan, Toiles A. Binant, Armand Drouant, and A. M. Duroziez (Fig. 1) [4, 5]. In Paris, artists could purchase a raw canvas and prepare it themselves or use commercially prepared canvases. The latter were either ready-stretched on wooden frames, usually of a standard size, or as a roll sold by the metre, which was a cheaper option.

Meanwhile, in China from around 1909, there was a high demand for commercial art, and art schools began to enjoy a boom [6], leading to an increased interest in art materials among students, and amateur and professional artists. According to T. Tsuruta, painting materials, including canvases from Winsor & Newton (W&N) and Reeves & Sons (R&S), were already available in Shanghai in the first decade of the twentieth century [7]. Advertisements published in the *Shanghai Art Academy Graduation Yearbook* [8, 9] and two famous Shanghai pictorials, *Liangyou* [10] and *Arts and Life* [11], reveal that the pre-war Shanghai art materials market offered a selection of local brands like Marie's and Eagle (Fig. 2a–c), as well as imported materials from Europe and America (Fig. 2d). In addition, local imitations were also available, creating a major challenge for R&S and others (Fig. 2e). Unfortunately, the authors have little information about the types of canvases that were available in pre-war Shanghai.

The study aims to characterise the canvases and grounds used by Liu Kang during his Paris and Shanghai phases. The obtained information can assist in the identification of the painting supports as commercially or artist prepared, giving insight into the artist's working practice during the discussed periods. The present study is supported with the archival photographs to give a rare glimpse into the artist's practice of preparation for painting. In addition, some references are made to Lefranc, Bourgeois Ainé, Toiles A. Binant, R&S and W&N colourmen catalogues from the turn of the 19th century and from the period under review, in relation to certain materials encountered in the studied painting supports. Although there were many other suppliers of art materials in France, Britain, and China who were active between 1928 and 1937, the references are restricted to the few aforementioned companies because of the scarcity of early 20th-century catalogues from other retailers.

Materials and methods

Investigated paintings

The discussion of Liu Kang's painting supports and grounds is based on the examination of 20 paintings from the National Gallery Singapore (NGS) and 35 paintings from the Liu family collection. None of the examined paintings has the original auxiliary support. All artworks from NGS and seven from the Liu collection are stretched over non-original strainers, stretchers, or boards. The remaining 28 paintings from the Liu family are unstretched. In addition, 16 NGS paintings have undergone treatments, which impacted the examination of the canvases. The treatments included the artist's commissioned lining of paintings onto plywood board, cardboard, and canvas. Some of them were strip and loose lined by conservators after the NGS accession. Seven NGS paintings and five from Liu family have their tacking margins cut off. The condition of the NGS paintings posed certain limitations for a proper examination of the canvases, while the inclusion of the paintings from the Liu collection significantly expanded the research base. Although the 55 paintings from both collections are not exhaustive, as a few hundred other paintings left in Shanghai perished during the Second Sino-Japanese War [12] and some others are with private collectors, they represent two artistic phases over a period of eight years and provide a sufficient material for the analyses.

Applied analytical methods

All paintings were photographed and technical data was recorded for each painting, including the dimensions, weave, and density of fabrics and the twist of threads. The density of canvases that provided no access to the reverse side was measured from the front, through the areas of thin paint layer that revealed a prominent texture of the fabric. The tacking margins were checked for the presence of a ground layer and nail holes. Unique features, such as partial ground coverage of the tacking margins or their absence, cusping, paintings on the reverse side of the canvases, underlying paint layers, and penetration of oil from the paint through to the back of the canvases, were documented. Paintings from the NGS collection with an unusual paint texture were also X-ray radiographed (XRR) to verify the presence of underlying paint layers. Then, samples of fibres were extracted from the canvases for the morphologic identification. A sampling of the grounds for the analyses was restricted to the tacking margins or edges of the paint layer from the areas of prior loss. With regard to four artworks painted on the reverse side of earlier compositions and seven stretched and framed paintings from the Liu collection, the standard features were recorded and fibre identification was conducted. The analytical results were studied to determine the presence of

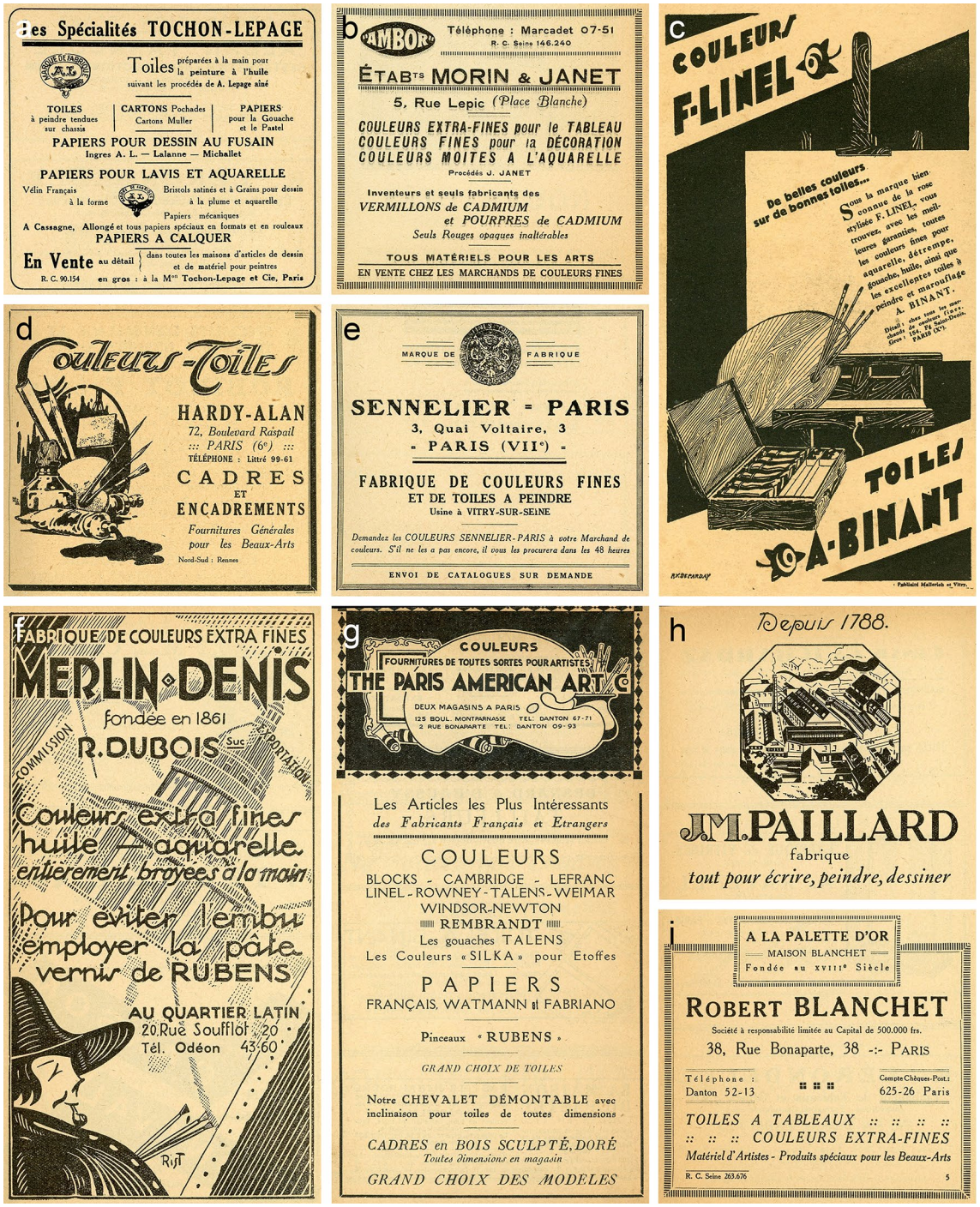


Fig. 1 Advertisements by manufacturers and retailers of art materials, including canvases, available in Paris in 1930 and 1932: **a** Tochon-Lepage; **b** Morin and Janet; **c** Toiles A. Binant; **d** Hardy-Alan; **e** Sennelier; **f** Merlin Denis; **g** Paris American Art Co.; **h** J.M. Paillard; **i** Robert Blanchet

Fig. 2 Advertisements by manufacturers and retailers of art materials, including canvases, available in Shanghai from 1934 to 1936: **a**, **b** Marie's (Chinese brand); **c** Eagle (Chinese brand); **d** local, European and American; **e** R&S

characteristic patterns that could be attributed to the examined artistic phases.

X-ray radiography

The paintings from the NGS collection were digitally X-ray radiographed using a Siemens Ysio Max digital X-ray system with a detector size of 35 × 43 cm and high pixel resolution of over 7 million pixels in the detector face. The X-ray tube operated at 40 kV and 0.5–2 mAs. The images were first processed with an X-ray medical imaging software, iQ-LITE, then exported to Adobe Photoshop CC for final alignment and merging.

Optical microscopy

Optical microscopy (OM) of samples was carried out in visible and ultraviolet reflected light on a Leica DMRX microscope at magnifications of × 40, × 100, and × 200 equipped with a Leica DFC295 digital camera.

High-resolution digital microscopy

The surface of the canvases was examined with a Keyence VHX-6000 digital microscope, using a zoom lens coupled with a high-speed camera. Observations were conducted at magnifications of × 20– × 200. For measurement analyses, a built-in Keyence software—VHX-H2M2 and VHX-H4M—was used.

Scanning electron microscope with energy dispersive spectroscopy

The cross-sections of the ground and paint samples containing a complete structure of layers were mounted on carbon tapes and examined with a Hitachi SU5000 field emission scanning electron microscope (FE-SEM) coupled with Bruker XFlash® 6/60 energy dispersive X-ray spectroscopy (EDS). The SEM, backscattered electron mode (BSE), was used in 60 Pa vacuum, with 20 kV beam acceleration, at 50–60 intensity spot and a working distance of 10 mm. Results were processed using the Bruker ESPIRIT 2.0 software.

Fourier transform infrared spectroscopy

Attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) was carried out using a Bruker Hyperion 3000 FTIR microscope with a mid-band MCT detector, coupled to a Vertex 80 FTIR spectrometer and Bruker ALPHA FTIR spectrometer. Measurements were carried out at room temperature in the spectral range of 4000–600 cm^{-1}, at a resolution of 4 cm^{-1}, averaging 64 scans. The interpretation of spectra relied on Bruker Opus 7.5 software.

Preparation of samples

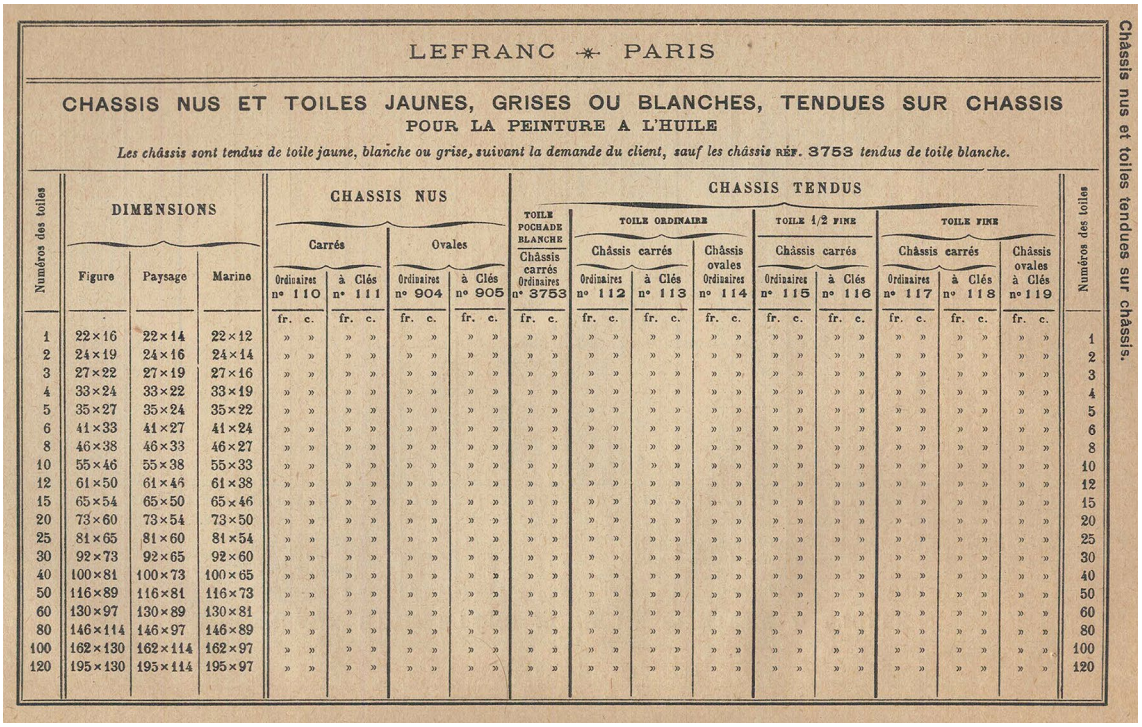
A total of 104 micro samples of fibres were collected from the threads of weft and warp for the microscopic examination. The samples were first boiled in water to remove contaminants and then mounted on microscope slides with a drop of water under the cover glass. In addition, 45 micro-samples of the ground and paint for cross-section analyses were embedded in a fast-curing acrylic resin, ClaroCit (supplied by Struers), and fine polished. The samples from all NGS paintings and the most representative ones from the Liu family collection, in all totalling 28 samples, were selected for the FTIR measurements.

Results and discussion

Auxiliary supports and canvas formats

Although Liu Kang's original auxiliary supports are not preserved, a photograph of the artist taken during the painting session in Saint-Gingolph, Switzerland, in 1929, shows his painting attached to a strainer with a cross-member (Fig. 3a, b). The strainer and canvas do not have a visible manufacturer or retailer stamp or label. Liu Kang's *Self-portrait in Paris* and *Self-portrait*, both from 1931, also document the auxiliary supports with cross-members and without keys (Fig. 3c, d). As these findings

Fig. 3 **a**, **b** Liu Kang during an outdoor painting session in Saint-Gingolph, Switzerland, in 1929; **c** *Self-portrait in Paris*, 1931, oil on canvas, 61 × 46 cm; **d** *Self-portrait*, 1931, oil on canvas, 55 × 46 cm; **e**, **f** Liu Kang during outdoor painting sessions in Shanghai, in 1933. Liu Kang Family Collection. Images courtesy of Liu family



LEFRANC ✳ PARIS

CHASSIS NUS ET TOILES JAUNES, GRISES OU BLANCHES, TENDUES SUR CHASSIS
POUR LA PEINTURE A L'HUILE

Les châssis sont tendus de toile jaune, blanche ou grise, suivant la demande du client, sauf les châssis RÉF. 3753 *tendus de toile blanche.*

Châssis nus et toiles tendues sur châssis.

Numéros des toiles	DIMENSIONS			CHASSIS NUS				CHASSIS TENDUS										Numéros des toiles
				Carrés		Ovales		TOILE POCHADE BLANCHE	TOILE ORDINAIRE			TOILE 1/2 FINE		TOILE FINE				
								Châssis carrés	Châssis carrés		Châssis ovales	Châssis carrés		Châssis carrés		Châssis ovales		
	Figure	Paysage	Marine	Ordinaires n° 110	à Clés n° 111	Ordinaires n° 904	à Clés n° 905	Ordinaires n° 3753	Ordinaires n° 112	à Clés n° 113	Ordinaires n° 114	Ordinaires n° 115	à Clés n° 116	Ordinaires n° 117	à Clés n° 118	à Clés n° 119		
				fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.	fr. c.		
1	22×16	22×14	22×12	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		1
2	24×19	24×16	24×14	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		2
3	27×22	27×19	27×16	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		3
4	33×24	33×22	33×19	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		4
5	35×27	35×24	35×22	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		5
6	41×33	41×27	41×24	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		6
8	46×38	46×33	46×27	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		8
10	55×46	55×38	55×33	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		10
12	61×50	61×46	61×38	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		12
15	65×54	65×50	65×46	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		15
20	73×60	73×54	73×50	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		20
25	81×65	81×60	81×54	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		25
30	92×73	92×65	92×60	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		30
40	100×81	100×73	100×65	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		40
50	116×89	116×81	116×73	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		50
60	130×97	130×89	130×81	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		60
80	146×114	146×97	146×89	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		80
100	162×130	162×114	162×97	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		100
120	195×130	195×114	195×97	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »	» »		120

Fig. 4 List of standard canvas formats, strainers, and stretchers, with and without primed fabrics, from Lefranc's catalogue in 1930

are rare examples of the artist's auxiliary supports, they cannot demonstrate his preference. However, Lefranc's price list from 1924 suggests that stretchers cost approximately twice as much as strainers; therefore, the artist may have opted for strainers as they were cheaper.

The assessment of the format of the paintings was done with reference to contemporary French standards, which became common even beyond France. According to the Lefranc catalogue from 1930, three rectangular formats (portrait, landscape, and marine) were offered in 19 standard sizes, from 22 × 16 cm (number 1) to 195 × 130 cm (number 120). The standard sizes applied to both strainers (*chassis ordinaire*) and keyed stretchers (*chassis à clés*), but without the indication of the cross-members (Fig. 4).

The majority of paintings from Liu Kang's Paris phase were created in plein air (18 paintings), revealing the influences of Impressionists, Post-Impressionists, and Fauvists advocating for plein air and modern life painting [13]. Other subjects that he explored were portraits (seven paintings) and still lifes (four paintings). The dimensions of all examined paintings can be considered to be standard; however, about 1 cm margin of difference from the standard may have resulted from subsequent treatments. It could be speculated that small painting supports (number 10 and 8) were more convenient to carry around on outdoor painting sessions (Figs. 3a, b, 14a–c). Larger painting supports (number 12 and 20), were used sparingly. Financial constraints could also have had an impact on the artist's choice of materials [14]. Therefore, it is worth noting that 11 paintings were created over rejected compositions and four on the reverse side of earlier paintings. A comparison of the paintings' genres with their formats revealed that a total of 16 landscapes and streetscapes were painted in the portrait format. This indicates that the artist did not follow common rules when choosing painting support formats (Table 1).

Regarding the type of auxiliary supports used by Liu Kang in Shanghai, two archival photographs from 1933 are the only evidence providing limited information (Fig. 3e, f). The said photographs captured the reverse sides of his paintings, which showed that they were probably stretched over unbranded strainers. Liu Kang's passion for outdoor painting intensified in Shanghai—out of 26 examined artworks, 24 were in plein air. Their dimensions conformed to common standards. The range of recorded sizes was 10–20. The artist frequently used the portrait format number 10 for outdoor paintings, reflecting his preference for handy painting supports, which we know from the Paris practice. He also bent rules to his preferences and 18 landscapes were painted in the portrait format. It is noticeable that he also employed larger canvases of sizes 15 and 20 with more confidence. Like in Paris, Liu Kang occasionally reused unsuccessful compositions. Of the examined paintings, 13 were painted over earlier, rejected artworks (Table 2).

Table 1 Details of paintings representing Paris phase whose supports were studied

Title and inventory number[a]	Date	Genre	Dimensions H × W (cm)	Orientation	Standard number	Standard format	Painted on earlier composition	Painted on the reverse side	Type of auxiliary support strainer/stretcher/rigid support	Major treatments impacting the examination of the canvases		
										Lining	Strip lining	Loose lining
St Gingolph, Lac Leman, Switzerland	1929	Landscape	45.5 × 37.5	Vertical	8	Portrait	Yes					
My room in Paris	1929	Still life	54 × 45.5	Vertical	10	Portrait			Strainer			
Landscape	1930	Landscape	46 × 38	Vertical	8	Portrait						
French countryside	1930	Landscape	46 × 54.5	Horizontal	10	Portrait						
Cottage with blue shutters, France	1930	Landscape	46 × 54.5	Horizontal	10	Portrait		Yes				
Portrait of a man with his hat, Belgium	1930	Portrait	55 × 45	Vertical	10	Portrait	Yes					
Autumn landscape	1930	Landscape	38.5 × 46	Horizontal	8	Portrait			Strainer			
Man in blue coat, Paris	1930	Portrait	46 × 37	Vertical	8	Portrait						
Village street, France	1930	Streetscape	46 × 55.5	Horizontal	10	Portrait	Yes		Strainer			
Landscape in Switzerland, Acc. no. P-1229	1930	Landscape	45.6 × 55.7	Horizontal	10	Portrait			Stretcher			
Street scene in France, Acc. no. 2003-03366	1930	Streetscape	46 × 54.6	Horizontal	10	Portrait	Yes		Plywood board	Yes		
Countryside in France, Acc. no. 2003-03365	1930	Landscape	46 × 54.7	Horizontal	10	Portrait			Strainer			
Farmers house, Acc. no. GI-0254-(PC)	1930	Landscape	45.5 × 53.5	Horizontal	10	Portrait			Strainer	Yes		
Autumn colours, Acc. no. GI-0255 (PC)	1930	Streetscape	38.3 × 45.3	Horizontal	8	Portrait	Yes		Strainer	Yes		
Zuo La Lu, Acc. no. 1993–00998	1930	Streetscape	46 × 55	Horizontal	10	Portrait	Yes		Strainer			
Still life with books, Paris	1931	Still life	45 × 38	Vertical	8	Portrait						
Portrait of a man with his pipe, Paris	1931	Portrait	45 × 38	Vertical	8	Portrait		Yes				
Self-portrait	1931	Portrait	55 × 46	Vertical	10	Portrait		Yes	Plywood board	Yes		
Self-portrait in Paris	1931	Portrait	61 × 46	Vertical	12	Landscape	Yes		Strainer			
Boats, Etretat	1931	Seascape	46 × 55	Horizontal	10	Portrait	Yes		Strainer			

Table 1 (continued)

Title and inventory number[a]	Date	Genre	Dimensions H × W (cm)	Orientation	Standard number	Standard format	Painted on earlier composition	Painted on the reverse side	Type of auxiliary support strainer/ stretcher/rigid support	Major treatments impacting the examination of the canvases		
										Lining	Strip lining	Loose lining
French lady, Acc. no. 1993-00996	1931	Portrait	60.7 × 45.8	Vertical	12	Landscape			Plywood board	Yes		
Boat near the cliff, Acc. no. 2003-03249	1931	Seascape	53.7 × 72.4	Horizontal	20	Landscape			Strainer		Yes	Yes
Village scene, Acc. no. 2003-03320	1931	Landscape	46 × 55	Horizontal	10	Portrait			Strainer		Yes	
Slope, Acc. no. 2003-03319	1931	Streetscape	46 × 55	Horizontal	10	Portrait		Yes	Strainer		Yes	
Winter, Acc. no. GI-0256	1931	Streetscape	46 × 55	Horizontal	10	Portrait	Yes		Strainer		Yes	
My landlady, Madame Normand	1932	Portrait	54 × 45	Vertical	10	Portrait						
Street	1932	Streetscape	46 × 39	Vertical	8	Portrait			Strainer			
Seafood, Acc. no. 2003-03250	1932	Still life	46 × 55	Horizontal	10	Portrait	Yes		Strainer		Yes	Yes
Breakfast, Acc. no. GI-0257 (PC)	1932	Still life	46 × 54	Horizontal	10	Portrait	Yes		Paper board	Yes		

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

Table 2 Details of paintings representing Shanghai phase whose supports were studied

Title and inventory number[a]	Date	Genre	Dimensions H × W (cm)	Orientation	Standard number	Standard format	Painted on earlier composition	Painted on the reverse side	Type of auxiliary support strainer/stretcher/rigid support	Major treatments impacting the examination of the canvases		
										Lining	Strip lining	Loose lining
Red and white walls	1933	Landscape	55 × 45.5	Vertical	10	Portrait						
Courtyard with tree	1933	Landscape	55.5 × 45.5	Vertical	10	Portrait						
Countryside landscape	1933	Landscape	45 × 54.5	Horizontal	10	Portrait						
Autumn countryside	1933	Landscape	45.5 × 54.5	Horizontal	10	Portrait						
Farmhouse and field	1933	Landscape	60 × 72.5	Horizontal	20	Portrait						
Pagoda near Shanghai	1933	Landscape	73 × 59	Vertical	20	Portrait						
Courtyard, Shanghai	1933	Landscape	73 × 60	Vertical	20	Portrait						
Still life with green stool	1933	Still life	56 × 46	Vertical	10	Portrait	Yes					
Working at the fields, Acc. no. 2003-03258	1933	Landscape	49.5 × 64	Horizontal	15	Landscape			Strainer		Yes	Yes
Countryside in China, Acc. no. 2003-03299	1933	Landscape	60.5 × 72	Horizontal	20	Portrait			Plywood board	Yes		
Countryside near Shanghai	1934	Landscape	46 × 54	Horizontal	10	Portrait						
Village lane	1934	Landscape	45 × 54	Horizontal	10	Portrait	Yes					
Farmhouses	1934	Landscape	45 × 54	Horizontal	10	Portrait						
Rustic landscape	1934	Landscape	54 × 46	Vertical	10	Portrait	Yes					
Backyard, Acc. no. 2003-03252	1934	Landscape	59.5 × 72.5	Horizontal	20	Portrait	Yes		Strainer			
Pagoda	1935	Landscape	45 × 55	Horizontal	10	Portrait	Yes					
Seascape near Shanghai	1935	Landscape	65 × 50	Vertical	15	Landscape	Yes					
House on the hill	1936	Landscape	64 × 49	Vertical	15	Landscape						
Street market I	1936	Landscape	45 × 54.5	Horizontal	10	Portrait	Yes					
Street market II	1936	Landscape	46 × 55	Horizontal	10	Portrait	Yes					
Seaside near Shanghai	1936	Landscape	46 × 55	Horizontal	10	Portrait						
Seascape	1936	Landscape	50 × 64	Horizontal	15	Landscape	Yes					
Nude, Acc. no. 2003-03367	1936	Nude	46 × 54.5	Horizontal	10	Portrait	Yes		Plywood board	Yes		
Waterfall, Acc. no. 2003-03247	1936	Landscape	65 × 50	Vertical	15	Landscape	Yes		Strainer		Yes	Yes

Table 2 (continued)

Title and inventory number[a]	Date	Genre	Dimensions H × W (cm)	Orientation	Standard number	Standard format	Painted on earlier composition	Painted on the reverse side	Type of auxiliary support strainer/ stretcher/rigid support	Major treatments impacting the examination of the canvases		
										Lining	Strip lining	Loose lining
Mount Huangshan, Acc. no. 2003-03369	1936	Landscape	66 × 50	Vertical	15	Landscape	Yes		Strainer		Yes	Yes
Seaside, Acc. no. 2003-03318	1936	Landscape	45 × 54	Horizontal	10	Portrait	Yes		Plywood board	Yes		

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

Fabric types

All the examined Paris paintings were executed on linen canvases made in plain weave with Z-twisted threads of weft and warp. Two types of canvases were identified (Table 3). Type 1 is a low-density canvas with a thread count in the range of 12–13 × 13–14 per cm (Fig. 5a); identified in 20 paintings. Type 2 is a denser canvas with a thread count in the range of 18–19 × 20–21 per cm (Fig. 5b); it was found in nine paintings. Based on the collected data, it appears that the artist's choice of canvas densities was not directed by the size of the planned painting. That can be exemplified by *Boat near the cliff* (1931), measuring 53.7 × 72.4 cm, which was painted on a low-density canvas, while *Autumn colours* (1930), measuring 38.3 × 45.3 cm, was painted on a dense canvas. Although the density of the canvases may vary from one supplier to another, the naming convention for the canvases was consistent across the trade at the turn of the 19th century and reflected the quality and proposed function of the material. The comparison of the features of the examined canvases with those of Binant from 1889 to 1898 [15], Bourgeois Ainé from the post-1906 period [16], and Lefranc from 1927 to 1934 (Fig. 6a) assisted in the preliminary identification of canvas types chosen by Liu Kang. Hence, thin canvases could be equivalent to *étude* or *pochade* grades, whereas denser canvases could be comparable to *demi-fine* or *fine*. As reported by A. Callen, cheap *étude* or *pochade* canvases exhibit excessive weave distortions—primary cusping—during the initial stretching prior to the ground application [16]. Such distortions were observed on four thin and two denser canvases.

The lack of a manufacturer's or retailer's stamp on the examined Paris canvases could mean that they were sold in lengths, by the metre, or purchased from small-scale retailers who did not brand the canvases. According to the 1930 Lefranc catalogue, bare and primed canvases were offered in rolls 10 × 2 m and 5 × 2 m as well as per square metre. The company also offered canvases prepared for decorative painting in rolls from 2 to 8 m wide and of unlimited length (Fig. 6a, b). As the art materials market in Paris was competitive, it is possible that other retailers offered similar items at more affordable prices.

As for the paintings executed in Shanghai, two types of painting supports were identified (Table 4). Type 1 comprises a dense, plain weave, cotton canvas, identified in 19 paintings; this type is characterised by a notable inconsistency of thread count in the range of 15–17 × 18–20 per cm (Fig. 5c), probably caused by uneven stretching forces before the ground application. Primary cusping, reflecting a susceptibility of the canvas to distortions, was observed in 10 paintings. Interestingly, the reverse side of *Rustic landscape* (1934) bears three similar stamps containing traditional Chinese characters. Although the poor print renders the top two characters almost illegible, it was possible to unravel the remaining six characters, as follows: 用 (yòng), 品 (pǐn), 商 (shāng), 店 (diàn), 經 (jīng), 售 (shòu) (Fig. 7a, b). Considering that Chinese words often consisted of characters appearing in pairs, a probable translation of the pairs of characters could be: "supplies (用品), shop (商店), sale (經售)", which together mean "sold by supplies shop". Hence, it is clear that the stamps correspond to a retailer of art materials. The first two characters might refer to the retailer, or they might be the family or place name or a generic word indicating the type of "supplies".

Type 2 comprises a low density, plain weave, linen canvas with a thread count approximating 10 × 10 per cm (Fig. 5d); this canvas type was identified in five paintings. The threads of weft and warp are characterised by an S-twist, suggesting a different manufacturing process. Primary cusping, was observed in three paintings. Exceptionally, the canvases for *Still life with green stool* (1933) and *Backyard* (1934) were made of linen, corresponding to Paris type 2. The collected data does not show a correlation between the sizes and thickness of the canvases of both types, suggesting flexibility in the artist's choices.

According to the advertisements of art suppliers, local and imported painting materials were readily available at dedicated shops or major stationery and bookstores in Shanghai (Fig. 2). However, our knowledge about the types of canvases available then remains limited. Western brands, such as W&N and R&S, were popular in pre-war Shanghai [7]. Therefore, it can be assumed that products available in Britain were also offered in China. The R&S catalogue from 1926 listed both linen and cotton canvases, while the W&N catalogue from 1934 offered "artists' prepared canvas", such as linen, jute, cotton, mixture of hemp and cotton in rolls, stretched over wedged and bevelled stretchers of standard sizes (Fig. 8a, b) [17]. Cotton canvases were preferred by Liu Kang. Considering that his teaching salary at Shanghai Art Academy was modest [6, 18], it can be deduced that Liu Kang preferred the more affordable local materials over the imported ones.

Characteristics of the grounds

Of the 29 examined Paris paintings, 19 have intact tacking margins with the ground layer on, suggesting a commercial preparation. The remaining 10 paintings have either cut-off tacking margins or were created on the unprepared reverse side of earlier compositions. Interestingly, five paintings created between 1929 and 1930, showed a partial ground coverage of tacking margins (Fig. 9, Table 5). It can be assumed that these canvases were part of long and wide pieces and the unprimed areas could have been used for mounting on a large frame for the commercial application of a ground.

Table 3 Summary of canvas characteristic of Paris phase paintings

Title and inventory number[a]	Date	Primary cusping	Weave	Average thread count/cm	Direction of warp	Twist	Fibre	Type of canvas
St Gingolph, Lac Leman, Switzerland	1929	Yes	Plain	V 14 × H 12	Vertical	Z	Linen	1
My room in Paris	1929	Yes	Plain	V 12 × H 14	Horizontal	Z	Linen	1
Landscape	1930	No	Plain	V 14 × H 12	Vertical	Z	Linen	1
French countryside	1930		Plain	V 13 × H 13		Z	Linen	1
Cottage with blue shutters, France	1930		Plain	V 13 × H 13		Z	Linen	1
Portrait of a man with his hat, Belgium	1930	No	Plain	V 13 × H 14	Horizontal	Z	Linen	1
Autumn landscape	1930	No	Plain	V 13 × H 12	Vertical	Z	Linen	1
Man in blue coat, Paris	1930	Yes	Plain	V 14 × H 13	Vertical	Z	Linen	1
Village street, France	1930	No	Plain	V 20 × H 18	Vertical	Z	Linen	2
Landscape in Switzerland, Acc. no. P-1229	1930	Yes	Plain	V 14 × H 13	Vertical	Z	Linen	1
Street scene in France, Acc. no. 2003–03366	1930		Plain	V 13 × H 14	Horizontal	Z	Linen	1
Countryside in France, Acc. no. 2003–03365	1930	No	Plain	V 19 × H 21	Horizontal	Z	Linen	2
Farmers house, Acc. no. GI-0254-(PC)	1930		Plain	V 21 × H 19	Vertical	Z	Linen	2
Autumn colours, Acc. no. GI-0255 (PC)	1930		Plain	V 18 × H 21	Horizontal	Z	Linen	2
Zuo La Lu, Acc. no. 1993–00998	1930	No	Plain	V 14 × H 13	Vertical	Z	Linen	1
Still life with books, Paris	1931		Plain	V 12 × H 13	Horizontal	Z	Linen	1
Portrait of a man with his pipe, Paris	1931		Plain	V 12 × H 13	Horizontal	Z	Linen	1
Self-portrait	1931		Plain	V 13 × H 13		Z	Linen	1
Self-portrait in Paris	1931	Yes	Plain	V 18 × H 20	Horizontal	Z	Linen	2
Boats, Etretat	1931	No	Plain	V 19 × H 20	Horizontal	Z	Linen	2
French lady, Acc. no. 1993–00996	1931		Plain	V 14 × H 13	Vertical	Z	Linen	1
Boat near the cliff, Acc. no. 2003–03249	1931		Plain	V 13 × H 13		Z	Linen	1

Table 3 (continued)

Title and inventory number[a]	Date	Primary cusping	Weave	Average thread count/cm	Direction of warp	Twist	Fibre	Type of canvas
Village scene, Acc. no. 2003–03320	1931		Plain	V 13 × H 13		Z	Linen	1
Slope, Acc. no. 2003–03319	1931		Plain	V 13 × H 13		Z	Linen	1
Winter, Acc. no. GI-0256	1931	No	Plain	V 14 × H 13	Vertical	Z	Linen	1
My landlady, Madame Normand	1932	Yes	Plain	V 18 × H 20	Horizontal	Z	Linen	2
Street	1932	No	Plain	V 12 × H 14	Horizontal	Z	Linen	1
Seafood, Acc. no. 2003–03250	1932	No	Plain	V 21 × H 19	Vertical	Z	Linen	2
Breakfast, Acc. no. GI-0257 (PC)	1932		Plain	V 20 × H 18	Vertical	Z	Linen	2

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

Table 4 Summary of canvas characteristic of Shanghai phase paintings

Title and inventory number[a]	Date	Primary cusping	Weave	Average thread count/cm	Direction of warp	Twist	Fibre	Type of canvas
Red and white walls	1933	Yes	Plain	V 15 × H 19	Horizontal	Z	Cotton	1
Courtyard with tree	1933	Yes	Plain	V 15 × H 20	Horizontal	Z	Cotton	1
Countryside landscape	1933	Yes	Plain	V 19 × H 16	Vertical	Z	Cotton	1
Autumn Countryside	1933	Yes	Plain	V 20 × H 17	Vertical	Z	Cotton	1
Farmhouse and field	1933	No	Plain	V 15 × H 19	Horizontal	Z	Cotton	1
Pagoda near Shanghai	1933	No	Plain	V 19 × H 15	Vertical	Z	Cotton	1
Courtyard, Shanghai	1933	No	Plain	V 19 × H 15	Vertical	Z	Cotton	1
Still life with green stool	1933	No	Plain	V 20 × H 18	Vertical	Z	Linen	Paris 2
Working at the fields, Acc. no. 2003–03258	1933		Plain	V 19 × H 17	Vertical	Z	Cotton	1
Countryside in China, Acc. No. 2003–03299	1933		Plain	V 17 × H 19	Horizontal	Z	Cotton	1
Countryside near Shanghai	1934	Yes	Plain	V 18 × H 16	Vertical	Z	Cotton	1
Village lane	1934	Yes	Plain	V 19 × H 16	Vertical	Z	Cotton	1
Farmhouses	1934	No	Plain	V 19 × H 15	Vertical	Z	Cotton	1
Rustic landscape	1934	No	Plain	V 15 × H 19	Horizontal	Z	Cotton	1
Backyard, Acc. no. 2003–03252	1934	No	Plain	V 19 × H 21	Horizontal	Z	Linen	Paris 2
Pagoda	1935	Yes	Plain	V 18 × H 16	Vertical	Z	Cotton	1
Seascape near Shanghai	1935	Yes	Plain	V 15 × H 18	Horizontal	Z	Cotton	1
House on the hill	1936	Yes	Plain	V 10 × H 11	Horizontal	S	Linen	2
Street market I	1936	No	Plain	V 10 × H 10	Horizontal	S	Linen	2
Street market II	1936	No	Plain	V 19 × H 15	Vertical	Z	Cotton	1
Seaside near Shanghai	1936	Yes	Plain	V 10 × H 10		S	Linen	2
Seascape	1936	Yes	Plain	V 17 × H 19	Horizontal	Z	Cotton	1
Nude, Acc. no. 2003–03367	1936	Yes	Plain	V 18 × H 17	Vertical	Z	Cotton	1
Waterfall, Acc. no. 2003–03247	1936	Yes	Plain	V 10 × H 10		S	Linen	2
Mount Huangshan, Acc. No. 2003–03369	1936		Plain	V 19 × H 16	Vertical	Z	Cotton	1
Seaside, Acc. No. 2003–03318	1936		Plain	V 11 × H 10	Vertical	S	Linen	2

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

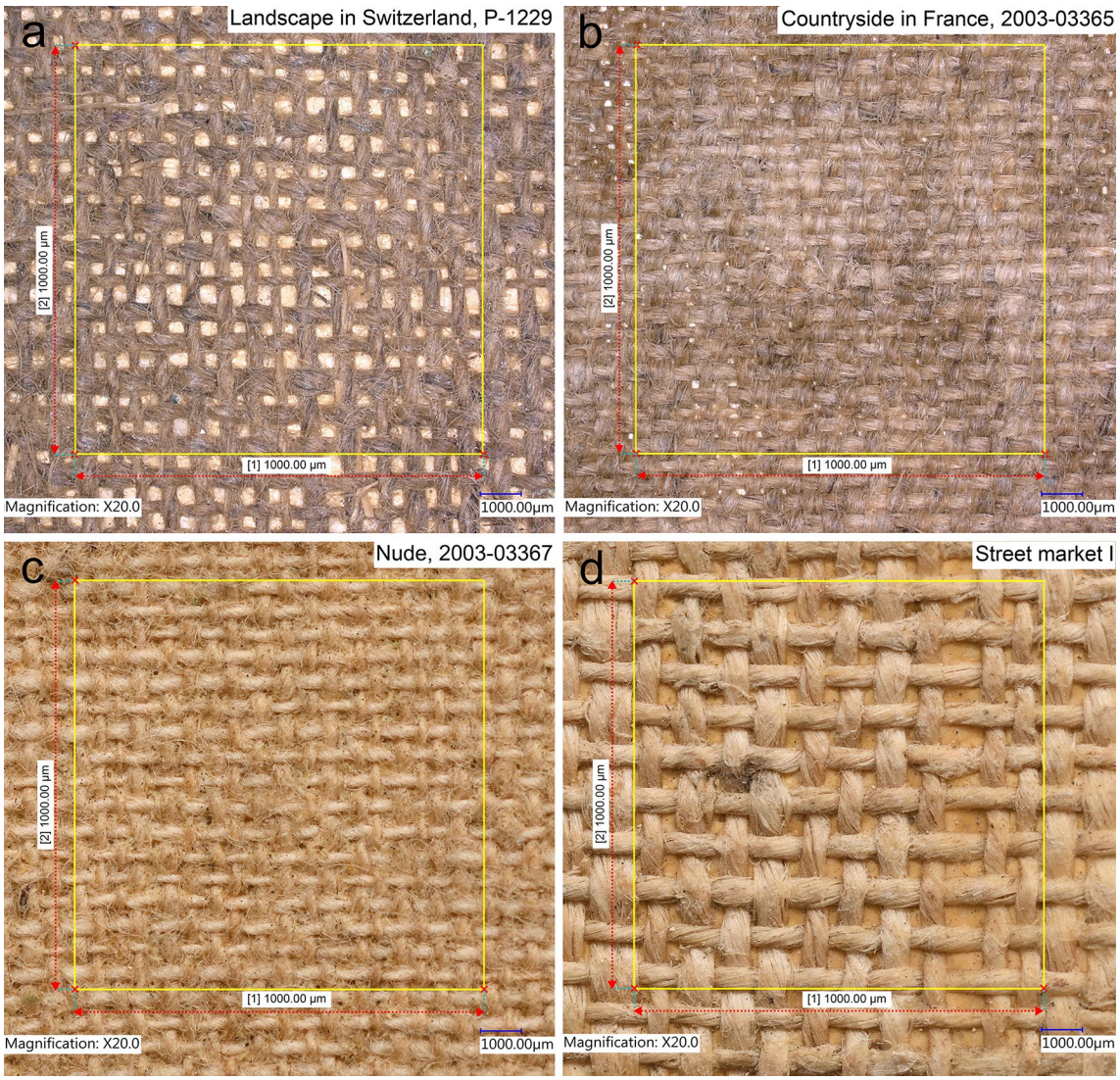


Fig. 5 Photomicrographs of different types of canvases identified in the Paris and Shanghai paintings; from Paris: **a** canvas type 1; **b** canvas type 2; from Shanghai: **c** canvas type 1; **d** canvas type 2

Based on the acquired data, all grounds are white and single-layered, partially revealing the canvas weave. The variations recorded in the compositions allowed to determine five different types of grounds (Table 5).

The ground of type 1 was identified in 10 paintings, including—as mentioned earlier—five canvases with a partial ground coverage of the tacking margins. It is a mixture of clumps of lead white (lead carbonate) and fine particles of chalk (calcium carbonate) with minor or trace amounts of zinc white (zinc oxide) (Fig. 10a, b). Literature sources indicate that lead white was available in various quality grades, usually modified due to its yellow hue or to reduce the manufacturing cost. Barium white (barium sulphate), zinc white, gypsum (calcium sulphate), and chalk were commonly used to modify or adulterate lead white [16, 19, 20]. For the binding medium, a drying oil was confirmed with FTIR by peaks at 2920, 2850, 1735, 1456, 1168, 721 (±5) cm^{-1}. However, the ground sample from *St Gingolph, Lac Leman, Switzerland* (1929) also displayed peaks indicative of proteins at 1630 and 1539 cm^{-1}. On one hand, this finding could suggest that the ground is a semi-absorbent emulsion of animal glue and oil binders and should be classified as a separate type. On the other hand, this could be an oil-based ground that absorbed proteins from the sized canvas [21]; however,

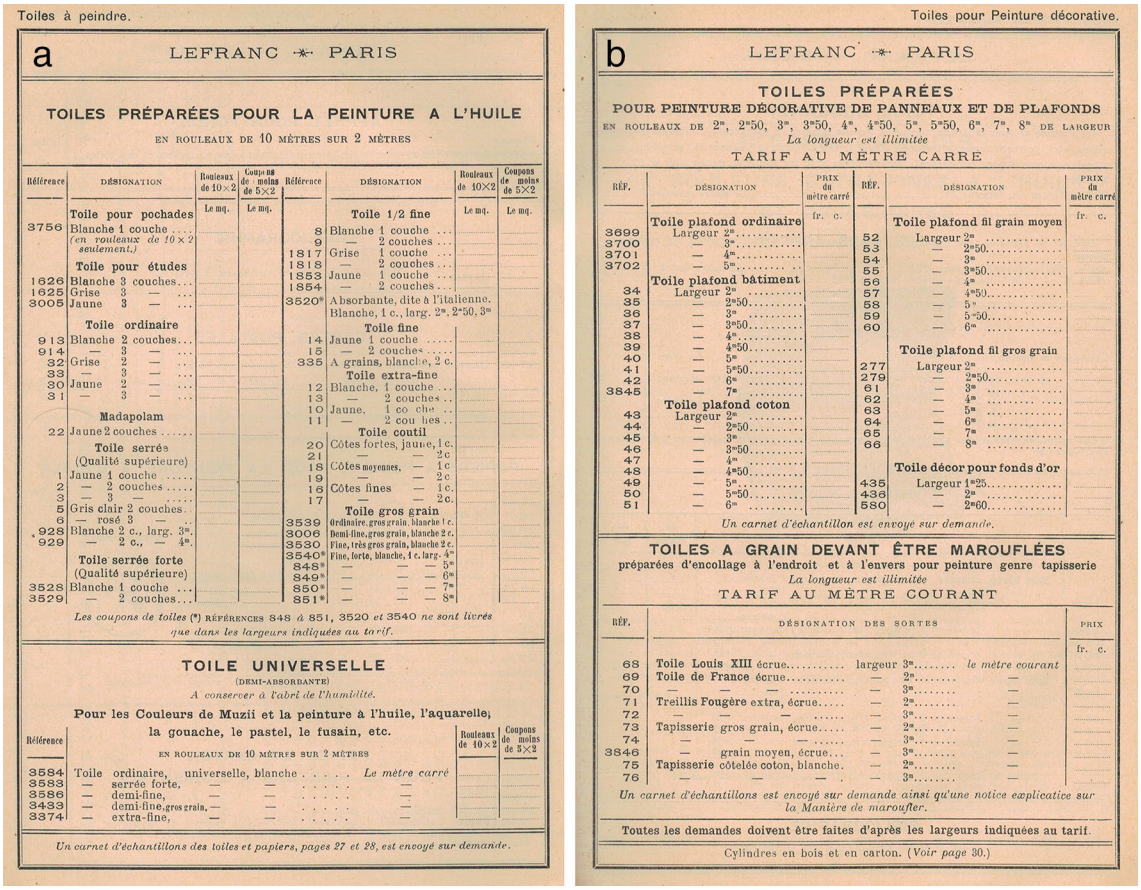


Fig. 6 List of commercially prepared (**a**) and raw canvases (**b**) available from Lefranc in 1930

this presumption requires FTIR analyses of more samples extracted from the painting. Additionally, a presence of lead soap formation was confirmed in two examined ground samples with FTIR by peaks at 2955, 2873, 1540 and 1515 cm^{-1} (Fig. 11a) [22–24].

The ground of type 2 was found in three paintings, and the elements identified are attributable to lead white extended with barium, zinc, and titanium (titanium dioxide) whites. The structure of these grounds is characterised by large, rectangular particles of barium white and clusters of lead white (Fig. 10c, d). The detection of Ti conforms to the introduction of titanium white by Bourgeois Ainé in 1925 and Lefranc in 1927 [25]. FTIR confirmed oil by absorption peaks at around 2919, 2849, 1737, 1460, 1243, 1172 cm^{-1} and suggests a concomitant presence of proteins. However, while proteins were confirmed in one examined ground sample, their identification in the remaining two samples was inconclusive due to overlapping peaks of zinc soap at 1540 cm^{-1} (Fig. 11b) [26–28]. Nevertheless, it is difficult to determine if the examined type of grounds is semi-absorbent emulsion of animal glue and oil binders or absorbent ground bound with animal glue as the oil may have originated from the artist's paint.

The ground of type 3 contains lead white extended with barium white and chalk. A concomitant presence of Sr and S in the analysed samples suggest strontium sulphate, a common impurity of barium white [29, 30]. This ground composition was identified in two paintings. The optical microscopy and SEM-BSE images of this type of grounds show a non-homogenous structure containing poorly ground particles of barium white and clumps of lead white (Fig. 10e, f). A drying oil was used as a binder, and lead soap was confirmed by peaks at 1515 and 1540 cm^{-1} in one sample.

The ground of type 4 was identified in two paintings and contains large and roughly ground chalk particles as the main component, mixed with lead and zinc whites (Fig. 10g, h). The grounds contain oil detected in *Man in blue coat* (1930) by peaks at 2917, 2849, 1734, 1456, 1233,

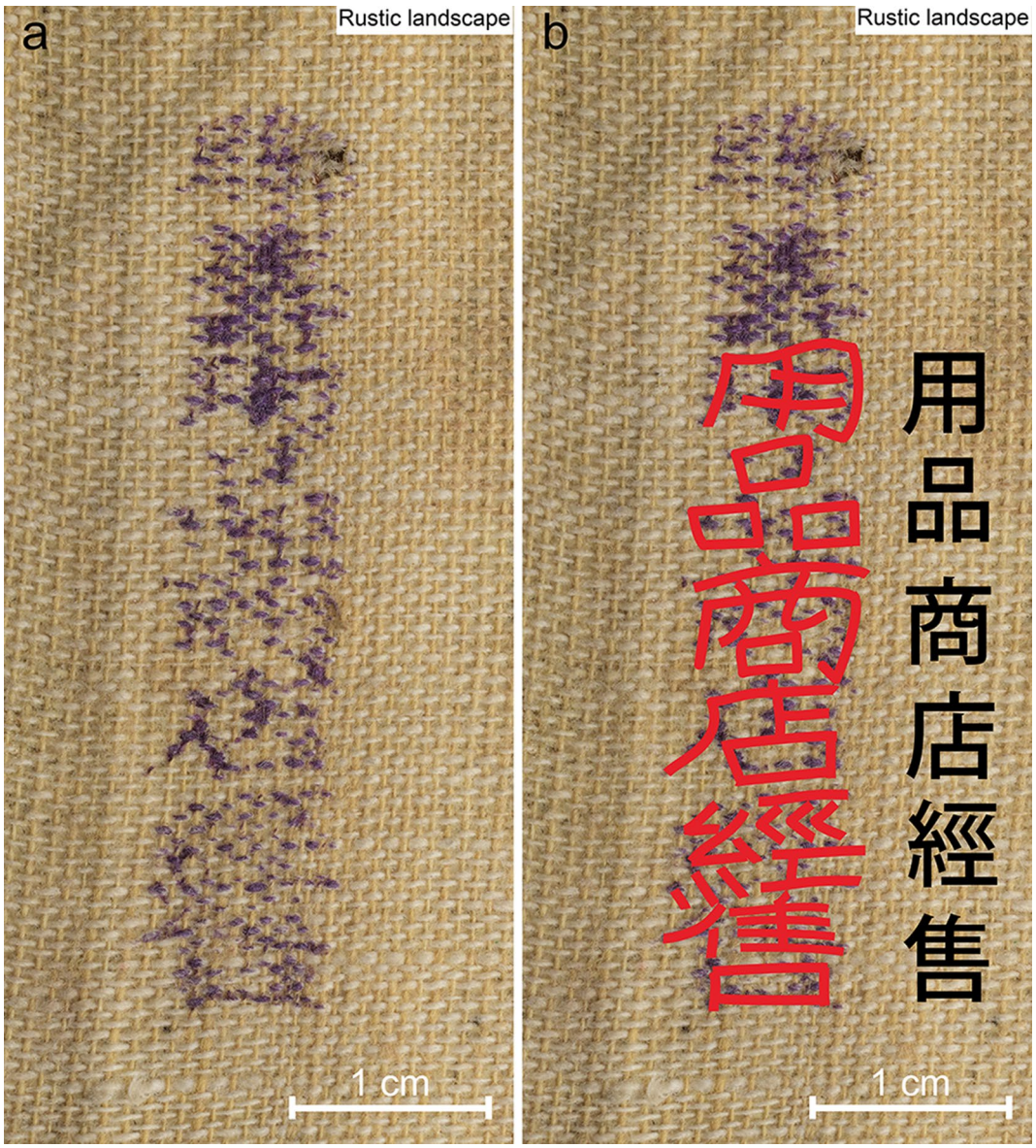
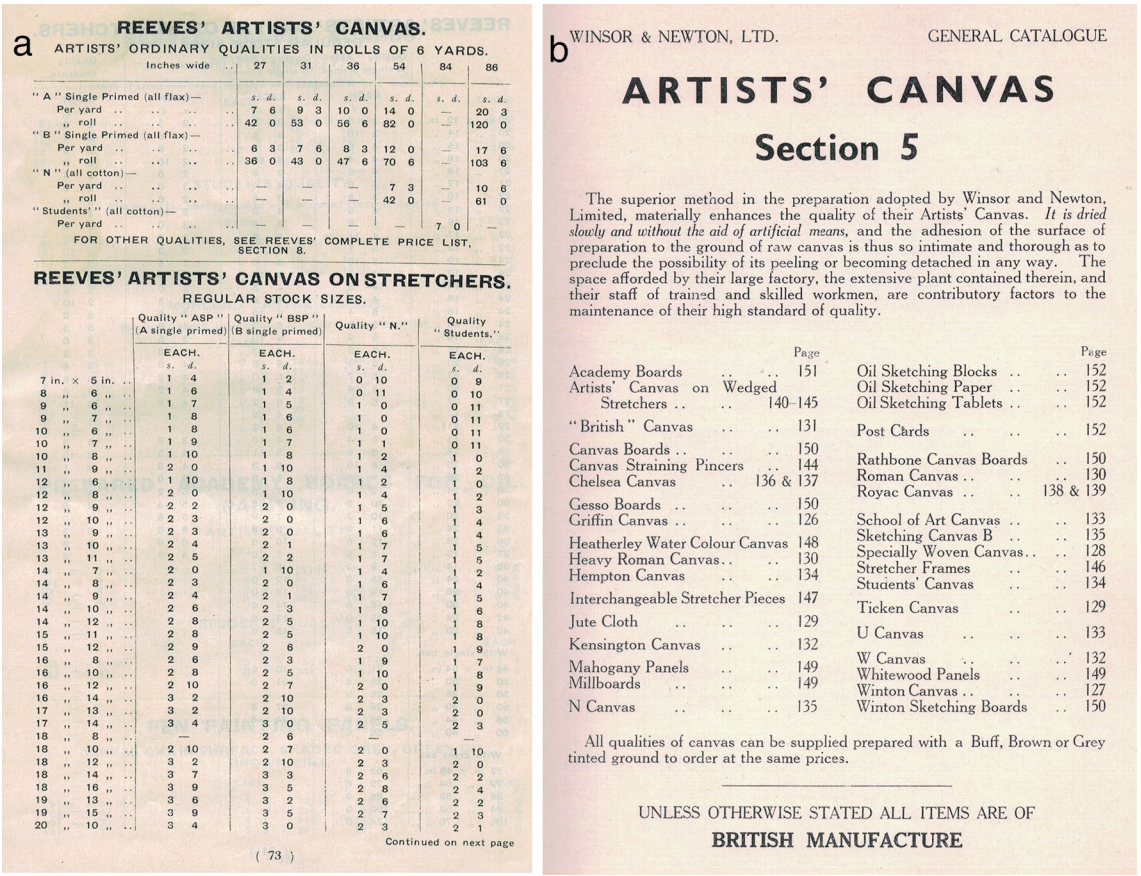


Fig. 7 Detail of the reverse side of *Rustic landscape* (1934) showing a retailer's stamp (**a**). Image (**b**) shows the stamp with superimposed tracing of the characters (red) and the Chinese characters for reference (black)

1160, 1103 cm^{-1} and in *Zuo La Lu* (1930) by peaks at 2952, 2918, 2849, 1728, 1151 cm^{-1}. A concomitant presence of proteins was confirmed in the ground from *Man in blue coat* by peaks at 1636 and 1533 cm^{-1}. The presence of proteins in the ground from *Zuo La Lu* remains inconclusive due to an overlapping band of zinc soap at 1538 cm^{-1}.

The ground of type 5, also detected in two paintings, is composed of small particles of chalk well mixed with lithopone (mixture of zinc sulphide and barium sulphate) and/or barium white and zinc white, as well as lead and titanium whites (Fig. 10i, j). A presence of drying oil was detected by peaks at 2923, 2853, 1734, 1456, 1168, 1097, 721 cm^{-1} and the presence of proteins was detected by peaks at 1646 and 1527 cm^{-1} in one available ground sample. The formation of zinc soap was detected by absorption peak at 1539 cm^{-1} (Fig. 12c).

The obtained results are not conclusive about whether the grounds of types 4 and 5 are semi-absorbent or absorbent as it is possible that the oil might also have come from the paint, as clearly seen on the reverse side of *My landlady, Madame*



a

REEVES' ARTISTS' CANVAS.

ARTISTS' ORDINARY QUALITIES IN ROLLS OF 6 YARDS.

	Inches wide ..	27	31	36	54	84	86
		s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
"A" Single Primed (all flax)—							
Per yard		7 6	9 3	10 0	14 0	—	20 3
,, roll		42 0	53 0	56 6	82 0	—	120 0
"B" Single Primed (all flax)—							
Per yard		6 3	7 6	8 3	12 0	—	17 6
,, roll		36 0	43 0	47 6	70 6	—	103 6
"N" (all cotton)—							
Per yard		—	—	—	7 3	—	10 6
,, roll		—	—	—	42 0	—	61 0
"Students'" (all cotton)—							
Per yard		—	—	—	—	7 0	—

FOR OTHER QUALITIES, SEE REEVES' COMPLETE PRICE LIST, SECTION 8.

REEVES' ARTISTS' CANVAS ON STRETCHERS.

REGULAR STOCK SIZES.

	Quality "ASP" (A single primed)	Quality "BSP" (B single primed)	Quality "N."	Quality "Students."
	EACH.	EACH.	EACH.	EACH.
	s. d.	s. d.	s. d.	s. d.
7 in. × 5 in. ..	1 4	1 2	0 10	0 9
8 ,, 6 ,, ..	1 6	1 4	0 11	0 10
9 ,, 6 ,, ..	1 7	1 5	1 0	0 11
9 ,, 7 ,, ..	1 8	1 6	1 0	0 11
10 ,, 6 ,, ..	1 8	1 6	1 0	0 11
10 ,, 7 ,, ..	1 9	1 7	1 1	0 11
10 ,, 8 ,, ..	1 10	1 8	1 2	1 0
11 ,, 9 ,, ..	2 0	1 10	1 4	1 2
12 ,, 6 ,, ..	1 10	1 8	1 2	1 0
12 ,, 8 ,, ..	2 0	1 10	1 4	1 2
12 ,, 9 ,, ..	2 2	2 0	1 5	1 3
12 ,, 10 ,, ..	2 3	2 0	1 6	1 4
13 ,, 9 ,, ..	2 3	2 0	1 6	1 4
13 ,, 10 ,, ..	2 4	2 1	1 7	1 5
13 ,, 11 ,, ..	2 5	2 2	1 7	1 5
14 ,, 7 ,, ..	2 0	1 10	1 4	1 2
14 ,, 8 ,, ..	2 3	2 0	1 6	1 4
14 ,, 9 ,, ..	2 4	2 1	1 7	1 5
14 ,, 10 ,, ..	2 6	2 3	1 8	1 6
14 ,, 12 ,, ..	2 8	2 5	1 10	1 8
15 ,, 11 ,, ..	2 8	2 5	1 10	1 8
15 ,, 12 ,, ..	2 9	2 6	2 0	1 9
16 ,, 8 ,, ..	2 6	2 3	1 9	1 7
16 ,, 10 ,, ..	2 8	2 5	1 10	1 8
16 ,, 12 ,, ..	2 10	2 7	2 0	1 9
16 ,, 14 ,, ..	3 2	2 10	2 3	2 0
17 ,, 13 ,, ..	3 2	2 10	2 3	2 0
17 ,, 14 ,, ..	3 4	3 0	2 5	2 3
18 ,, 8 ,, ..	—	2 6	—	—
18 ,, 10 ,, ..	2 10	2 7	2 0	1 10
18 ,, 12 ,, ..	3 2	2 10	2 3	2 0
18 ,, 14 ,, ..	3 7	3 3	2 6	2 2
18 ,, 16 ,, ..	3 9	3 5	2 8	2 4
19 ,, 13 ,, ..	3 6	3 2	2 6	2 2
19 ,, 15 ,, ..	3 9	3 5	2 7	2 3
20 ,, 10 ,, ..	3 4	3 0	2 3	2 1

Continued on next page

b

WINSOR & NEWTON, LTD. GENERAL CATALOGUE

ARTISTS' CANVAS

Section 5

The superior method in the preparation adopted by Winsor and Newton, Limited, materially enhances the quality of their Artists' Canvas. *It is dried slowly and without the aid of artificial means*, and the adhesion of the surface of preparation to the ground of raw canvas is thus so intimate and thorough as to preclude the possibility of its peeling or becoming detached in any way. The space afforded by their large factory, the extensive plant contained therein, and their staff of trained and skilled workmen, are contributory factors to the maintenance of their high standard of quality.

All qualities of canvas can be supplied prepared with a Buff, Brown or Grey tinted ground to order at the same prices.

UNLESS OTHERWISE STATED ALL ITEMS ARE OF

BRITISH MANUFACTURE

Fig. 8 List of commercially prepared canvases available from: **a** R&S in 1926; **d** W&N in 1934

Normand (1932). The figure outline in thinned paint penetrated through to the back of the canvas (Fig. 12a, b).

Commercially prepared canvases with varied degrees of ground absorbency were available for artists from Lefranc, among others, in 1930 (Fig. 6a). The main advantage of semi-absorbent and absorbent grounds is the ability to absorb the oil from the paint and to accelerate drying, a feature especially desired during plein air painting and rapid sketching. These types of ground were also considered for producing a bright, rough paint surface that scattered light and was less prone to darkening. Their use by Liu Kang would be reasonable as most of his paintings were created outdoors; however, a comparison of the grounds with the subject matter did not reveal any noticeable correlation. It is unclear whether the artist deliberately selected these grounds for his work to take advantage of their properties.

A comparison of the grounds' formulation with the density of the canvases revealed a distinct correlation between them. The grounds of type 1 and 4 were identified on thin linen fabrics. However, the former makes up the most often used painting support. This suggests that the artist purchased them in larger quantities. In contrast, grounds of type 2 and 3 were found on thick linen fabrics. Only grounds of type 5 were found on fabrics of both densities.

The evidence collected from 15 paintings created in Paris confirmed that artist did not mind reusing his earlier compositions or utilising their reverse sides if he was short of painting supports. These paintings were created without the application of an intermediate ground layer [14]. Hence, it could be possible that Liu Kang had seen a few, rare, examples of such an approach among Impressionist and Neo-impressionist painters [16], whose works influenced his own [13]. Moreover, an investigation of the canvases and grounds of paintings created in Switzerland—*St Gingolph, Lac Leman, Switzerland* (1929), and *Landscape in Switzerland* (1930)—and Belgium—*Portrait of a man with his hat* (1930)—revealed identical features to the canvases and grounds used in Paris. This indicates that artist brought

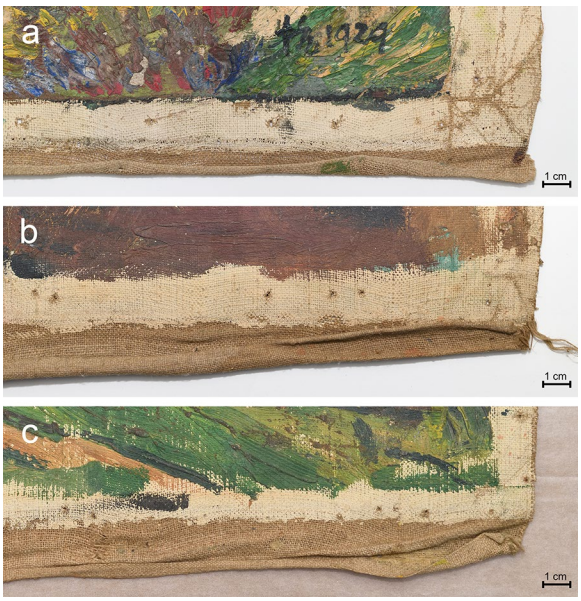


Fig. 9 Close-ups of the partial ground coverage found on the tacking margins of: **a** *St Gingolph, Lac Leman, Switzerland*, 1929, oil on canvas, 45.5 × 37.5 cm; **b** *Portrait of a man with his hat, Belgium*, 1930, oil on canvas, 55 × 45 cm; **c** *French countryside*, 1930, oil on canvas, 46 × 54.5 cm. Liu Kang Family Collection. Images courtesy of Liu family

painting supports from Paris for his painting sessions in Switzerland and Belgium.

As for the paintings from Shanghai, 22 examined artworks out of the 26 show preserved tacking margins with a white ground indicating a commercial preparation. All examined grounds are single-layered and their composition is different from those prepared in Paris.

SEM–EDS and FTIR analyses allowed us to identify two types of grounds (Table 6). Type 1, detected in 23 paintings, contains a high concentration of chalk with admixtures of lithophone and/or barium white and zinc white, with trace amounts of titanium white and/or lead white. The structure of this type of ground is characterised by large and poorly ground particles of chalk (Fig. 13a, b). A concomitant presence of drying oil and proteins was detected in five examined ground samples. The proteins were either identified by bands at around 1635 cm^{-1} or 1536 cm^{-1}. However, the latter band was challenging to interpret due to an overlapping band of zinc soap at 1540 cm^{-1} and the presence of a wide band of chalk at 1400 cm^{-1}. In the remaining paintings, oil was prevalent while the identification of proteins was inconclusive due to absent or weak absorption peaks at 1636 cm^{-1} and an overlapping absorption band of zinc soap. This leads to the conclusion that the examined group of grounds could be semi-absorbent or absorbent, with oil originating from the artist's paint. Dark outlines observed on the reverse side of three paintings seem to support this notion.

The ground of type 2 was identified in one painting. It is oil-based, composed of lithopone and/or barium white with zinc white and trace amounts of lead white. Its structure is homogenous with small and well-mixed ingredients (Fig. 13c, d). A distinctive absorption peak at 1539 cm^{-1} confirmed the formation of zinc soaps.

In *Still life with green stool* (1933) and *Backyard* (1934), the canvas structure and ground formulation are consistent with the Paris painting supports, suggesting that artist reused earlier artworks created in France.

Both R&S and W&N, which were active at that time in Shanghai, did not distinguish between absorbent and non-absorbent canvases. However, we know from the catalogues that R&S offered "single primed" linen and cotton canvases in 1926 (Fig. 8a). W&N listed "single" and "full primed" canvases in their 1934 London catalogue. The latter was usually composed of three coats of ground [17]. A comparison of the composition of the grounds with the density of the canvases revealed that the ground of type 1 is present on both cotton and linen canvases. However, its predominance on cotton canvases suggests a bulk purchase by the artist. The ground of type 2 was found on one cotton canvas. The evidence collected from 13 Shanghai paintings suggests that Liu Kang continued his practice of reusing earlier canvases without the application of an intermediate ground layer [14].

Formation of metal soaps

As illustrated in the Tables 5 and 6, the pervasive formation of metal soaps has been detected in many of the analysed ground samples. Their presence is probably due to the reaction of metals in the lead- and zinc-containing pigments, with free fatty acids from the oil binder. However, their formation may be accelerated by the quality of the ingredient materials as well as the environmental condition [31]. Coarse pigment particles used for the grounds enhanced their porosity, leading to an increased absorption of more oil from the paints. In addition, the exposure of the paintings to the hot and humid tropical climate of Singapore could also have played an important role in the development of the soap formations [32–34]. Future care and conservation treatments of the paintings should minimise the risk of their exposure to high relative humidity and take into consideration a negative impact of heat and moisture during the lining, consolidation and aqueous cleaning procedures [33, 35].

Stretching practice and role of auxiliary supports

The collected archival evidence seems to support the notion that in both locations, Liu Kang used

Table 5 Summary of ground characteristic of Paris phase paintings

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
St Gingolph, Lac Leman, Switzerland	1929	Yes	Yes	Yes	No	*Pb*, *C*, *O*, (Zn, Ca, Na, Al, Mg, Ba)	Lead white, traces of lithopone and/or barium white and zinc white, chalk, oil, proteins	Lead white, traces of lithopone and/or barium white and zinc white, chalk, oil, proteins	1
My room in Paris	1929	Yes	Yes	No	No				
Landscape	1930	Yes	Yes	No	No	*O*, *C*, *Pb*, *Ca*, *Zn*, Na, (Si, Al)		Lead white, chalk, zinc white	1
French countryside	1930	Yes	Yes	Yes		*Pb*, *C*, *O*, (Ca, Mg)		Lead white, traces of chalk	1
Cottage with blue shutters, France	1930	Yes	No	No					
Portrait of a man with his hat, Belgium	1930	Yes	Yes	Yes	No	*Pb*, *O*, *C*, Ca, (Mg, Cr, Zn, Si, Al)	Lead white, chalk, oil	Lead white, chalk, traces of zinc white, oil	1
Autumn landscape	1930	Yes	Yes	No	No				
Man in blue coat, Paris	1930	Yes	Yes	No	No	*C*, *O*, *Ca*, Pb, Zn, Na, (As, Cr, Si, Al, Ba)	Chalk, lead white, oil, proteins, zinc soap	Chalk, lead white, zinc white, zinc soap, oil, proteins, traces of As, Cr considered as contamination	4
Village street, France	1930	Yes	Yes	No	Yes				
Landscape in Switzerland, Acc. no. P-1229	1930	Yes	Yes	Yes	No	*Pb*, *C*, *O*, (Cl, Zn, Al, Ba, Cr, Na, Si)	Lead white, lithopone and/or barium white and zinc white, oil lead soap	Lead white, lithopone and/or barium white and zinc white, oil, lead soap	1
Street scene in France, Acc. no. 2003–03366	1930	Yes	Yes	Yes		*Pb*, *O*, C, (Mg, Ca, Si)	Lead white, oil	Lead white, traces of chalk, oil	1
Countryside in France, Acc. no. 2003–03365	1930	Yes	Yes	No	No	*C*, *Pb*, *O*, *Ba*, Ti, Zn, S, Na, (Fe, Si, Al)	Lead white, barium white, zinc white, oil, proteins	Lead white, barium white, zinc white, titanium white, oil, proteins	2
Farmers house, Acc. no. GI-0254-(PC)	1930	No				*Pb*, *C*, *O*, *Ba*, Ti, Zn, S, Na, (Ca, Si, Al)	Lead white, barium white, zinc white, traces of chalk, oil, zinc soap	Lead white, barium white, zinc white, titanium white, traces of chalk, oil, zinc soap	2

Table 5 (continued)

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Autumn colours, Acc. no. GI-0255 (PC)	1930	No				*Pb*, *Ba*, *O*, *C*, S, (Sr, Si, Ca, Al, Na, Fe)	Lead white, barium white, oil, lead soap	Lead white, barium white, traces of chalk, oil, lead soap	3
Zuo La Lu, Acc. no. 1993–00998	1930	Yes	Yes	No		*O*, *C*, *Ca*, Pb, Zn, Na, (Si, Al, Mg)	Chalk, lead white, oil, unconfirmed detection of proteins due to the overlapping peak of zinc soap	Chalk, lead white, zinc white, oil, unconfirmed detection of proteins due to the overlapping peak of zinc soap	4
Still life with books, Paris	1931	No				*C*, *O*, *Ba*, *Ca*, Zn, S, Pb, (Ti, Si, Al, Mg)		Lithopone and/or barium white and zinc white, chalk, lead white, traces of titanium white	5
Portrait of a man with his pipe, Paris	1931	No							
Self-portrait	1931	No							
Self-portrait in Paris	1931	Yes	Yes	No	Yes				
Boats, Etretat	1931	Yes	Yes	No	No				
French lady, Acc. no. 1993–00996	1931	No				*Pb*, *C*, *O*, (Ca, Cl, Zn, Na, Si, Al)	Lead white, oil, lead soap	Lead white, traces of chalk and zinc white, oil, lead soap	1
Boat near the cliff, Acc. no. 2003–03249	1931	Yes	Yes	No		*Pb*, *C*, *O*, Zn, (Na, Al)	Lead white, oil	Lead white, zinc white, oil	1
Village scene, Acc. no. 2003–03320	1931	Yes	Yes	No		*Pb*, *C*, *O*, (Ca, S, Zn, Al, Na)	Lead white, oil	Lead white, traces of chalk and zinc white, oil	1
Slope, Acc. no. 2003–03319	1931	Yes	No	No					
Winter, Acc. no. GI-0256	1931	No				*Pb*, *O*, *C*, (Ca, Mg, Si, Na)	Lead white, oil	Lead white, traces of chalk, oil	1
My landlady, Madame Normand	1932	Yes	Yes	No	Yes	*O*, *C*, *Ca*, Ba, Zn, S, (Na, Pb, Ti)	Chalk, lithopone and/or barium white and zinc white, oil, proteins, zinc soap	Chalk, lithopone and/or barium white and zinc white, traces of lead and titanium whites, oil, proteins, zinc soap	5
Street	1932	Yes	Yes	No	No				

Table 5 (continued)

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Seafood, Acc. no. 2003–03250	1932	Yes	Yes	No		*Pb*, *C*, *Ba*, *O*, S, (Sr, Si, Ca, Fe)	Lead white, barium white, oil	Lead white, barium white, traces of chalk, oil	3
Breakfast, Acc. no. GI-0257 (PC)	1932	No				*Pb*, *C*, *O*, *Ba*, S, Zn, Ti, (Si, Na, Cr, Sr, Cl, Al)	Lead white, barium white, zinc white, oil, unconfirmed detection of proteins due to the overlapping peak of zinc soap	Lead white, barium white, zinc white, titanium white, oil, unconfirmed detection of proteins due to the overlapping peak of zinc soap	2

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

[b] Major elements are given in italics, minor elements in plain type and trace elements in brackets

Table 6 Summary of ground characteristic of Shanghai phase paintings

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Red and white walls	1933	Yes	Yes	No	No	*O*, *C*, *Ca*, Ba, Zn, S, Pb, Na, (Ti, Si, Al)		Chalk, lithopone and/or barium white and zinc white, lead white, traces of titanium white	1
Courtyard with tree	1933	Yes	Yes	No	No	*O*, *C*, *Ca*, Ba, Zn, S, (Na, Pb, Ti)		Chalk, lithopone and/or barium white and zinc white, traces of lead white and titanium white	1
Countryside landscape	1933	Yes	Yes	No	Yes	*O*, *Ca*, *C*, Ba, Zn, Pb, S, (Na, Si, Cr, Ti)		Chalk, lithopone and/or barium white and zinc white, lead white, traces of titanium white	1
Autumn Countryside	1933	Yes	Yes	No	No	*O*, *Ca*, *C*, Ba, Zn, Pb, S, (Na, Al, Si, Mg)		Chalk, lithopone and/or barium white and zinc white, lead white	1
Farmhouse and field	1933	Yes	Yes	No	Yes	*O*, *C*, *Ca*, Ba, Zn, S, (Na, Cr, Al)		Chalk, lithopone and/or barium white and zinc white	1
Pagoda near Shanghai	1933	Yes	Yes	No	Yes	*O*, *C*, *Ca*, Zn, Ba, S, (Na, Ti)		Chalk, lithopone and/or barium white and zinc white, traces of titanium white	1
Courtyard, Shanghai	1933	Yes	Yes	No	No	*O*, *C*, *Ca*, Zn, Ba, S, (Na, Ti)		Chalk, lithopone and/or barium white and zinc white, traces of titanium white	1
Still life with green stool	1933	Yes	Yes	Yes	No	*Pb*, *O*, *C*, (Ca, Na, Mg)	lead white, oil	Lead white, traces of chalk, oil	1 (Paris)

Table 6 (continued)

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Working at the fields, Acc. no. 2003–03258	1933	No				*O*, *Ca*, *C*, Zn, Ba, S, (Si, Na, Sr, Ti)	chalk, lithopone and/or barium white and zinc white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	1
Countryside in China, Acc. No. 2003–03299	1933	Yes	Yes	No		*O*, *C*, *Ca*, Zn, Ba, S, Na, (Ti, Si)	Chalk, lithopone and/or barium white and zinc white, oil, proteins	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, proteins	1
Countryside near Shanghai	1934	Yes	Yes	No	No	*C*, *O*, *Ca*, Zn, Ba, S, (Na, Ti, Si)		Chalk, lithopone and/or barium white and zinc white, traces of titanium white	1
Village lane	1934	Yes	Yes	No	No	*O*, *Ca*, *C*, Ba, Zn, S, (Na, Ti, Pb)		Chalk, lithopone and/or barium white and zinc white, traces of lead white and titanium white	1
Farmhouses	1934	No			No	*C*, *O*, *Ca*, Zn, Ba, S, Na		Chalk, lithopone and/or barium white and zinc white	1
Rustic landscape	1934	Yes	Yes	No	No	*O*, *C*, *Ca*, Ba, Zn, S, (Na, Pb, Fe, Si, Ti, Al, Mg)	Chalk, lithopone and/or barium white and zinc white, oil, proteins	Chalk, lithopone and/or barium white and zinc white, traces of lead and titanium whites, oil, proteins	1
Backyard, Acc. no. 2003–03252	1934	Yes	Yes	No	No	*C*, *Ba*, *O*, *S*, *Zn*, Pb, Na, Ti, (Si, Ca, Al, Cr, Cl, Sr)	Lithopone and/or barium white and zinc white, lead white, chalk, oil, proteins	Lithopone and/or barium white and zinc white, lead white, titanium white, traces of chalk, oil, proteins	5 (Paris)

Table 6 (continued)

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Pagoda	1935	Yes	Yes	No	No	*O*, *C*, *Ca*, Zn, Ba, S, (Na, Si, Sr)		Chalk, lithopone and/or barium white and zinc white	1
Seascape near Shanghai	1935	Yes	Yes	No	No	*C*, *O*, *Ca*, *Zn*, Ba, S, Na, (Ti, Sr, Si)	Chalk, lithopone and/or barium white and zinc white, oil, proteins	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, proteins	1
House on the hill	1936	Yes	Yes	No	No	*O*, *C*, *Ca*, Zn, Ba, (S, Na, Cr, Si)		Chalk, lithopone and/or barium white and zinc white	1
Street market I	1936	Yes	Yes	No	No	*O*, *Ca*, *C*, Ba, Zn, S, (Na, Ti, Si)		Chalk, lithopone and/or barium white and zinc white, traces of titanium white	1
Street market II	1936	Yes	Yes	No	No	*O*, *C*, *Ca*, Ba, Zn, S, Pb, (Na, Ti)		Chalk, lithopone and/or barium white and zinc white, traces of titanium white	1
Seaside near Shanghai	1936	Yes	Yes	No	No	*O*, *C*, *Ca*, Ba, Zn, S, (Na, Ti, Si)	Chalk, lithopone and/or barium white and zinc white, oil, proteins	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, proteins	1
Seascape	1936	No			No	*Zn*, *C*, *O*, *Na*, (Ba, S, Pb)	Lithopone and/or barium white and zinc white, chalk, oil, zinc soap	Lithopone and/or barium white and zinc white, traces of lead white, chalk, oil, zinc soap	2
Nude, Acc. no. 2003–03367	1936	Yes	Yes		No	*C*, *O*, *Ca*, Zn, Ba, Na, S, (Cr, Ti, Si, Al, Sr)	Chalk, lithopone and/or barium white and zinc white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	1

Table 6 (continued)

Title and inventory number[a]	Date	Tacking margins	Commercial preparation	Partial ground coverage of the tacking margins	Penetration of oil through to the back	SEM–EDS detected elements[b]	FTIR identification	Result	Type of ground
Waterfall, Acc. no. 2003–03247	1936	Yes	Yes	No		*O*, *C*, *Ca*, Zn, Ba, S, (Na, Si, Ti, Sr)	Chalk, lithopone and/or barium white and zinc white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	1
Mount Huangshan Acc. No. 2003–03369	1936	No				*O*, *C*, *Ca*, Zn, Ba, S, (Na, Si, Ti)	Chalk, lithopone and/or barium white and zinc white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	Chalk, lithopone and/or barium white and zinc white, traces of titanium white, oil, inconclusive detection of proteins due to weak or absent absorption peaks at 1636 cm^{-1} and overlapping absorption band of zinc soap	1
Seaside, Acc. No. 2003–03318	1936	Yes	Yes			*O*, *Ca*, *C*, Ba, Zn, S, (Na, Si, Pb, Ti)	Chalk, lithopone and/or barium white and zinc white, oil, proteins	Chalk, lithopone and/or barium white and zinc white, traces of lead and titanium whites, oil, proteins	1

[a] Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection

[b] Major elements are given in bold, minor elements in plain type and trace elements in brackets

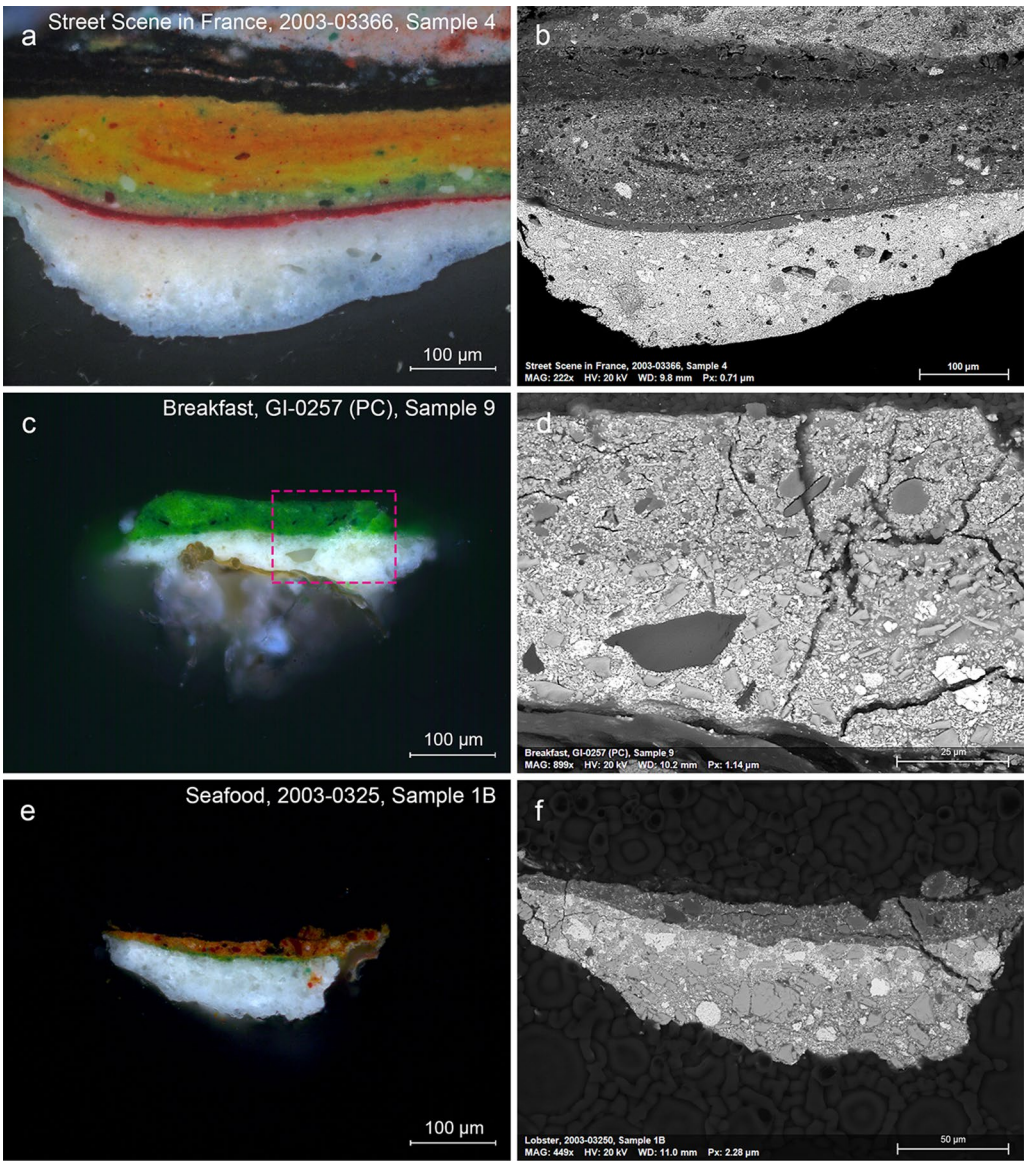


Fig. 10 Microscopy and corresponding backscattered electron (BSE) images of cross-sections with the ground layer extracted from the Paris paintings. The images show five types of identified grounds: **a**, **b** ground of type 1 with clumps of lead white (white) and fine particles of chalk; **c**, **d** ground of type 2 with rectangular particles of barium white (grey) and clusters of lead white (white); **e**, **f** ground of type 3 with coarse particles of barium white (grey) and clumps of lead white (white); **g**, **h** ground of type 4 with particles of chalk (dark grey); **i**, **j** ground of type 5 with particles of chalk (grey)

commercially prepared canvas purchased by the roll or by the metre that he later cut to the required size. The examined works and archival photographs show that the artist fastened the canvas to the sides of the auxiliary supports (strainers or stretchers), probably with nails. The crudely cut edges and excess of the unfolded material in the corners reflect the transitional role of auxiliary supports (Fig. 14a–d). His unstretched paintings, seen on the walls of his rented accommodation in Paris (Fig. 14e, f) provide additional evidence that the auxiliary supports

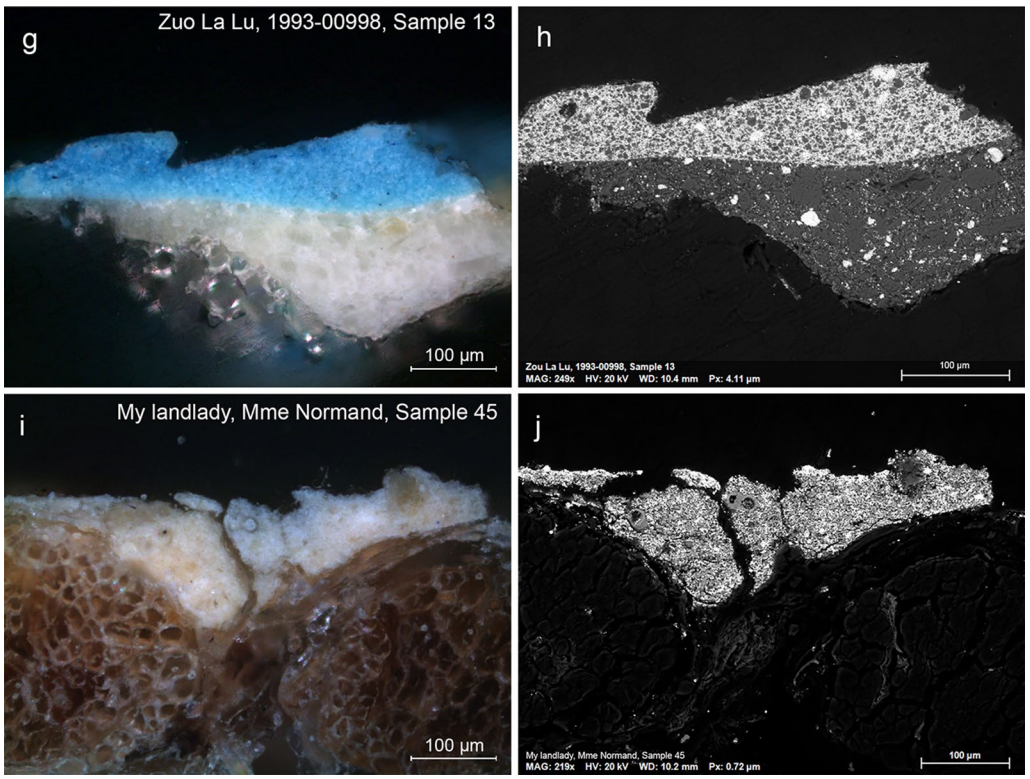


Fig. 10 continued

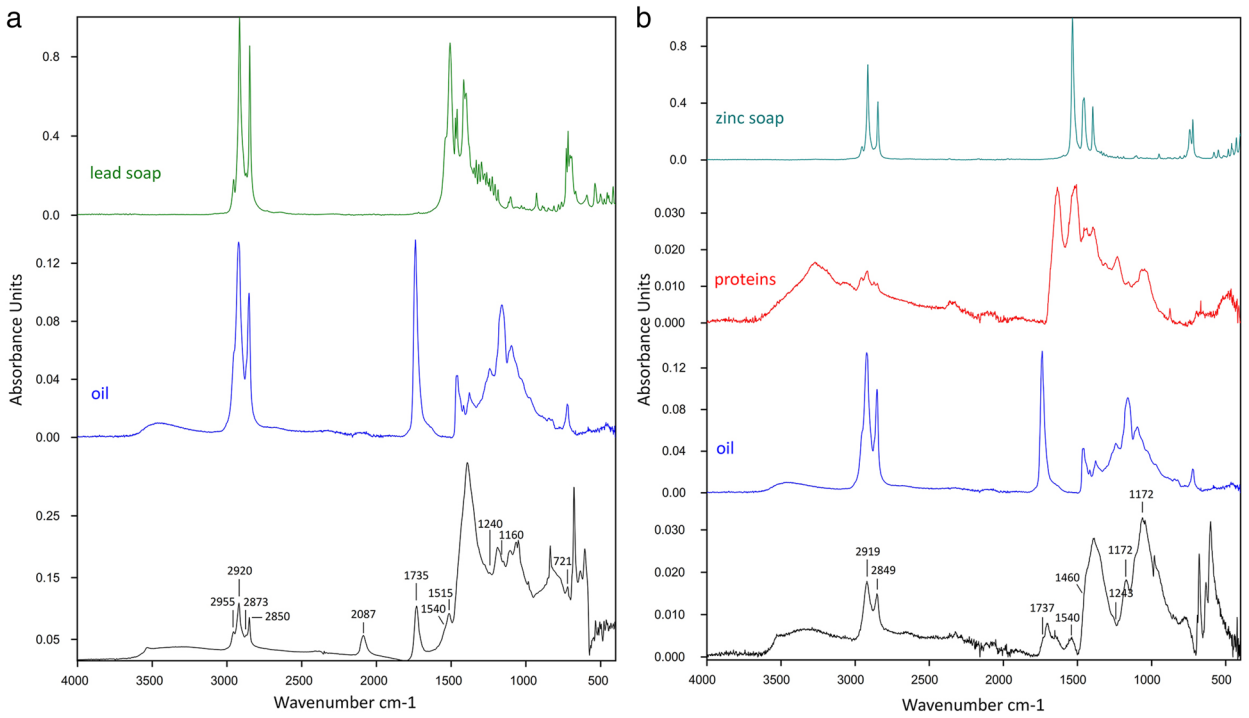


Fig. 11 ATR-FTIR spectra of grounds and reference samples of binders and metal soaps: **a** ground of type 1 from *Landscape in Switzerland*, with labelled marker peaks of oil and lead soap, peak 2087 indicates Prussian blue originating from the paint layer; **b** ground of type 2 from *Breakfast* with labelled marker peaks of proteins, oil and zinc soap

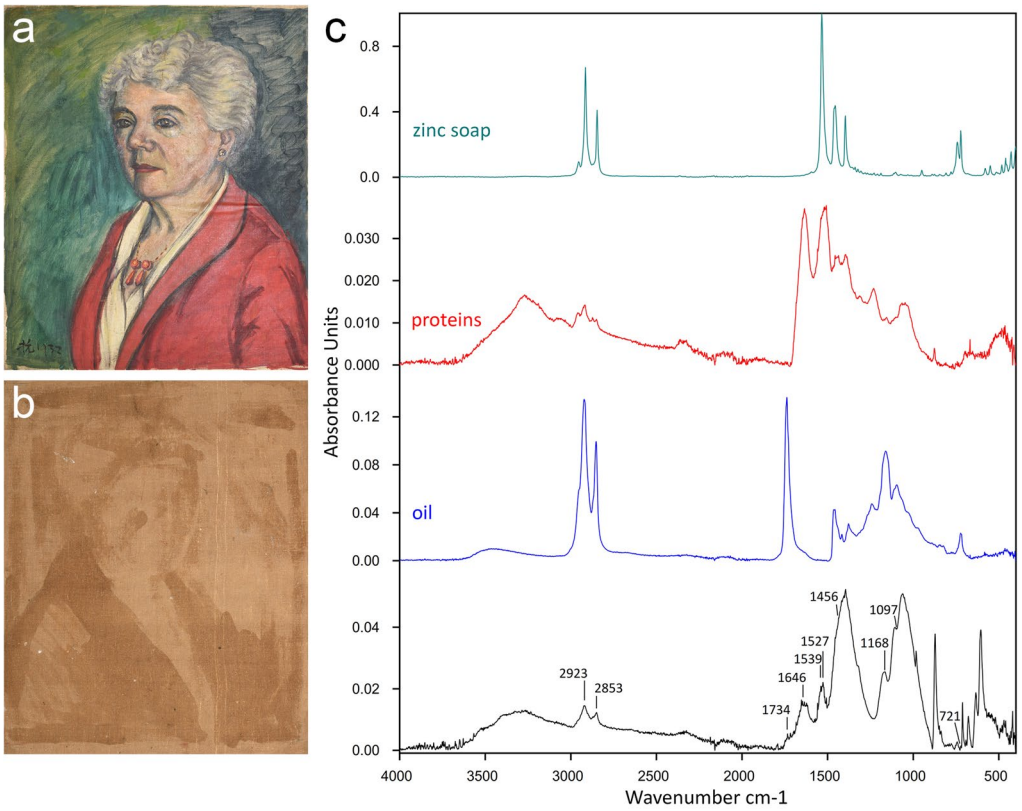


Fig. 12 Liu Kang, *My landlady, Madame Normand*, 1932, oil on canvas, 54 × 45 cm. Images of the painting photographed in normal light: **a** front; **b** reverse side. Liu Kang Family Collection. Images courtesy of Liu family. **c** ATR-FTIR spectra of a ground and reference samples, identifying proteins, oil and zinc soap

were reused continuously, suggesting that this practice could have been motivated by financial constraints.

Conclusions

The cross-referencing of archival and technical research provided insights into the type of painting supports used by Liu Kang in pre-war Paris and Shanghai. The archival photographs proved to be invaluable as they gave a rare glimpse into the artist's practice. The contemporary colourmen catalogues and advertisements greatly assisted with understanding the industry trends and availability of materials, and provided a point of reference for an in-depth characterisation of the artist's canvases. Unfortunately, mainly due to the language barrier, only a limited number of Chinese sources were accessible to support this study.

Based on the collected analytical data, it appears that, in both locations, the artist relied on small-scale retailers who supplied him with commercially prepared canvases. Liu Kang probably purchased the canvas by the roll or by the metre, together with bare strainers or stretchers, as these were affordable painting supports. Thus, his role in the preparation of the painting supports was limited only to cutting the canvas to the required size and mounting it on the auxiliary support, which played a transitional role. The archival photographs provide evidence that Liu Kang was equipped only with a few strainers or stretchers of different sizes, which he continuously reused. As for the auxiliary supports, the portrait format numbers 8 and 10 in Paris, as well as number 10 in Shanghai, were his most favoured, probably because they were more portable. However, it is clearly evident that the artist used larger canvases—of numbers 15 and 20—with greater confidence in Shanghai. In addition, the study shows that, in both locations, the artist ignored commonly accepted format-subject matter rules for his paintings. The investigation of the canvases did not reveal the names of the Paris and Shanghai retailers; however, the stamps on the reverse side of *Rustic landscape* (1934) correspond to a Chinese retailer.

Furthermore, the analyses revealed a difference in the characteristics of the fabrics and grounds of the Paris and Shanghai paintings. The artist's choice of painting supports used in Paris consisted of linen canvases of various densities. Based on the comparative studies with other

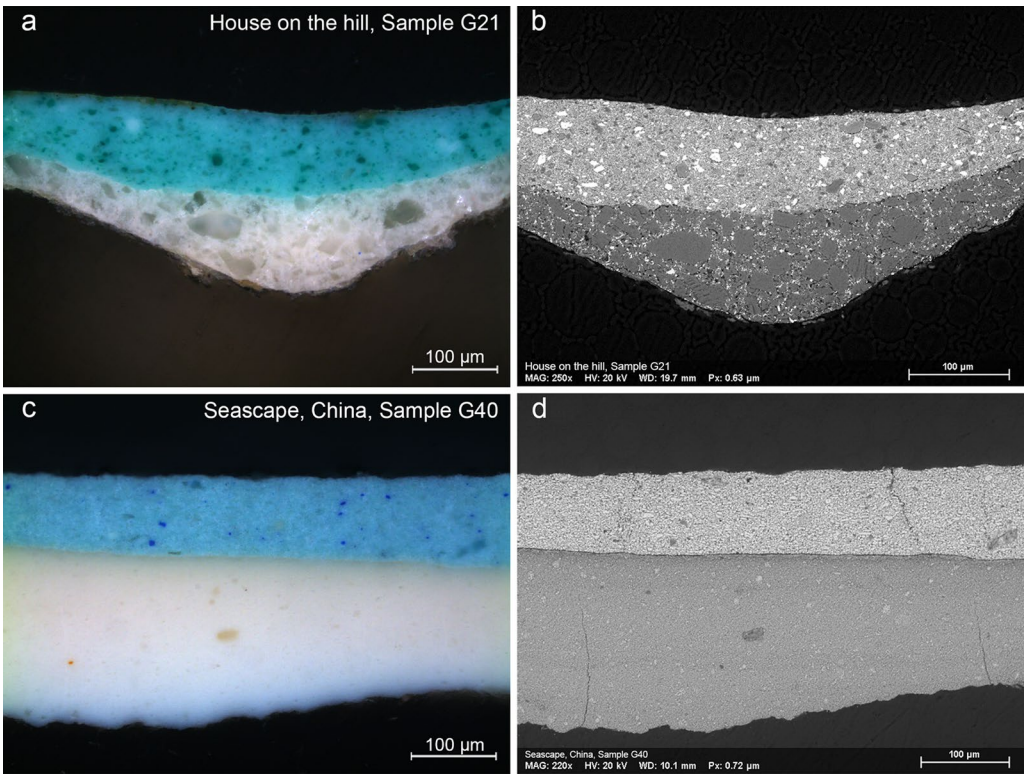


Fig. 13 Microscopy and relevant backscattered electron images (BSE) of cross-sections with ground extracted from the Shanghai paintings. The images show different types of identified grounds: **a**, **b** ground type 1 with large particles of chalk (grey); **c**, **d** ground type 2 with homogenous structure

French canvases reported in the literature and listed in contemporary catalogues, the low-density linen used in Liu Kang's canvases was preliminarily identified as *étude* or *pochade* grades, whereas the denser linen could be comparable to *demi-fine* or *fine* grades. A detection of variations in the composition of the grounds allowed at least five different types of grounds to be distinguished. The single-layered grounds composed predominantly of lead white with extenders and drying oil as a binder are considered as exclusive to the Paris phase. The absorbent grounds with natural glue or semi-absorbent grounds with natural glue and oil as a binder were chosen by the artist less frequently. It also appears that partial ground coverage of the tacking margins is a feature unique to the Paris phase. In Shanghai, Liu Kang displayed a preference for cotton canvases, probably for their affordability. Linen canvases were used sporadically. The majority of the examined grounds are single-layered and complex mixtures with chalk as a principal component. A concomitant presence of oil and proteins in the examined grounds suggests that the majority of the supports could be semi-absorbent or absorbent.

It was noticed that the artist painted over rejected compositions or on the reverse sides of his earlier artworks. None of these recycled supports were coated with an intermediate ground layer, confirming that the artist relied on commercially prepared canvases and did not prepare his own grounds.

The results obtained from this study may aid in preliminary dating of undated artworks or in determining the provenance of Liu Kang's painting supports, as in the cases of *Still life with green stool* (1933) and *Backyard* (1934). The collected data can also be used in comparative studies with other commercially or artist prepared canvases of the same period and provenance. A notable presence of lead and zinc soaps detected during this study may be useful information for future conservation diagnostics and treatment. Further research on Liu Kang's painting supports might include a longer period of time to determine whether the artist's painting preparation practice underwent any fundamental evolution.

Fig. 14 Archival photographs of Liu Kang showing his practice of stretching the painting canvases: **a**–**c** Liu Kang during an outdoor painting session in Saint-Gingolph, Switzerland, in 1929, with canvas paintings on stretchers or strainers; **d**–**f** Liu Kang in his rented rooms in Paris in 1930, 1931, and 1932, respectively. Liu Kang Family Collection. Images courtesy of Liu family

Abbreviations

NGS: National Gallery Singapore; XRR: X-ray radiography; OM: Optical microscopy; FE-SEM: Field emission scanning electron microscope; ATR-FTIR: Attenuated total reflectance-Fourier transform infrared spectroscopy; W&N: Winsor & Newton; R&S: Reeves & Sons.

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Authors' contributions

DL carried out the examination of the paintings, sampling, SEM–EDS analysis; provided the interpretation of the datasets; and wrote the manuscript. TK carried out the FTIR analysis and provided the interpretation of data. BS carried out the FTIR analysis. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the authors upon request.

Competing interests
Authors declare that have no competing interests.

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