Uniwersytet Mikołaja Kopernika w Toruniu
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Interdyscyplinarne badania materiałów malarskich i techniki w obrazach singapurskiego artysty Liu Kanga (1911–2004)

Rozprawa Doktorska
w dziedzinie sztuk plastycznych
w dyscyplinie konserwacja i restauracja dzieł sztuki

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Spis treści

1. Problem badawczy

Praca doktorska podejmuje zagadnienie techniki i technologii malarskiej jednego z najwybitniejszych singapurskich artystów Liu Kanga (1911–2004). Ponad siedemdziesięcioletnia kariera artystyczna Liu Kanga wyraża silne wpływy modernizmu, a także tradycyjnego chińskiego malarstwa tuszem. Oba te źródła inspiracji znalazły się w orbicie jego zainteresowań podczas studiów artystycznych w dwóch wielkich stolicach kultury Wschodu i Zachodu początku dwudziestego wieku – w Szanghaju i Paryżu. Artysta studiował w Akademii Artystycznej Xinhua w Szanghaju (1926–1928) w okresie istotnych reform społecznych oraz debaty podejmowanej w kręgach artystycznych nad ożywieniem pogrążonego w konserwatyzmie chińskiego malarstwa [1,2] poprzez zaimplementowanie idei modernizmu [3]. Dalszą edukację artystyczną Liu Kang kontynuował w Académie de la Grande Chaumière na Montparnassie (1929–1932), a kilkuletni pobyt w Paryżu zainicjował jego fascynację przede wszystkim twórczością Matisse'a, a także Cézanne'a, Gauguina i van Gogha [4], do których twórczości nawiązywał w trakcie swojej późniejszej kariery. Wyrazem uznania dla talentu Liu Kanga w trakcie pobytu w Paryżu było dwukrotne przyjęcie jego obrazów na Salon d'Automne w latach 1930 i 1931.

Jednym z największych osiągnięć artystycznych Liu Kanga jest jego udział w rozwoju stylu malarskiego Nanyang, który został zainicjowany w latach 1940–1960 w Singapurze przez grupę artystów-imigrantów pochodzenia chińskiego. Koncepcja stylu została oparta na zobrazowaniu aspektów życia lokalnych społeczności Azji Południowo-Wschodniej za pomocą środków wyrazu asymilujących wpływy szkoły paryskiej oraz chińskiego tradycyjnego malarstwa tuszem [5-7]. W rozwoju stylu Nanyang Liu Kang odegrał szczególną rolę, głównie dzięki wprowadzeniu stylistycznej innowacji nawiązującej do techniki batiku. Mimo że styl ten z biegiem czasu stracił na swojej atrakcyjności, artysta często do niego wracał w swoich późniejszych pracach malarskich [8]. Jednakże, jego twórczość jako całość, jest stylistycznie zróżnicowana za sprawą nieustannych poszukiwań nowych źródeł inspiracji, podejmowania porzuconych wcześniej tematów, eksperymentowania z nowymi technikami malarskimi, co skutkowało niezamierzonymi efektami wizualnymi, które mogą przyczyniać się do błędnej interpretacji artystycznej dzieł, technik malarskich artysty oraz prowadzić do niewłaściwej oceny stanu zachowania obrazów, a w konsekwencji do nieumyślnego usunięcia autorskich nawarstwień. W zawiązku z tym, aby zapobiec nieprawidłowej ocenie artystycznej i technicznej obrazów artysty, konieczne było zrozumienie warsztatu malarskiego Liu Kanga oraz czynników odpowiedzialnych za stan zachowania obrazów poprzez kompleksowe badania analityczne [9]. Ta zasada ma kluczowe znaczenie w kontekście jednorodności kolekcji obrazów Liu Kanga, ponieważ dokładne zrozumienie procesu twórczego, użytych materiałów malarskich oraz rozpoznanie sposobu ich zastosowania może zagwarantować spójną strategię kuratorsko-konserwatorską i przyczynić się do zmiany percepcji niektórych dzieł Liu Kanga.

2. Stan badań

Bibliografia dotycząca twórczości Liu Kanga, jako artysty uznawanego powszechnie za ikonę malarstwa singapurskiego i współtwórcę regionalnego stylu, jest stosunkowo skromna i składa się na nią kilka dysertacji i opracowań zbiorowych w większości omawiających jego działalność w kontekście innych lokalnych twórców lub stylu Nanyang. Inne materiały źródłowe obejmują liczne katalogi wystaw, artykuły prasowe, wywiady oraz dokumenty telewizyjne. Ponadto, żaden z autorów nie podjął się zadania scharakteryzowania warsztatu malarskiego artysty w sposób koherentny lub omówienia wybranych aspektów jego techniki i materiałów. Pierwszą próbą przedstawienia sylwetki artysty zawierającą omówienie jego życiorysu i głównych dokonań jest artykuł autorstwa Ho Kok Hoe z 1955 roku [10]. Publikacja ta jest również pierwszą i jedyną, w której lakonicznie wymienione zostały trzy ulubione pigmenty malarskie artysty. Dwa wywiady prasowe przeprowadzone przez Gretchen Mahbubani [11] i Thiagarajan Kanaga Sabapathy [12] z 1981 roku wzbogacają wiedzę czytelnika o anegdoty z życia artysty, które mogą być pomocne w wyjaśnieniu pewnych aspektów jego warsztatu malarskiego. Natomiast dokument telewizyjny z 1982 roku [13] mimo, że skupia się na bogatym życiorysie Liu Kanga, zawiera kilka ujęć z jego pracowni rejestrujących w przypadkowy sposób niektóre materiały malarskie, jednak bez podjęcia próby dyskusji na ten temat z artystą.

Liu Kang prezentował swoją twórczość na licznych indywidualnych i zbiorowych wystawach, z których najważniejsze to: pierwsza indywidualna wystawa w Singapurze (1957), retrospekcyjna wystawa w National Museum Singapore (1981) oraz wystawy zagraniczne w Taiwanie (1983), Hong Kongu (1985), Japonii (1997) i Chinach (2000). Katalogi tych oraz wielu innych wystaw służą za dodatkowe źródło wiedzy o Liu Kangu. Jednak tylko dwa z nich, z 1997 i 2000 roku [14,15], oraz monografia z 2011 roku [16], wydana z okazji setnej rocznicy urodzin artysty, są istotnymi pozycjami dla historyków sztuki z uwagi na kompleksowe analizy stylu malarskiego. Innym źródłem cennych informacji jest zbiór esejów napisanych przez samego Liu Kanga w latach 1937–1980, a opublikowanych w 2011 roku [17]. Autor podjął w nich dyskusję na temat edukacji, kultury i malarstwa, niestety, omijając zagadnienia własnego warsztatu malarskiego.

3. Cel badań

Głównym celem badań było stworzenie spójnego poglądu na warsztat artysty poprzez wyodrębnienie zasadniczych cech techniczno-technologicznych dla jego najważniejszych okresów stylistycznych oraz prześledzenie ewolucji doboru materiałów i techniki malarskiej na przestrzeni jego twórczości. Istotne zatem było szczegółowe rozpoznanie rodzajów i sposobu przygotowania podobrazi malarskich, struktury i chemicznej kompozycji zapraw oraz warstw malarskich, a także określenie roli studiów przygotowawczych w procesie twórczym artysty. Ponadto przeprowadzone badania miały umożliwić wyjaśnienie przyczyn obecności modyfikacji malarskich oraz niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł. Osiągnięcie tego celu umożliwi przygotowanie w przyszłości spójnej strategii kuratorsko-konserwatorskiej dla obrazów Liu Kanga z kolekcji National Gallery Singapore (NGS) i rodziny artysty [9]. W sensie praktycznym zebrane wyniki badań mogą być użyteczne w studiach nad autentycznością prac przypisywanych artyście. Ten aspekt jest istotny z uwagi na coraz częstszą obecność obrazów Liu Kanga w ofercie domów aukcyjnych i ich rosnący trend cenowy [18-21] a przez to możliwość wystawiania na sprzedaż dzieł o wątpliwej proweniencji lub odróżniających się technicznie i stylistycznie od rozpoznanej praktyki artysty.

4. Materiały i metody badawcze

4.1. Materiały

Przedmiotem badań było 97 obrazów Liu Kanga namalowanych w okresie od 1927 do 1999 roku. Przebadano 56 obrazów z kolekcji NGS i 41 obrazów z kolekcji rodziny artysty. Badania obrazów z prywatnej kolekcji miały na celu zapewnienie obiektywnego przedstawienia bogatej twórczości artystycznej, materiałów i technik malarskich Liu Kanga. Wyniki wykonanych badań nieinwazyjnych dodatkowo podparto rezultatami analiz fizykochemicznych 152 próbek włókien podobrazi płóciennych oraz 448 próbek warstw malarskich i zapraw. Przyjęty tok postępowania badawczego umożliwił sformułowanie konkretnych i logicznych wniosków o technologii i technice wykonania dzieł artysty.

4.2. Metody badawcze

Przyjęta w ramach pracy metodyka badawcza zakładała zastosowanie w pierwszej kolejności technik nieinwazyjnych, których wyniki określiły zakres wykorzystania inwazyjnych, fizykochemicznych technik analitycznych.

Na początku postępowania badawczego udokumentowano takie podstawowe informacje o obrazach, jak wymiary, rodzaj podłoża malarskiego i sposób jego zamocowania oraz obecność sygnatur, dat i inskrypcji. Powierzchnie lica i odwrocia obrazów zarejestrowano za pomocą następujących technik fotograficznych: fluorescencja wzbudzana ultrafioletem (UVF, ang. ultraviolet fluorescence), reflektografia w ultrafiolecie (UVR, ang. ultraviolet reflectance) oraz reflektografia w świetle widzialnym (VIS, ang. visible light) i bliskiej podczerwieni (NIR, ang. near-infrared). Fotografie uzupełniono o metodę obrazowania fałszywym kolorem w podczerwieni (IRFC, ang. infrared false-colour) w celu odróżnienia obszarów opracowanych tym samym odcieniem koloru, ale z wykorzystaniem rożnych pigmentów [1]. Techniki fotograficzne umożliwiły szybką i nieinwazyjną rejestrację stanu zachowania obrazów, wstępną identyfikację pigmentów oraz określenie najbardziej reprezentatywnych miejsc, z których pobrano próbki do dalszych szczegółowych badań instrumentalnych. W kolejnym etapie wykonano analizy budowy technicznej podobrazi przy wykorzystaniu cyfrowej mikroskopii optycznej w celu precyzyjnego określenia splotu, gęstości oraz skrętu nitek podobrazi płóciennych [2]. Obecność wcześniejszych, zakrytych warstw malarskich była weryfikowana za pomocą cyfrowej mikroskopii optycznej, analizy faktury rejestrowanej w technice obrazowania z transformacją odbicia (RTI, ang. reflectance transformation imaging)[3], a także stosując NIR i badania rentgenowskie (XRR, ang. X-ray radiography)[4]. Wizualizację wcześniejszych opracowań malarskich umożliwiała również rentgenowska analiza fluorescencyjna (XRF, ang. X-ray fluorescence) przy użyciu makroskanera XRF. Instrument

[1] Fotografia w zakresie widma elektromagnetycznego 350–1100 nm oraz wygenerowanie obrazów w technice IRFC wykonał autor w Heritage Conservation Centre, Singapore.
[2] Cyfrową mikroskopię optyczną wykonał autor w Heritage Conservation Centre, Singapore.
[3] Obrazowanie w technice RTI wykonał autor w Heritage Conservation Centre, Singapore.
[4] Badania XRR wykonano w Division of Radiological Sciences, Singapore General Hospital.

ten oraz przenośny spektrometr XRF[5] pozwoliły także na wstępną identyfikację pigmentów i wypełniaczy w zaprawach i warstwach malarskich.

W następnym etapie wykonane zostały badania inwazyjne. Identyfikację włókien roślinnych pobranych z podobrazi płóciennych wykonano mikroskopowo na podstawie cech morfologicznych oraz za pomocą reakcji barwnych z wykorzystaniem mikroskopu polaryzacyjnego (PLM, ang. polarised light microscopy) wyposażonego w kamerę cyfrową[6]. W celu identyfikacji pigmentów, wypełniaczy i spoiw zapraw oraz warstw malarskich przygotowano preparaty mikroskopowe do badań PLM[7] oraz przekroje poprzeczne próbek. Naszlify warstw sfotografowano w VIS oraz UV[8]. Ilościowy skład pierwiastkowy w badanych warstwach określono przy użyciu skaningowego mikroskopu elektronowego (SEM-EDS, ang. scanning electron microscope with energy dispersive X-ray spectroscopy)[9]. Wyniki tych badań dodatkowo uzupełniono spektroskopią w podczerwieni z transformatą Fouriera przy zastosowaniu techniki osłabionego całkowitego wewnętrznego odbicia (ATR-FTIR, ang. attenuated total reflectance-Fourier transform infrared spectroscopy)[10]. Badania ATR-FTIR umożliwiły rozpoznanie spoiw, żywic, barwników oraz pigmentów [11]. W niektórych przypadkach wykonano reakcje barwne na przekrojach poprzecznych warstw malarskich w celu dodatkowego potwierdzenia obecności określonych związków chemicznych[12].

Istotnym elementem metodyki były badania materiałów archiwalnych z kolekcji rodziny artysty oraz studia katalogów i reklam materiałów artystycznych z okresów odpowiadających aktywności malarskiej Liu Kanga. Zebrane w ten sposób informacje były pomocne w interpretacji wyników badań analitycznych.

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[5] Analizy XRF wykonał autor w Heritage Conservation Centre, Singapore.
[6] Mikroskopową identyfikację włókien wykonał autor w Heritage Conservation Centre, Singapore.
[7] Mikroskopową identyfikację pigmentów oraz wypełniaczy wykonał autor w Heritage Conservation Centre, Singapore.
[8] Naszlify warstw malarskich oraz ich fotografię mikroskopową wykonał autor w Heritage Conservation Centre, Singapore.
[9] Analizy SEM-EDS na przekrojach stratygraficznych wykonał autor w Heritage Conservation Centre, Singapore.
[10] Pomiary i analizy ATR-FTIR wykonali: dr Bogusław Szczupak, dr Mateusz Mądry z Wydziału Informatyki i Telekomunikacji, Politechnika Wrocławska we Wrocławiu oraz dr Teresa Kurkiewicz z Wydziału Sztuk Pięknych, Katedra Technologii i Techniki Sztuk Plastycznych, Uniwersytet Mikołaja Kopernika w Toruniu.
[11] Interpretację widm wykonali: dr Teresa Kurkiewicz z Wydziału Sztuk Pięknych, Katedra Technologii i Techniki Sztuk Plastycznych, Uniwersytet Mikołaja Kopernika w Toruniu oraz dr hab. Paweł Szroeder z Wydziału Fizyki, Uniwersytet Kazimierza Wielkiego w Bydgoszczy.
[12] Reakcje barwne na naszlifach wykonał autor w Heritage Conservation Centre, Singapore.

4.2.1. Techniki fotograficzne

Fotografia cyfrowa obrazów w zakresie widma elektromagnetycznego 350–1100 nm została przeprowadzona zgodnie z procedurą zaproponowaną przez Cosentino [22-24]. Posłużono się zmodyfikowanymi aparatami cyfrowymi Nikon D90 i Nikon D850 wyposażonymi w obiektyw Nikon AF Micro NIKKOR 60 mm f/2.8D. Aparaty zostały skalibrowane przy użyciu wzornika X-Rite ColorChecker Passport. Do kontroli balansu bieli i ekspozycji zarejestrowanych obrazów w formacie RAW wykorzystano wzornik American Institute of Conservation Photo Documentation (AIC PhD). Edycję zdjęć w formacie RAW przeprowadzono na programie Adobe Photoshop CC zgodnie z wytycznymi zaproponowanymi przez American Institute of Conservation (AIC) [25].

Fotografia VIS w świetle rozproszonym i bocznym rejestruje powierzchnię obrazów, umożliwiając wstępną ocenę stanu zachowania i budowy technicznej. Do oświetlenia powierzchni obrazów użyto dwóch lamp fotograficznych Lastolite Ray D8 wyposażonych w żarówki o mocy 500 W. Natomiast na obiektywie aparatu zainstalowano filtry X-Nite CC1 oraz B+W 415 korygujące rejestrowane promieniowanie elektromagnetyczne w zakresie światła widzialnego.

Fotografia UVF rejestruje w zakresie światła widzialnego natężenie i barwę fluorescencji warstw malarskich wzbudzoną przez promieniowanie ultrafioletowe. Technika ta umożliwia zlokalizowanie wtórnych lub nieoryginalnych nawarstwień oraz ułatwia proces identyfikacji niektórych pigmentów, barwników oraz spoiw stosowanych w malarstwie. Analiza zarejestrowanej fluorescencji pozwala potwierdzić obecność werniksów oraz określić ich rodzaj. Wyniki obserwacji nie powinny być traktowane jednoznacznie, ponieważ technika UVF nie pozwala odróżnić oryginalnych warstw malarskich od bardzo starych, wtórnych nawarstwień farby, które z czasem charakteryzują się podobnym natężeniem fluorescencji [26]. Obrazy oświetlono dwiema lampami wyposażonymi w 8 świetlówek fluorescencyjnych z filtrem Wooda o mocy 40 W emitujących promieniowanie ultrafioletowe od długości fali 365 nm. Rejestrację fotografii UVF wykonano, posługując się tym samym zestawem filtrów jakiego użyto w fotografii VIS.

Technika UVR rejestruje natężenia promieniowania ultrafioletowego odbitego od powierzchni badanego obiektu. Rejestrowanie obrazów w tej technice umożliwia wyodrębnienie obszarów, które wykazują taki sam kolor w świetle widzialnym, ale różnią się składem chemicznym. Technika ta jest także przydatna w rozróżnieniu wtórnych nawarstwień, które charakteryzują się podobnym natężeniem fluorescencji wzbudzonej ultrafioletem co warstwy oryginalne [26]. Obrazy reflektograficzne w ultrafiolecie wykonano, stosując ten sam rodzaj oświetlenia jaki wykorzystano w technice UVF, natomiast na obiektywie zamocowano filtr Andrea „U" MK II, który odcina pasmo promieniowania elektromagnetycznego w zakresie światła widzialnego i podczerwieni umożliwiając rejestrację odbitego promieniowania ultrafioletowego.

Fotografia w technice NIR polega na rejestracji różnych własności optycznych absorpcji, rozpraszania oraz odbicia promieniowania elektromagnetycznego od badanej powierzchni w zakresie bliskiej podczerwieni. Bliska podczerwień nadaje się do badań warstw malarskich, ponieważ częściowo je penetruje i jest odbijana od ich struktur wewnętrznych. Dzięki temu wtórnie wprowadzone materiały, autorskie modyfikacje warstwy malarskiej (pentimenti) oraz rysunki kompozycyjne stają się widoczne. Fotografia w technice NIR została wykonana przy zastosowaniu tego samego rodzaju oświetlenia co w technice VIS. Na obiektyw aparatu założono filtr Heliopan RG1000 odcinający promieniowanie elektromagnetyczne w zakresie światła widzialnego i umożliwiający rejestrację promieniowania podczerwonego.

Technika IRFC polega na fotograficznej rejestracji obiektu w VIS i NIR a następnie na komputerowej separacji zdjęcia zarejestrowanego w VIS na poszczególne kanały w technice RGB. W dalszej kolejności dokonuje się zamiany obrazów przechowywanych w kanałach w następującej kolejności: G→B, R→G, oraz umieszczenia obrazu zarejestrowanego w NIR w miejsce kanału R. W efekcie otrzymuje się zdjęcie IR, R, G. Uzyskany za pomocą tej techniki obraz posiada barwy o innej chromatyce niż zdjęcie zarejestrowane w zakresie światła widzialnego, w wyniku czego jest pomocny w wykrywaniu wtórnych nawarstwień na oryginalnych powierzchniach oraz umożliwia wstępną identyfikację pigmentów i barwników. Wygenerowanie obrazów w technice IRFC zostało przeprowadzone na programie Adobe Photoshop CC według wytycznych AIC [25].

4.2.2. Cyfrowa mikroskopia optyczna

Cyfrowa mikroskopia optyczna pozwala na szczegółową obserwację i rejestrację powierzchni obrazów w różnych powiększeniach w świetle rozproszonym i bocznym.

Technika ta została wykorzystana do analiz budowy technicznej oraz sposobu malowania obrazów Liu Kanga, a także oceny ich stanu zachowania. W tym celu użyto mikroskopu Keyence VHX-6000, którego konstrukcja oparta jest na cyfrowej kamerze i obiektywie o zmiennym powiększeniu 20×−2000×. Mikroskop był sterowany oprogramowaniem Keyence VHX-H2M2, a pomiary zarejestrowanych zdjęć wykonano programem Keyence VHX-H4M.

4.2.3. RTI

Technika RTI wykorzystuje serię fotografii obiektu wykonanych w VIS lub NIR, uzyskanych z tego samego miejsca, ale przy kontrolowanej i regularnej zmienności kierunku padania światła. Technika ta pozwala na wygenerowanie modelu dwuwymiarowego fotografowanego przedmiotu i szczegółową analizę jego faktury poprzez kontrolowaną symulację oświetlania jego powierzchni.

RTI wykonano według procedury zaproponowanej przez Cultural Heritage Imaging [27-29]. Uzyskane serie zdjęć zostały przygotowane w programie Adobe Photoshop CC, a następnie RTIBuilder. Rezultaty zostały zwizualizowane w programie RTIViewer

4.2.4. XRR

Technika XRR polega na rejestracji promieni rentgenowskich penetrujących badany obiekt. Uzyskany obraz zawiera informacje o jego wewnętrznej strukturze oraz zakresie występowania materiałów o zróżnicowanej gęstości. W badaniach obrazów technika ta jest szczególnie przydatna do wizualizacji struktury podobrazi, ubytków i ich reperacji, pentimenti, przemalowań warstw malarskich oraz obecności i zakresu użycia pigmentów silnie pochłaniających promieniowanie rentgenowskie. Badanie XRR pozwala uzyskać informacje na temat warsztatu artysty oraz o sposobie użycia materiałów malarskich.

Badania XRR obrazów Liu Kanga były wykonane cyfrowym systemem Siemens Ysio Max z detektorem o wymiarach 35 × 43 cm i rozdzielczości 7 Mpx. Źródłem promieniowania była lampa rentgenowska o następujących parametrach: 40 kV oraz 0,5–2 mAs. Rezultaty badań zostały zwizualizowane, stosując dedykowane oprogramowanie iQ-LITE. Korekcja kontrastu, jasności oraz scalanie rentgenogramów zostały wykonane programem Adobe Photoshop CC.

4.2.5. XRF

Analiza XRF warstw malarskich umożliwia nieinwazyjne badanie ich składu pierwiastkowego. Zasada działania XRF polega na rejestracji wtórnej emisji promieniowania rentgenowskiego (fluorescencji) z materiału, który został wzbudzony za pomocą promieniowania rentgenowskiego. Wyniki dostarczane są w postaci widm fluorescencji z liniami emisyjnymi charakterystycznymi dla każdego pierwiastka zawartego w analizowanym materiale. Mimo że analiza XRF jest nieinwazyjna i szybka, to charakteryzuje się niską czułością dla pierwiastków o małej masie atomowej, wykluczając identyfikację materiałów organicznych i ultramaryny [30].

W badaniach obrazów Liu Kanga wykorzystano przenośny instrument Thermo Scientific™ Niton™ XL3t 970 wyposażony w detektor GOLDD+, anodę Ag o maksymalnych parametrach: 50 kV i 0,2 mA. Wielkość plamki promieniowania wynosiła 3 mm. Czas pojedynczego pomiaru wynosił 200 s i był on wykonywany z odległości 1 mm. Uzyskane widma były interpretowane dedykowanym oprogramowaniem Thermo Scientific™ Niton Data Transfer (NDT™) 8.4.3. Dodatkowo badania XRF wykonano, posługując się makroskanerem Bruker M6 JetStream, w którym głowica pomiarowa została umieszona na mechanicznych szynach umożliwiających przemieszczanie w kierunkach X, Y i Z, w zakresie 800 × 600 × 90 mm w płaszczyźnie równoległej do powierzchni badanej. Instrument potrafi uzyskać dane o składzie pierwiastkowym odrębnie w każdym punkcie badanej powierzchni. Uzyskane dane są prezentowane w postaci map ukazujących rozmieszczenie i koncentrację wykrytych pierwiastków w badanej powierzchni. Źródłem promieniowania rentgenowskiego jest lampa z anodą Rh o maksymalnych parametrach: 50 kV i 0,6 mA. Instrument jest wyposażony w detektor XFlash o wielkości 30 mm^2. Wielkość plamki promieniowania była regulowana w zakresie 100 µm–500 µm [31]. Zebrane dane były analizowane programem Bruker's M6.

4.2.6. Przygotowanie próbek

Drobne łuski warstw malarskich wyselekcjonowane do badań na ich przekrojach poprzecznych zostały umieszone w żywicy akrylowej ClaroCit. Po związaniu żywicy próbki były szlifowane i polerowane na szlifierko-polerce Buehler MetaServ 250. Próbki warstw malarskich przeznaczone do mikroskopii polaryzacyjnej zostały drobno rozkruszone w kropli etanolu, zamocowane na szkiełkach mikroskopowych przy wykorzystaniu preparatu Cargille Meltmount o współczynniku załamania światła nD = 1,662 i zabezpieczone szkiełkiem nakrywkowym. Próbki włókien pobrane z nitek wątku i osnowy podobrazi płóciennych zostały oczyszczone przez zanurzenie w gorącej wodzie, a następnie ułożone na szkiełkach mikroskopowych, zwilżone kroplą wody destylowanej i zabezpieczone szkiełkiem nakrywkowym.

4.2.7. Mikroskopia optyczna i polaryzacyjna

Mikroskopia optyczna polega na obserwacji i rejestracji obrazów przekrojów poprzecznych próbek warstw malarskich w świetle odbitym VIS i UVF. Analiza porównawcza próbek zarejestrowanych w tych dwóch rodzajach oświetlenia ułatwia charakterystykę układu warstw malarskich, identyfikację rodzaju użytego spoiwa oraz pozwala obserwować pigmenty wygaszające luminescencję, a także charakterystyczną barwę fluorescencji pigmentów i barwników organicznych.

Mikroskopia polaryzacyjna polega na obserwacji właściwości optycznych badanego materiału umieszczonego pomiędzy dwoma filtrami polaryzacyjnymi w świetle przechodzącym. Materiał badawczy jest charakteryzowany wizualnie na podstawie określenia koloru, kształtu, wielkości, dwójłomności, współczynnika załamania światła i kolorów polaryzacji. Technika ta jest przydatna w badaniu materiałów malarskich, ponieważ umożliwia identyfikację materiałów krystalicznych, do których należy większość pigmentów.

Próbki włókien roślinnych identyfikowano na podstawie ich morfologii w świetle przechodzącym.

Wszystkie próbki analizowano przy użyciu mikroskopu polaryzacyjnego Leica DMRX z opcją oświetlenia odbitego VIS i UF oraz oświetlenia przechodzącego VIS, stosując powiększenia 50×, 100×, 200× i 400×. Obrazy próbek rejestrowano zintegrowaną kamerą cyfrową Leica DFC295 o rozdzielczości 3 Mpx, którą sterowano oprogramowaniem Leica

Application Suite 4.8. Mikroskopię polaryzacyjną pigmentów wykonano, stosując procedurę zaproponowaną przez Petera i Ann Mactaggartów [32].

4.2.8. SEM-EDS

Skaningowa mikroskopia elektronowa wykorzystuje strumień wiązki elektronów, które skierowane na powierzchnię próbki powodują emisję elektronów wtórnych lub wstecznie rozproszonych, umożliwiając obrazowanie i analizę powierzchni badanego materiału. Analizator EDS widma rentgenowskiego emitowanego przez atomy cząsteczek, wzbudzane wiązką elektronów, pozwala na wyznaczenie składu elementarnego zarówno w punktach, jak i w różnej wielkości obszarach próbki oraz tworzyć mapy rozmieszczenia pierwiastków na powierzchni próbek. Technika SEM-EDS umożliwia wykonanie nieniszczących badań składu pierwiastkowego poszczególnych warstw malarskich na przekrojach poprzecznych próbek [30].

Badania SEM-EDS próbek warstw malarskich pobranych z obrazów Liu Kanga wykonano przy użyciu mikroskopu Hitachi SU5000 FE-SEM z modułem EDS Bruker XFlash® 6/60. Przekroje poprzeczne warstw malarskich były analizowane w trybie wstecznie rozproszonych elektronów (BSE), stosując napięcie przyśpieszające 20 kV oraz ciśnienie 60 Pa. Czas pomiaru próbki wynosił 180 s i był wykonany z odległości 10 mm. Pomiary i analizy próbek były wykonane oprogramowaniem Bruker ESPIRIT 2.0.

4.2.9. ATR-FTIR

Spektroskopia w podczerwieni to metoda badania związków chemicznych, która polega na analizie ich zdolności do absorpcji promieniowania podczerwonego. Wyniki dostarczane są w postaci widm, czyli wykresów intensywności pochłaniania/odbicia w zależności od energii promieniowania wyrażonej w liczbach falowych [cm^{-1}]. Absorpcja promieniowania podczerwonego powoduje wzbudzenie cząsteczek na wyższe poziomy oscylacyjne. Każda z cząsteczek posiada unikalny zestaw oscylacyjnych poziomów energetycznych, a absorpcja promieniowania przedstawiona jest w postaci pasm (pików) na rejestrowanych widmach. ATR to technika osłabionego całkowitego wewnętrznego odbicia, w której pomiar odbywa się przez dociśnięcie kryształu (diamentu, germanu lub cyrkonu) do próbki. Promieniowanie podczerwone przechodzi przez kryształ i oddziałuje z próbką znajdującą się pod nim, dając widmo IR. Analiza widm opiera się na identyfikacji pasm pochodzących od wiązań chemicznych poszczególnych grup funkcyjnych oraz na porównaniu widma badanej próbki z widmami substancji wzorcowych. W badaniach próbek pobranych z obiektów zabytkowych technika ATR-FTIR jest stosowana do identyfikacji związków organicznych i nieorganicznych, m.in. spoiw, żywic naturalnych i syntetycznych, barwników oraz pigmentów [30].

Badania próbek warstw malarskich pobranych z obrazów Liu Kanga były wykonane przy użyciu mikroskopu FTIR Bruker Hyperion 3000, wyposażonego w detektor LN-MCT oraz obiektyw ATR, który został podłączony do spektrometru Vertex 80. Próbki poddane były 64 skanom w rozdzielczość 4 cm^{-1} i zakresie pomiarowym 4000–600 cm^{-1}. Interpretacja widm została wykonana w programie Bruker Opus 7.5 oraz przy wykorzystaniu także bibliotek widm referencyjnych związków z kolekcji Katedry Technologii i Technik Sztuk Plastycznych Uniwersytetu Mikołaja Kopernika w Toruniu, Infrared and Raman Users Group (IRUG) [33] oraz Database of ATR-FTIR spectra of various materials [34].

4.2.10. Reakcje barwne

Reakcje barwne są nieskomplikowanym sposobem wykrycia określonych związków chemicznych obecnych w materiałach zabytkowych. Reakcje te polegają na zainicjowaniu reakcji chemicznej między zastosowanym odczynnikiem a badanym materiałem i wywołaniu jego zmiany kolorystycznej, która wskazuje na obecność określonych grup chemicznych umożliwiających dalszą identyfikację [30].

W pracy badawczej wykorzystano płyn Lugola do identyfikacji skrobi w wybranych próbkach warstw malarskich [35] oraz floroglucynę do identyfikacji ligniny we włóknach roślinnych nitek pobranych z podobrazi płóciennych [35].

5. Struktura pracy

Rozprawę doktorską stanowi jedenaście artykułów naukowych oraz cztery dokumentacje konserwatorskie. Artykuły zestawiono w kolejności odpowiadającej głównym okresom stylistycznym artysty oraz jego cyklom tematycznym:

- okres paryski (1929–1932), artykuły D1-D4;
- okres szanghajski (1933–1937), artykuły D3, D5;
- okres emigracji na Półwyspie Malajskim i poszukiwanie nowego stylu (1937–1949), artykuł D6;
- udział w rozwoju stylu Nanyang (1950–1960), artykuł D7;

- cykl aktów kobiecych (1927–1954 oraz 1992–1999), artykuł D8;
- cykl chińskich pejzaży górskich Huangshan i Guilin (1977–1996), artykuł D9.

Intrygujące cechy praktyki malarskiej artysty oraz związaną z nimi problematykę konserwatorską zaprezentowano w artykule D10. Cykl zamyka publikacja D11 podsumowująca rezultaty wszystkich badań i charakteryzująca technikę i technologię malarską Liu Kanga na przestrzeni całego okresu jego pracy twórczej.

Zabiegi konserwatorskie zostały wykonane na czterech obrazach wytypowanych przez NGS na stałą wystawę. Zastosowane rozwiązania konserwatorskie wykorzystywały kombinację działań prewencyjnych i inwazyjnych. Istotną rolę w przeprowadzeniu działań konserwatorskich było kompleksowe zrozumienie techniki malarskiej artysty w trakcie całej jego kariery artystycznej oraz wyjaśnienie przyczyn obecności modyfikacji malarskich i niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł z kolekcji NGS. Cel ten osiągnięto, a wyniki badań przedstawiono w wymienionym poniżej cyklu publikacji.

6. Lista publikacji oraz opis merytorycznego wkładu autora w ich powstanie

Publikacje zostały napisane w języku angielskim w specjalistycznych czasopismach o zasięgu międzynarodowym.

L.p.	Publikacja	Punktacja
D1	**Lizun, D.; Szroeder, P.; Kurkiewicz, T.; Szczupak, B. *Examination of painting technique and materials of Liu Kang's Seafood and hidden self-portrait.* „International Journal of Conservation Science" 2021, 12, 3–26.** Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazu w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, wykonaniu fotografii w technice RTI, wykonaniu pomiarów XRF, pobraniu i przygotowaniu próbek warstwy malarskiej, wykonaniu fotografii	IF – 0.762 MNiSW – 140

	mikroskopowej próbek, wykonaniu reakcji barwnych z płynem Lugola, analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	
D2	**Lizun, D.** ***A preliminary study of Liu Kang's palette and the discovery and interpretation of hidden paint layers*****. „Heritage Science" 2020, 8, 21,** https://doi.org/10.1186/s40494-020-0363-x. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, wykonaniu fotografii w technice RTI, wykonaniu pomiarów MA-XRF, pobraniu i przygotowaniu próbek warstw malarskich, wykonaniu fotografii mikroskopowej próbek, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – 2.900 MNiSW – 140
D3	**Lizun, D.; Kurkiewicz, T.; Szczupak, B.** ***Technical examination of Liu Kang's Paris and Shanghai painting supports (1929–1937)*****. „Heritage Science" 2021, 9, 37,** https://doi.org/10.1186/s40494-021-00492-6. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w VIS, analizie struktury płócien, pobraniu i przygotowaniu próbek włókien i warstw malarskich, wykonaniu fotografii mikroskopowej próbek, identyfikacji mikroskopowej włókien podstawie cech morfologicznych, wykonaniu analiz SEM-EDS próbek warstw malarskich, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – 2.900 MNiSW – 140

D4	**Lizun, D.; Kurkiewicz, T.; Szczupak, B. *Exploring Liu Kang's Paris practice (1929–1932): insight into painting materials and technique.* „Heritage" 2021, 4, 828–863,** https://doi.org/10.3390/heritage4020046. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, wykonaniu fotografii w technice RTI, wykonaniu pomiarów XRF i MA-XRF, pobraniu i przygotowaniu próbek warstw malarskich, wykonaniu fotografii mikroskopowej próbek, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – MNiSW – 20
D5	**Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. *A multi-analytical investigation of Liu Kang's colour palette and painting technique from the Shanghai period (1933–1937).* „Applied Sciences" 2023, 13, 2414,** https://doi.org/10.3390/app13042414. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, pobraniu i przygotowaniu próbek warstw malarskich, wykonaniu fotografii mikroskopowej próbek, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – 2.838 MNiSW – 100

D6	**Lizun, D.** ***From Paris and Shanghai to Singapore: a multidisciplinary study in evaluating the provenance and dating of two of Liu Kang's paintings.*** **„Journal of Conservation Science" 2021, 37, 322–339,** https://doi.org/10.12654/JCS.2021.37.4.02. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, analizie struktury płócien, pobraniu i przygotowaniu próbek włókien i warstw malarskich, wykonaniu fotografii mikroskopowej próbek, mikroskopowej identyfikacji włókien na podstawie cech morfologicznych oraz przy pomocy reakcji barwnychj z floroglucyną, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – MNiSW –
D7	**Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.** ***The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique.*** **„Heritage Science" 2022, 10, 16,** https://doi.org/10.1186/s40494-021-00641-x. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, wykonaniu fotografii w technice RTI, analizie struktury płócien, wykonaniu pomiarów XRF warstw malarskich, pobraniu i przygotowaniu próbek włókien i warstw malarskich, wykonaniu fotografii mikroskopowej próbek, mikroskopowej identyfikacji włókien na podstawie cech morfologicznych oraz przy pomocy reakcji barwnych z floroglucyną, wykonaniu analiz PLM i SEM-EDS, interpretacji	IF – 2.900 MNiSW – 140

	wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	
D8	**Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J.** ***Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre.*** **„Heritage" 2022, 5, 896–935,** https://doi.org/10.3390/heritage5020050. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, pobraniu i przygotowaniu próbek warstw malarskich, wykonaniu fotografii mikroskopowej próbek, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – MNiSW – 20
D9	**Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J.** ***Painting materials and technique for the expression of Chinese inheritance in Liu Kang's Huangshan and Guilin landscapes (1977–1996).*** **„Materials" 2022, 15, 7481,** https://doi.org/10.3390/ma15217481. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie 350–1100 nm, wygenerowaniu obrazów w technice IRFC, analizie struktury płócien, pobraniu i przygotowaniu próbek włókien i warstw malarskich, wykonaniu fotografii mikroskopowej próbek, mikroskopowej identyfikacji włókien na podstawie cech morfologicznych oraz przy pomocy reakcji barwnych z floroglucyną, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – 3.748 MNiSW – 140

D10	**Lizun, D.; Rogóż, J. *Observations on selected aspects of Liu Kang's painting practice.* „Journal of Conservation Science" 2022, 38, 460-481,** https://doi.org/10.12654/JCS.2022.38.5.09. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, wykonaniu fotografii w technice RTI, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – MNiSW –
D11	**Lizun, D.; Rogóż, J. *Overview of materials and techniques of paintings by Liu Kang made between 1927 and 1999 from the National Gallery Singapore and Liu family collections.* „Heritage" 2023, 6, 3271-3291,** https://www.mdpi.com/2571-9408/6/3/173. Mój wkład w powstanie tej publikacji polegał na wyborze tematu, stworzeniu koncepcji badań, wykonaniu fotografii obrazów w zakresie widma elektromagnetycznego 350–1100 nm, wygenerowaniu obrazów w technice IRFC, analizie struktury płócien, pobraniu i przygotowaniu próbek włókien i warstw malarskich, wykonaniu fotografii mikroskopowej próbek, identyfikacji włókien na podstawie cech morfologicznych oraz przy pomocy reakcji barwnych z floroglucyną, wykonaniu analiz PLM i SEM-EDS, interpretacji wyników badań, przygotowaniu ilustracji, napisaniu manuskryptu do publikacji i opracowaniu odpowiedzi na recenzje.	IF – MNiSW – 20

Sumaryczny IF – 16,048

Suma punktów MNiSW – 860

7. Oświadczenia współautorów określające indywidualny wkład w powstanie publikacji

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Katedra Technologii i Technik Sztuk Plastycznych

Toruń, 30.03.2023

Oświadczenie

Niniejszym oświadczam, że mój wkład w powstanie publikacji:

L.p.	Publikacja
D5	Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. A multi-analytical investigation of Liu Kang's colour palette and painting technique from the Shanghai period (1933–1937). Applied Sciences 2023, 13, 2414, https://doi.org/10.3390/app13042414.
D8	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J. Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre. Heritage 2022, 5, 896–935, https://doi.org/10.3390/heritage5020050.
D9	Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóz, J. Painting materials and technique for the expression of Chinese inheritance in Liu Kang's Huangshan and Guilin landscapes (1977–1996). Materials 2022, 15, 7481, https://doi.org/10.3390/ma15217481.
D10	Lizun, D.; Rogóż, J. Observations on selected aspects of Liu Kang's painting practice. Journal of Conservation Science 2022, 38, 460-481, https://doi.org/10.12654/JCS.2022.38.5.09.
D11	Lizun, D.; Rogóż, J. Overview of materials and techniques of paintings by Liu Kang made between 1927 and 1999 from the National Gallery Singapore and Liu family collections. Heritage 2023, 6, 3271-3291, https://www.mdpi.com/2571-9408/6/3/173

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Oświadczenie

Niniejszym oświadczam, że mój wkład w powstanie publikacji:

L.p.	Publikacja
D1	Lizun, D.; Szroeder, P.; Kurkiewicz, T.; Szczupak, B. Examination of painting technique and materials of Liu Kang's Seafood and hidden self-portrait. International Journal of Conservation Science 2021, 12, 3–26.
D3	Lizun, D.; Kurkiewicz, T.; Szczupak, B. Technical examination of Liu Kang's Paris and Shanghai painting supports (1929–1937). Heritage Science 2021, 9, 37, https://doi.org/10.1186/s40494-021-00492-6.
D4	Lizun, D.; Kurkiewicz, T.; Szczupak, B. Exploring Liu Kang's Paris practice (1929–1932): insight into painting materials and technique. Heritage 2021, 4, 828–863, https://doi.org/10.3390/heritage4020046.
D5	Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. A multi-analytical investigation of Liu Kang's colour palette and painting technique from the Shanghai period (1933–1937). Applied Sciences 2023, 13, 2414, https://doi.org/10.3390/app13042414.
D7	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B. The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique. Heritage Science 2022, 10, 16, https://doi.org/10.1186/s40494-021-00641-y.
D8	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J. Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre. Heritage 2022, 5, 896–935, https://doi.org/10.3390/heritage5020059.
D9	Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. Painting materials and technique for the expression of Chinese inheritance in Liu Kang's Huangshan and Guilin landscapes (1977–1996). Materials 2022, 15, 7481, https://doi.org/10.3390/ma15217481.

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- analizie FTIR materiału badawczego do publikacji D3
- interpretacji widm FTIR do publikacji D1, D3, D4, D5, D7, D8, D9

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- korekcie edytorskiej manuskryptów do publikacji D1, D3, D4, D5, D7, D8, D9
- pomocy w opracowaniu odpowiedzi na recenzje do publikacji D1, D3, D4, D5, D7, D8, D9

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L.p.	Publikacja
D1	Lizun, D.; Szroeder, P.; Kurkiewicz, T.; Szczupak, B. Examination of painting technique and materials of Liu Kang's Seafood and hidden self-portrait. International Journal of Conservation Science 2021, 12, 3–26.
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D7	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B. The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique. Heritage Science 2022, 10, 16, https://doi.org/10.1186/s40494-021-00641-x.
D8	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J. Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre. Heritage 2022, 5, 896–935, https://doi.org/10.3390/heritage5020050.
D9	Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. Painting materials and technique for the expression of Chinese inheritance in Liu Kang's Huangshan and Guilin landscapes (1977–1996). Materials 2022, 15, 7481, https://doi.org/10.3390/ma15217481.

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Oświadczenie

Niniejszym oświadczam, że mój wkład w powstanie publikacji:

L.p.	Publikacja
D7	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B. The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique. Heritage Science 2022, 10, 16, https://doi.org/10.1186/s40494-021-00641-x.
D8	Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J. Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre. Heritage 2022, 5, 896–935, https://doi.org/10.3390/heritage5020050.

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D1	Lizun, D.; Szroeder, P.; Kurkiewicz, T.; Szczupak, B. Examination of painting technique and materials of Liu Kang's Seafood and hidden self-portrait. International Journal of Conservation Science 2021, 12, 3–26.

wchodzącej w skład rozprawy doktorskiej mgr Damiana Lizuna, polegał na:

- interpretacji widm FTIR
- korekcie edytorskiej manuskryptów
- pomocy w opracowaniu odpowiedzi na recenzje

Paweł Szroeder
....

8. Omówienie prac wchodzących w zakres rozprawy doktorskiej

Poniżej omówiono prace wchodzące w skład rozprawy doktorskiej. Dla każdej pracy przedstawiono szczegółowy cel naukowy oraz wyniki badań.

8.1. Okres paryski (1929–1932)

Streszczenie pracy D1: Lizun, D.; Szroeder, P.; Kurkiewicz, T.; Szczupak, B. *Examination of painting technique and materials of Liu Kang's Seafood and hidden self-portrait.* „International Journal of Conservation Science" 2021, 12, 3–26.

Artykuł stanowi przyczynek do badań techniki i technologii malarskiej Liu Kanga i przedstawia wyniki interdyscyplinarnego studium obrazu *Seafood* namalowanego przez niego w Paryżu w 1932 roku. Analizę obrazu przeprowadzono ze względu na intrygujące cechy techniki malarskiej artysty, takie jak ciemne kontury i kolorowe plamy niepowiązane stylistycznie z przedstawioną kompozycją malarską martwej natury. Uznanie tych cech za integralne z kompozycją obrazu mogło wywoływać niezrozumienie intencji artystycznych, dlatego w celu wyjaśnienia tych wątpliwości konieczne było przeanalizowanie zastosowanych przez Liu Kanga materiałów i techniki malarskiej.

Analizy warstwy malarskiej obrazu za pomocą cyfrowej mikroskopii dostarczyły danych sugerujących obecność odmiennej kompozycji pod obrazem *Seafood*. Badania RTI, NIR w świetle przechodzącym i odbitym, a także XRR potwierdziły te domysły, ukazując portret mężczyzny, sygnaturę artysty oraz datę 193(2). Dodatkowo wyniki przeprowadzonych badań dostarczyły cennych informacji o technice wykonania portretu. Badanie NIR w świetle przechodzącym oraz XRR uwidoczniły dukt pędzla artysty wskazujący na swobodny sposób malowania portretu. Na zdjęciu wykonanym w NIR w świetle przechodzącym zarejestrowano w obrębie marynarki portretowanej osoby użycie szerokiego pędzla oraz ślady wzmocnienia konturu poprzez wydrapanie twardym narzędziem w świeżej farbie. Ponadto technika XRR ukazała miejsca podziału kompozycji za plecami portretowanego. Porównanie zdjęć NIR w świetle przechodzącym i XRR wykazało prawdopodobny ubytek warstwy malarskiej w obszarze czoła portretowanej osoby. Ubytek ten mógł być przyczyną ponownego wykorzystania podobrazia przez artystę do namalowania *Seafood*. Zdjęcie kompozycji z wykorzystaniem techniki RTI, wykonanej w NIR, nie zaś w świetle widzialnym, umożliwiło uwypuklenie i prześledzenie faktury warstwy malarskiej portretu z jego równoczesnym częściowym uwidocznieniem niezbędnym do analiz. Wykonane badania nieinwazyjne ukazały związek pomiędzy elementami zamalowanego portretu a intrygującymi plamami kolorystycznymi widocznymi na obrazie *Seafood*.

Ponieważ rysy twarzy portretowanej osoby wskazują na jej azjatyckie pochodzenie, w dalszej kolejności przeprowadzono analizę porównawczą portretu z dwoma znanymi autoportretami Liu Kanga namalowanymi w Paryżu w 1931 roku. Szczegółowe badania porównawcze wykazały duże podobieństwo w budowie kompozycji, sugerując odkrycie kolejnego, choć być może mniej udanego autoportretu, który wpisuje się w eksplorację tego tematu malarskiego przez artystę podczas pobytu w stolicy Francji. Ponadto analiza zdjęć archiwalnych artysty z Paryża dostarczyła pośrednich dowodów na to, że artysta wielokrotnie wykorzystywał podłoża malarskie, co mogło być spowodowane jego trudną sytuacją materialną. Na tej podstawie wydaje się prawdopodobne, że artysta w poszukiwaniu oszczędności zamalował nieudany autoportret.

W artykule wykonano również analizę pigmentów i spoiw wykorzystanych do namalowania obu kompozycji w celu ich porównania. Badania rozpoczęto od technik nieinwazyjnych. Fotografia obrazu *Seafood* w UVR wstępnie sugerowała zastosowanie bieli ołowiowej w obrębie namalowanego talerza. Natomiast fotografia IRFC okazała się bardzo pomocna w rozróżnieniu zielonych obszarów obu kompozycji uzyskanych prawdopodobnie za pomocą różnych zielonych pigmentów. Uzyskane wstępne wyniki zostały doprecyzowane w toku badań XRF oraz badań inwazyjnych na próbkach warstw malarskich PLM, SEM-EDS i ATR-FTIR.

Przeprowadzone analizy pozwoliły stwierdzić, że zaprawa, na której został namalowany autoportret, jest mieszaniną bieli ołowiowej z domieszką kredy i bieli barytowej utartej ze spoiwem olejnym. Natomiast obraz *Seafood* został wykonany bezpośrednio na wcześniejszej kompozycji bez nałożenia warstwy zaprawy. Z analiz jednoznacznie wynika, że oba przedstawienia malarskie zostały namalowane w technice olejnej. Prawdopodobnie słaba siła krycia farb użytych do namalowania *Seafood* odpowiada za uwidocznienie fragmentów kompozycji autoportretu.

Do namalowania obu kompozycji artysta wykorzystał w większości te same pigmenty, takie jak viridian, karmin alizarynowy, żółcień żelazową, żółcień chromową, żółcień azową

Hansa 10G, czerń kostną, biel ołowiową i barytową. Ponadto w pobranych z *Seafood* próbkach farb wykryto domieszki błękitu pruskiego i zieleni szwajnfurckiej, podczas gdy ultramarynę zidentyfikowano tylko w autoportrecie. Analizy próbek czerwonej farby wykazały, że Liu Kang użył dwóch różnych mieszanin czerwieni organicznych w *Seafood*. Jedna składa się z karminu alizarynowego, czerwieni i żółcieni azowych z domieszką żółcieni chromowej. Druga czerwień była mieszaniną karminu alizarynowego i czerwieni brazylijskiej osadzonej na substracie cynowym i skrobiowym.

Artysta nie pozostawił żadnych informacji wskazujących bezpośrednio na markę używanych farb olejnych w Paryżu, aczkolwiek zachował on dwie strony z katalogu Lefranca z października 1928 roku, które zawierały cenniki farb olejnych. Ta archiwalna informacja pozwala przypuszczać, że artysta mógł zaopatrywać się w farby tego producenta, chociaż nie jest to wystarczający dowód do konstruowania ostatecznych wniosków. Jednakże fakt zainteresowania Liu Kanga farbami Lefranca uznano za wystarczający do przeanalizowania katalogów tego producenta z okresu 1928–1932 i wykorzystano do wsparcia interpretacji wyników badań analitycznych mieszanin pigmentów.

Całkowite wyjaśnienie pochodzenia ciemnych plam barwnych w kompozycji *Seafood,* a także odkrycie autoportretu artysty oraz szczegółowy opis techniki i materiałów użytych w obu przedstawieniach malarskich stanowią kluczowe wyniki badań przedstawionych w artykule.

Streszczenie pracy D2: Lizun, D. *A preliminary study of Liu Kang's palette and the discovery and interpretation of hidden paint layers*. „Heritage Science" 2020, 8, 21.

W artykule tym porównano materiały i technikę malarską dwóch obrazów Liu Kanga reprezentujących dwie wczesne fazy artystyczne związane z pobytem artysty w Paryżu (1929–1932) i Szanghaju (1933–1937). Obraz *Zuo La Lu* powstał w 1930 roku w Paryżu. Liu Kang wówczas kontynuował edukację artystyczną w Académie de la Grande Chaumière na Montparnassie, a w swojej twórczości wyrażał fascynację malarstwem postimpresjonistycznym. Obraz *Nude* został namalowany w 1936 roku w Szanghaju. Artysta prowadził tam pracownię malarstwa w prestiżowej Szanghajskiej Akademii Sztuki i znajdował się w sferze ruchu reformatorskiego, który rzucił wyzwanie chińskim tradycyjnym praktykom malarskim, stosując środki wyrazu artystycznego wzorowane na zachodnim malarstwie modernistycznym. Działalność artystyczna Liu Kanga koncentrowała się wówczas na konsolidowaniu doświadczeń z okresu paryskiego i rozwijaniu indywidualnych metod malarskiej ekspresji.

Celem badań było scharakteryzowanie zapraw podobrazi oraz mieszanin pigmentów użytych przez artystę oraz wyodrębnienie cech wspólnych i rozbieżności pomiędzy zastosowanymi materiałami malarskimi.

W pierwszej kolejności w badaniach wykorzystano techniki nieinwazyjne, takie jak RTI, XRR oraz MA-XRF. Wyniki uzyskane tymi technikami sugerowały obecność zamalowanych przedstawień malarskich. Obraz *Zuo La Lu* został namalowany na wcześniejszej kompozycji przedstawiającej dwukondygnacyjny budynek usytuowany nad strumieniem lub kanałem wodnym. Natomiast do namalowania *Nude* Liu Kang wykorzystał prawdopodobnie nieznany pejzaż. Wykorzystanie starych podobrazi do namalowania obu obrazów może sugerować problemy z dostępnością materiałów malarskich lub trudności finansowe artysty.

Oprócz wizualizacji elementów wcześniejszych kompozycji badania MA-XRF wraz z fotografią IRFC pozwoliły na wstępną identyfikację mieszanin pigmentów oraz wyselekcjonowanie obszarów do pobrania próbek warstw malarskich przeznaczonych do dalszych, szczegółowych badań pigmentów, stosując PLM oraz SEM-EDS.

Analizy pozwoliły stwierdzić prawdopodobną obecność tych samych pigmentów w obu obrazach, czyli błękitu pruskiego, ultramaryny, viridianu, żółcieni strontowej, żółcieni chromowej, żółcieni kadmowej, żółcieni żelazowej, bieli ołowiowej, cynkowej oraz barytowej, czerni kostnej i czerwieni organicznej. Ponadto zwrócono uwagę na preferencyjne użycie bieli ołowiowej w warstwie malarskiej i zaprawie obrazu *Zuo La Lu* oraz bieli cynkowej w obrazie *Nude*. Wyniki te sugerowały zróżnicowaną dostępność białych pigmentów w Paryżu i Szanghaju.

Uzyskane wyniki zainicjowały dalsze szczegółowe badania porównawcze podobrazi oraz warstw malarskich z okresu paryskiego i szanghajskiego.

Streszczenie pracy D3: Lizun, D.; Kurkiewicz, T.; Szczupak, B. *Technical examination of Liu Kang's Paris and Shanghai painting supports (1929–1937)*. „Heritage Science" 2021, 9, 37.

W prezentowanym artykule porównano podobrazia malarskie stosowane przez Liu Kanga w okresie paryskim (1929–1932) i szanghajskim (1932–1937). Zadanie zrealizowano na podstawie charakterystyki formatów i budowy płócien oraz struktury i kompozycji chemicznej warstw zapraw. Badania wykonano na 55 obrazach autorstwa artysty.

Formaty malarskie zostały sklasyfikowane na podstawie szczegółowej inwentaryzacji podobrazi oraz porównania ich wymiarów ze specyfikacjami podobrazi oferowanych przez głównych producentów w Paryżu i Szanghaju. Precyzyjne określenie splotu, gęstości oraz skrętu nitek podobrazi płóciennych wykonano z wykorzystaniem mikroskopu cyfrowego. Identyfikację włókien roślinnych wykonano wizualnie przy użyciu mikroskopu polaryzacyjnego na podstawie cech morfologicznych oraz za pomocą reakcji z floroglucyną. Wstępną analizę struktury i składu chemicznego warstw zapraw przeprowadzono na przekrojach stratygraficznych pod mikroskopem optycznym w VIS i UV. Natomiast skład pierwiastkowy oraz rodzaj spoiw obecnych w zaprawach zostały określone przy użyciu SEM-EDS oraz ATR-FTIR. Ponadto archiwalne reklamy producentów i dystrybutorów materiałów malarskich w Paryżu i Szanghaju z lat 1928–1937 oraz katalogi niektórych z nich okazały się istotne w formułowaniu wniosków na postawie badań analitycznych. Dodatkowo zdjęcia archiwalne Liu Kanga dały wgląd w jego warsztat malarski z obu okresów artystycznych.

Z analiz wynika, że zarówno w Paryżu, jak i Szanghaju artysta zaopatrywał się w płótna fabryczne oraz krosna u drobnych sprzedawców. Odwrocia płócien malarskich nie posiadają oznaczeń producentów lub dystrybutorów, z wyjątkiem obrazu *Rustic landscape* (1934), na odwrociu którego odnaleziono pieczęć nieznanego szanghajskiego sprzedawcy. Rola artysty w przygotowaniu podobrazi ograniczała się jedynie do przycięcia płótna do wymaganego rozmiaru i zamocowaniu go na krośnie. Ustalono, że krosna pełniły funkcję tymczasową, ponieważ ograniczone możliwości finansowe skłaniały Liu Kanga do zdejmowania ukończonych obrazów z krosien i ponownego ich wykorzystania.

Większość dzieł z Paryża i Szanghaju powstała w plenerze na małych podobraziach o numerach 8 i 10, przeznaczonych do malarstwa portretowego. Jednakże większe podobrazia, o numerach 15 i 20, Liu Kang stosował częściej w Szanghaju. Płótna lniane o zróżnicowanej gęstości są charakterystyczne dla okresu paryskiego. Na podstawie badań porównawczych z innymi francuskimi płótnami, opisanymi w literaturze oraz prezentowanymi w ówczesnych katalogach, podobrazia Liu Kanga o małej gęstości zostały skalsyfikowane jako gatunki *étude* lub *pochade*, podczas gdy gęstsze płótna uznano za podobne do typów *demi-fine* lub *fine*. Płótna paryskie pokryte są w większości jednowarstwowymi zaprawami składającymi się głównie z bieli ołowiowej z wypełniaczami w spoiwie olejnym. Zaprawy zawierające spoiwo białkowe lub zaprawy emulsyjne zawierające w swym składzie spoiwo białkowe oraz olej były wybierane przez artystę rzadziej. W Szanghaju Liu Kang preferował płótna bawełniane, natomiast płócien lnianych używał sporadycznie. Podobrazia szanghajskie w większości były pokryte jedną warstwą zaprawy zawierającej głównie kredę w spoiwie emulsyjnym lub białkowym.

W artykule zwrócono uwagę na częstą praktykę zamalowywania nieudanych kompozycji lub wykorzystywania odwroci wcześniejszych prac bez pokrywania ich warstwą gruntu. Na podstawie cech charakterystycznych płócien i zapraw możliwe jest wstępne datowanie lub ustalenie proweniencji obrazów artysty, co do których istnieją wątpliwości. Za przykład mogą posłużyć obrazy *Still life with green stool* (1933) oraz *Backyard* (1934). Oba obrazy, choć namalowane w Szanghaju, mają podobrazia wykazujące cechy typowe dla płócien francuskich, sugerując, że Liu Kang wykorzystał ponownie wcześniejsze prace. Ponadto badania wykazały znaczną obecność mydeł cynkowych w zaprawach, co może być użyteczną informacją dla diagnostyki i zabiegów konserwatorskich prowadzonych w przyszłości. Natomiast źródła archiwalne, takie jak reklamy oraz katalogi materiałów malarskich, pomogły w zrozumieniu trendów branżowych i dostępności materiałów artystycznych w Paryżu oraz Szanghaju.

Streszczenie pracy D4: Lizun, D.; Kurkiewicz, T.; Szczupak, B. *Exploring Liu Kang's Paris practice (1929–1932): insight into painting materials and technique*. „Heritage" 2021, 4, 828–863.

Artykuł przedstawia wyniki badań warstw malarskich czternastu obrazów Liu Kanga reprezentujących jego okres paryski (1929–1932). Celem interdyscyplinarnych badań było poznanie mieszanin pigmentów oraz techniki malarskiej stosowanych przez artystę w Paryżu. Artykuł poszerza zakres wcześniejszych badań skoncentrowanych na studiach technicznych dwóch obrazów (D1, D2) oraz badań podobrazi malarskich z okresu paryskiego Liu Kanga (D3).

W pierwszej kolejności obrazy zbadano przy użyciu technik nieinwazyjnych, takich jak IRFC i UVR, które umożliwiły wstępną identyfikację pigmentów. Użycie skanera MA-XRF do analiz obrazu *Landscape in Switzerland* (1930) ukazało rozmieszczenie pierwiastków wskazujących na stosowanie określonych pigmentów i ich rolę w ewolucji kolorystycznej obrazu. Dodatkowe analizy PLM, SEM-EDS i ATR-FTIR na próbkach warstw malarskich umożliwiły szczegółową identyfikację mieszanin pigmentów. Interpretacja wyników była wsparta katalogami materiałów malarskich dostępnych w Paryżu w okresie działalności artysty oraz archiwalnymi fotografiami, które przybliżyły niuanse jego praktyki malarskiej.

Badania wykazały, że Liu Kang posługiwał się farbami olejnymi o skromnym zakresie kolorystycznym, charakteryzującym się preferencyjnym użyciem ultramaryny, viridianu, żółcieni chromowej, żółcieni żelazowej, czerwieni organicznej, bieli ołowiowej, czerni kostnej i czerni sadzy. Mieszaniny na bazie tych pigmentów były sporadycznie modyfikowane błękitem kobaltowym, błękitem pruskim, zielenią szwajnfurcką, żółcienią kadmową, żółcienią kobaltową i bielą cynkową. Błękit kobaltowy został zidentyfikowany jako dodatek do niebieskich, zielonych i czarnych mieszanin farb. Natomiast błękit pruski był używany do modyfikacji zieleni i czerni. Interesującym odkryciem były dodatki żółcieni kadmowej i kobaltowej, zidentyfikowane wyłącznie w obrazie *Landscape in Switzerland* (1930). Komplementarne analizy PLM, SEM-EDS i ATR-FTIR były szczególnie pomocne w charakterystyce czerwieni organicznych. Ustalono, że Liu Kang prawdopodobnie używał czerwieni organicznej osadzonej na substracie cynowym i skrobiowym, eozyny osadzonej na substracie glinowym lub ołowiowym oraz czerwieni organicznej na substracie glinowym. Pomimo dominującej roli bieli ołowiowej w palecie artysty, zdecydowane użycie litoponu i/lub bieli barytowej i cynkowej zostało potwierdzone w obrazach *Landscape in Switzerland* (1930) oraz *Boat near the Cliff* (1931). Ponadto artysta czasami wykorzystywał niezamalowaną biel zaprawy jako dodatkowy element kolorystyczny podkreślający kontrast kompozycji malarskich. Analizy wykazały przeważające użycie czerni kostnej w *Autumn colours* (1930), natomiast intensywne czernie w innych obrazach były uzyskane przez mieszanie czerni sadzy z ultramaryną, błękitem pruskim, błękitem kobaltowym i viridianem.

Badania nie ujawniły obecności wstępnych rysunków kompozycji na podobraziach malarskich. Jednakże na podstawie zachowanego szkicu akwarelowego będącego studium do obrazu *Breakfast* (1932) można sądzić, że przed przystąpieniem do pracy na płótnie Liu Kang studiował koncepcję artystyczną. Szkice wykonywane w różnych technikach umożliwiały artyście sprawne określenie kompozycji malarskich na płótnie za pomocą szybkich i zdecydowanych pociągnięć pędzla ciemną farbą. Badania wykazały również, że artysta czasami wykonywał szkice malarskie bezpośrednio na podobraziach, które następnie rozbudowywał przez stopniowe wprowadzanie szczegółów i tworzenie złożonych przejść tonalnych.

Okres paryski Liu Kanga charakteryzuje się różnorodnością technik malarskich, ujawniając odważne eksperymentowanie zainspirowane prawdopodobnie obserwacjami dzieł mistrzów europejskiego modernizmu. Liu Kang w obrazie *Autumn colours* (1930) zastosował krótkie, energiczne uderzenia narzędzia malarskiego, które odzwierciedlają jego dbałość o szczegóły. Natomiast śmiałe, równoległe pociągnięcia pędzla widoczne w *St Gingolph, Lac Leman, Switzerland* (1929) sugerują inspirację malarstwem van Gogha. Cechą wspólną wszystkich badanych obrazów jest obecność silnego, ciemnego konturu, który definiuje formy elementów kompozycji. Obserwacja przekrojów poprzecznych warstw malarskich ujawniła, że artysta nakładał farbę na zasadzie mokre na mokre i mokre na suche. Dlatego jest prawdopodobne, że Liu Kang kontynuował pracę po wyschnięciu początkowej kompozycji. Ta cecha warsztatu malarskiego mogła być wynikiem pracy Liu Kanga nad kilkoma obrazami podczas jednej sesji, co zostało udokumentowane na archiwalnej fotografii.

Liu Kang chętnie malował na wcześniejszych kompozycjach lub wykorzystywał ich odwrocia do tworzenia kolejnych obrazów. Obecność ukrytych przedstawień malarskich została potwierdzona w pięciu obrazach na podstawie analizy wizualnej krajek oraz technik RTI, NIR i XRR.

Badania obrazów Liu Kanga z okresu paryskiego przyczyniają się do lepszego zrozumienia jego techniki malarskiej, szczegółowo prezentują użyte materiały malarskie, a także ujawniają obecność mydeł cynkowych i ołowiowych w mieszaninach pigmentów. Rezultaty tych badań mogą być wykorzystane w przyszłej diagnostyce konserwatorskiej i planowaniu zabiegów konserwatorskich obrazów tego artysty.

8.2. Okres szanghajski (1933–1937)

Streszczenie pracy D5: Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. *A multi-analytical investigation of Liu Kang's colour palette and painting technique from the Shanghai period (1933–1937)*. „Applied Sciences" 2023, 13, 2414.

W artykule tym scharakteryzowano paletę kolorystyczną oraz technikę malarską Liu Kanga z okresu szanghajskiego (1933–1937), w którym artysta utrwalił doświadczenia nabyte w Paryżu oraz zaczął wyrażać nowe idee w malarstwie, stanowiące podstawę dla dalszego rozwoju artystycznego. Interdyscyplinarne badania wykonano na dwunastu reprezentatywnych obrazach namalowanych przez artystę w omawianym okresie. Artykuł poszerza zakres wcześniejszych badań skoncentrowanych na studium technicznym obrazu *Nude* (1936) (D1) oraz badań podobrazi malarskich z okresu szanghajskiego Liu Kanga (D3).

Interpretację wyników nieinwazyjnych i mikroinwazyjnych metod analitycznych, wsparto źródłami archiwalnymi, które pozwoliły na dokładniejsze scharakteryzowanie badanych mieszanin pigmentów i techniki malarskiej artysty. Mimo że nie udało się ustalić producenta farb, którymi posługiwał się Liu Kang, źródła archiwalne dały częściowy wgląd w dostępne wówczas w Szanghaju materiały malarskie, którymi artysta mógł dysponować. Ustalono, że w Szanghaju były dostępne farby artystyczne lokalnej produkcji Marie and Eagle oraz importowane marki Reeves i Winsor & Newton. Możliwe było także posługiwanie się przez artystę farbami przywiezionymi z Paryża.

Badania dowiodły umiejętności Liu Kanga tworzenia atrakcyjnej kolorystyki obrazów przy użyciu nieskomplikowanych mieszanin pigmentów. Powszechnie używanym przez artystę niebieskim pigmentem była ultramaryna, którą często stosował w połączeniu z viridianem, żółcienią żelazową, żółcieniami chromianowymi lub błękitem pruskim. Zielenie bazują na viridianie, który był łączony z ultramaryną, błękitem pruskim, żółcieniami żelazowymi oraz żółcieniami chromianowymi. Kolory żółte i brązowe uzyskano głównie za pomocą żółcieni i czerwieni żelazowych oraz żółcieni chromianowych. Umbra i czerń zostały zidentyfikowane w brązowych kolorach. Białe obszary kompozycji malarskich zawierają głównie biel cynkową i barytową, choć możliwa jest również obecność litoponu. Niewielkie ilości bieli ołowiowej w badanych mieszaninach pigmentów uznano za domieszkę. Nie zaobserwowano obszarów malowanych czarną farbą; jednak ciemne pociągnięcia pędzla uzyskano w wyniku połączenia ultramaryny z błękitem pruskim i odrobiną czerni kostnej. Zieleń szwajnfurcka i żółcień kadmowa lub jej warianty są rzadko występującymi dodatkami do analizowanych mieszanin kolorystycznych. W większości badanych obrazów, z wyjątkiem pracy *Pagoda* (1936), artysta nie użył czerwonej farby, jednakże z uwagi na życzenie rodziny artysty, aby nie wykonywać inwazyjnych badań na grupie obrazów z ich kolekcji, próbka czerwieni nie została pobrana do analiz. Mimo to czerwienie żelazowe zostały zidentyfikowane w brązowych warstwach malarskich obrazów z kolekcji NGS. Badania wykazały obecność spoiwa olejnego we wszystkich badanych próbkach warstw malarskich.

Artysta przystępował do prac malarskich z ustaloną koncepcją kompozycji i kolorystyki, ukształtowaną prawdopodobnie poprzez szkice rysunkowe i malarskie. Przypuszczenie to oparto na jednym szkicu akwarelowym, wykonanym przez Liu Kanga przed namalowaniem obrazu *Pagoda* (1936). Obserwacje mikroskopowe powierzchni warstw malarskich badanych obrazów oraz fotografia NIR nie potwierdziły obecności rysunków wstępnych na podobraziach. Dlatego można sądzić, że artysta tworzył kompozycje za pomocą konturów wykonanych pędzlem i rozrzedzoną farbą na zagruntowanym płótnie. Następnie kontury te stopniowo wypełniał kolorem, a rozbudowywane kompozycje wzbogacał niezbędnymi detalami. Wszystkie badane obrazy odzwierciedlają zdolność artysty do łatwego i syntetycznego uchwycenia złożonych przedstawień malarskich. Choć dobrze zaplanowane, kompozycje ujawniają spontaniczną i szybką realizację typową dla malarstwa plenerowego. Śmiałe, płaskie uderzenia pędzlem i szeroko rozprowadzana farba szpachlami malarskimi były najodpowiedniejsze do szybkiego wykonania obrazów w plenerze w trakcie pojedynczej sesji. Obserwacja ta została potwierdzona badaniami mikroskopowymi przekrojów stratygraficznych, które ujawniły częściowo wymieszane kolory oraz nakładanie farby na zasadzie mokre na mokre. Wrażenie spontanicznego malowania podkreślają również częściowo odsłonięte białe zaprawy, sugerujące brak czasu na szczegółowe wykończenie dzieła malarskiego i pokrycie farbą całej powierzchni podobrazia. Choć fragmenty niezamalowanych zapraw wprowadzają dodatkowy kontrast między kolorami, wydaje się, że ten atrakcyjny efekt optyczny nie był zamierzony, w przeciwieństwie do obrazów powstałych w Paryżu. Artysta zwykle nie powracał do swoich kompozycji, aby nanieść poprawki, z wyjątkiem obrazu *Chinese house* (1934), w którym wykryto pentimenti. Preferowane przez Liu Kanga metody ekspresji artystycznej obejmowały ciemne i kręte kontury form przypominające chińską kaligrafię, uszczegóławianie form poprzez wydrapywanie twardym narzędziem w mokrej farbie oraz odejście od konwencji światłocieniowej. Technika malarska artysty odbiega od eksperymentalnego charakteru wcześniejszej fazy paryskiej. Liu Kang w Szanghaju skupił się na syntezie cech malarstwa szkoły paryskiej z tradycyjną chińską kaligrafią.

Przydatność szczegółowych badań obrazów okresu szanghajskiego polega na wyjaśnieniu techniki malarskiej artysty oraz określeniu stosowanej palety kolorystycznej, które mogą być pomocne w określeniu autentyczności dzieł Liu Kanga.

8.3. Okres emigracji na Półwyspie Malajskim i poszukiwanie nowego stylu (1937–1949)

Streszczenie pracy D6: Lizun, D. *From Paris and Shanghai to Singapore: a multidisciplinary study in evaluating the provenance and dating of two of Liu Kang's paintings*. "Journal of Conservation Science" 2021, 37, 322–339.

W artykule przedstawiono problematykę datowania i proweniencji obrazów Liu Kanga *Climbing the hill* z kolekcji National Gallery Singapore oraz *View from St. John's Fort* z kolekcji rodziny artysty. Na podstawie daty – 1937, widniejącej w prawym dolnym rogu *Climbing the hill*, powszechnie uznawano, że artysta namalował obraz krótko po opuszczeniu Szanghaju i po przyjeździe do brytyjskich Malajów (dzisiejsza Malezja), ponieważ przedstawia ruiny portugalskiej fortecy św. Jana w Malakka. Rutynowe badania warstwy malarskiej w VIS i NIR ujawniły obecność wcześniejszych warstw malarskich oraz zamalowanej sygnatury artysty wraz z datą „1948". Odkrycie te skłoniło do wykonania kompleksowych badań technicznych obrazu *Climbing the hill* i przeprowadzenia analizy porównawczej z techniką wykonania obrazu *View from St. John's Fort* (1948), który według zgodnej opinii rodziny artysty i historyków sztuki powstał w tej samej lokalizacji, natomiast przedstawia widok z ruin fortecy na Cieśninę Malakka w kierunku odległych wzgórz wyspy Palu Besar. Wstępna analiza wizualna *View from St. John's Fort* ujawniła obecność wcześniejszej kompozycji, której fragmenty z częściowo zamalowaną datą „1931" są widoczne na krajkach. Z tych też powodów głównym celem analiz było ustalenie prawidłowego czasu powstania oraz proweniencji obu obrazów i zrozumienie praktyki malarskiej artysty w latach 40. XX wieku.

Szczegółowe badania rozpoczęto od określenia splotu, gęstości oraz skrętu nitek podobrazi płóciennych. Identyfikację włókien roślinnych wykonano wizualnie na mikroskopie polaryzacyjnym na podstawie cech morfologicznych oraz przy wykorzystaniu reakcji z floroglucyną. Wstępną analizę budowy i składu chemicznego warstw zapraw przeprowadzono wizualnie na przekrojach stratygraficznych pod mikroskopem optycznym w VIS i UV. Cechy charakterystyczne struktury zapraw oraz ich składu pierwiastkowego określono przy użyciu SEM-EDS. Za pomocą technik fotograficznych w VIS, UVF, NIR, XRR i mikroskopii cyfrowej zarejestrowano wtórne nawarstwienia na obrazach, przeprowadzono wstępną charakterystykę pigmentów oraz wytypowano miejsca pobrania próbek warstw malarskich. Analizę pigmentów wykonano przy użyciu PLM i SEM-EDS. Wyniki badań zostały uzupełnione informacjami archiwalnymi pochodzącymi ze zbiorów rodziny artysty.

Badania doprowadziły do zaskakujących rezultatów. Ustalono, że *Climbing the hill* został namalowany na wcześniejszej kompozycji wykonanej w Szanghaju w latach 1933–1937. Wniosek ten wysnuto na podstawie budowy technicznej podobrazia, które posiada cechy zgodne z płótnami i zaprawami znanymi z okresu szanghajskiego artysty. Ponadto, mikroskopia cyfrowa zarejestrowała w ubytkach obecnej kompozycji fragmenty wcześniejszego malowidła, które prawdopodobnie zostało namalowane w Szanghaju. Badania XRR, niestety, nie uwidoczniły tej wcześniejszej kompozycji. Oryginalne malowidło z Szanghaju zostało następnie zamalowane przez artystę w 1948 lub 1949 roku. Potwierdza to archiwalna, niedatowana fotografia obrazu, na której widnieje sygnatura artysty i data „1948(9)" w lewym dolnym rogu. Zauważalny jest także brak sygnatury i daty „1937" w prawym dolnym rogu obrazu. Umiejscowienie i forma graficzna sygnatury i daty „1948(9)", udokumentowanych na archiwalnej fotografii, są zbieżne z tymi zarejestrowanymi w NIR badanego obrazu. Ponadto badania porównawcze VIS, UVF i IRFC oraz archiwalnej fotografii obrazu wykazały, że zamalowanie w obszarze pierwotnej sygnatury i daty jest formą autorskiej korekty w dolnej części przedstawienia malarskiego. Chociaż nie wiadomo, kiedy te zmiany zostały wykonane, to można przypuszczać, że po tych poprawkach obraz pozostał niesygnowany i niedatowany przez dłuższy czas, być może aż do wystawy w 1993 roku. Katalog wystawy przedstawia obraz w obecnym stanie – z zamalowaniem w obszarze pierwotnej sygnatury i daty wtórnie namalowaną sygnaturą i datą „1937". Możliwym wytłumaczeniem tego faktu mogą być późne prace przygotowawcze obrazu do wystawy. W wyniku znacznego upływu czasu Liu Kang nie był w stanie przypomnieć sobie właściwego czasu powstania obrazu i nieświadomie popełnił błąd.

Natomiast obraz *View from St. John's Fort*, został rzeczywiście namalowany w 1948 roku, jednakże na wcześniejszej i nieznanej kompozycji z 1931 roku. Podobrazie malarskie wykazuje cechy zbieżne ze strukturą płócien i zapraw okresu paryskiego artysty, co dodatkowo potwierdza częściowo widoczna data „1931” na krajce obrazu.

Fakt, że Liu Kang użył starych podobrazi do namalowania obu dzieł w 1948 roku, wzbudził dodatkowe zainteresowanie motywacjami, które skłoniły go do podjęcia takiej decyzji. W związku z tym przeanalizowano dostępność materiałów artystycznych w Singapurze w drugiej połowie lat 40. XX wieku. Źródła archiwalne ujawniły słabą aktywność środowiska artystycznego w Singapurze we wczesnych latach powojennych, co w konsekwencji wpłynęło na niski popyt na materiały artystyczne, które w większości były importowane i prawdopodobnie niedostępne dla artystów z ograniczonymi środkami finansowymi.

Porównanie palety kolorystycznej obu obrazów wykazało dominującą rolę błękitów, zieleni i żółcieni. Liu Kang używał prawie identycznych mieszanin pigmentów składających się głównie z ultramaryny, błękitu pruskiego, viridianu, bieli ołowiowej, żółcieni chromowej oraz żółcieni i czerwieni żelazowych.

Badania mikroskopowe na przekrojach poprzecznych warstw malarskich nie wykazały obecności zapraw lub warstw wyrównawczych nałożonych na pierwotne kompozycje przed namalowaniem aktualnych przedstawień malarskich. Natomiast fotografie w VIS i NIR nie potwierdziły obecności rysunków wstępnych. Jednak zachowany szkic do obrazu *Climbing the hill* oraz dwie fotografie wykonane przez artystę pokazujące wzgórze z ruinami fortyfikacji sugerują, że artysta zebrał wystarczający materiał wizualny, który mógł być pomocny w dalszej pracy studyjnej w Singapurze. Badania ujawniły pewne różnice pomiędzy technikami malarskimi obu dzieł, mimo że powstały one w tym samym czasie. Przeważające użycie szpachel malarskich jest zauważalne w całej kompozycji *Climbing the hill,* podczas gdy w *View from St. John's Fort* szpachle zostały użyte tylko do opracowania murów fortyfikacji. W trakcie malowania obu kompozycji pędzle posłużyły artyście przede wszystkim do przedstawienia detali.

Przeprowadzone badania pomogły w poprawnym datowaniu obrazu *Climbing the hill* oraz wyjaśnieniu prowieniencji obrazów *Climbing the hill* oraz *View from St. John's Fort*. Ponadto badania przybliżyły technikę i materiały malarskie artysty z okresu powojennego lat 40. XX wieku.

8.4. Udział w rozwoju stylu Nanyang (1950–1960)

Streszczenie pracy D7: Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B. *The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique*. „Heritage Science" 2022, 10, 16.

Artykuł ten omawia wkład Liu Kang'a w rozwój stylu malarskiego Nanyang w latach 50. XX wieku poprzez analizę doboru materiałów i rozwoju jego techniki malarskiej.

Styl Nanyang był praktykowany przez chińskich malarzy-migrantów w Singapurze od późnych lat 40. do 60. XX wieku. Styl reprezentuje różne aspekty tropikalnego stylu życia, łącząc tradycje artystyczne szkoły paryskiej i chińskiego malarstwa tuszem z indywidualnymi innowacjami stylistycznymi artystów. Jednak według niektórych badaczy definicja stylu Nanyang jest nieprecyzyjna, ponieważ nie ma on uzgodnionego i spójnego manifestu artystycznego. Artykuł ten charakteryzuje materiały i ewolucję techniki malarskiej Liu Kanga w okresie od 1950 do 1958 roku skutkującej wykrystalizowaniem się głównych zasad technicznych nowego stylu malarskiego w interpretacji artysty. Badania wykonano na podobraziach i warstwach malarskich 10 obrazów.

Interpretacje badań analitycznych wsparto informacjami na temat dostępności określonych materiałów malarskich w Singapurze. W tym celu pomocne okazały się reklamy producentów i dystrybutorów materiałów artystycznych w lokalnych czasopismach oraz ich katalogi opisujące dostępne pigmenty, jak i wykonane na ich bazie farby. Wyniki analiz pigmentów umożliwiły także krytyczne porównanie z informacjami pochodzącymi z pojedynczego źródła historycznego wskazującego preferowane pigmenty Liu Kanga w badanym okresie. Ponadto archiwalne rysunki i fotografie artysty umożliwiły lepsze poznanie jego praktyki malarskiej.

Badania ujawniły dominujące użycie przez artystę lnianych płócien fabrycznych o gęstości liniowej 13 na 15 w cm^2 z dwuwarstwowymi zaprawami olejnymi. Zaprawy zawierają w swoim składzie kredę, litopon i/lub biel barytową i biel cynkową, biel ołowiową oraz biel tytanową, które zostały wymieszane w różnych proporcjach w zależności od warstwy. Olejne zaprawy jedno- i trójwarstwowe oraz zaprawy emulsyjne na płótnach o wyraźnie małej i bardzo dużej gęstości były użyte sporadycznie.

Zidentyfikowana grupa pigmentów zawiera te, które artysta wykorzystywał we wcześniejszych fazach artystycznych, ale także kilka rzadkich pigmentów, takich jak błękit manganowy, ceruleum, błękit ftalocyjaninowy, zieleń ftalocyjaninową, żółcień cynkową i czerwień naftolową AS-D. Badania wykazały jednak, że Liu Kang nie był przekonany do zwiększenia roli tych nowych pigmentów w swojej praktyce malarskiej w latach 50.

Wszystkie badane próbki warstw malarskich zawierają spoiwo olejne. Ultramaryna była konsekwentnie wykorzystywana do malowania niebieskich obszarów kompozycji, chociaż wykryto w nich domieszki błękitu pruskiego, ceruleum i błękitu manganowego. Zauważono, że ceruleum i błękit kobaltowy są głównymi niebieskimi pigmentami występującymi tylko w obrazie *Government Office in Johore Bahru* (1953). Błękit manganowy został użyty jako domieszka do ultramaryny w obrazie *Scene in Bali* (1953). Interesujące jest zastosowanie przez artystę błękitu ftalocyjaninowego jako jedynego niebieskiego pigmentu w obrazie *Painting kampong* (1954). Jeśli chodzi o farby zielone, to należy stwierdzić, że viridian był najpowszechniejszym zielonym pigmentem, chociaż występuje on przede wszystkim w mieszaninach z innymi pigmentami. Częste użycie żółcieni kadmowej i/lub żółcieni cynkowej nie wyklucza stosowania fabrycznej zieleni kadmowej lub zieleni trwałej. Inne zielone pigmenty występujące sporadycznie to zieleń ftalocyjaninowa i zieleń szwajnfurcka. Ta ostatnia została zidentyfikowana w warstwach malarskich dwóch obrazów – *Village* (1950) i *Orchids* (1952), podczas gdy zieleń ftalocyjaninowa została użyta do malowania *Char Siew seller* (1958). Zielone kolory uzyskano również przez zmieszanie błękitu pruskiego i/lub ultramaryny z żółcieniami zawierającymi kadm i chrom. Żółte farby zawierają w swym składzie głównie żółcień kadmową lub jej odmiany, a inne wykryte żółte pigmenty to żółcień żelazowa, żółcień chromowa, cynkowa i kobaltowa. Do uzyskania brązowych kolorów Liu Kang używał żółcieni i czerwieni żelazowych oraz umbry, a czasami modyfikował je żółcienią chromianową, kadmową lub jej odmianą oraz czernią kostną. Analizy czerwonych kolorów wykazały, że Liu Kang stosował przede wszystkim czerwienie organiczne, takie jak: eozyna, szkarłat alizarynowy i czerwień naftolowa AS-D. Wykryto także bardzo małe użycie czerwieni kadmowej. W przypadku farb białych potwierdzono użycie bieli ołowiowej, litoponu i/lub bieli barytowej i cynkowej. Obszary pomalowane na czarno zawierają głównie czerń kostną a jej występowanie stwierdzono także w mieszaninach z innymi wymienionymi już pigmentami. Uzyskane wyniki analiz pigmentów nie potwierdzają w pełni relacji Ho Kok Hoe z 1955 roku, który wymienił viridian, błękit pruski i cynober jako ulubione pigmenty Liu Kanga. Poza częstym użyciem viridianu, jako głównego zielonego pigmentu w obrazach Liu Kanga, widać wyraźnie, że błękit pruski był stosowany jako domieszka do zielonych farb. Natomiast cynobru nie stwierdzono w żadnych badanych próbkach farb. Niemniej jednak jest prawdopodobne, że Liu Kang, dzieląc się informacjami z Ho Kok Hoe, miał na myśli nazwę handlową farby, która mogła zawierać mieszaninę pigmentów organicznych i nieorganicznych.

Badania procesu twórczego Liu Kanga ujawniły charakterystyczny etap konceptualny reprezentowany przez studia rysunkowe i fotografie, które prawdopodobnie były wygodnym sposobem rejestracji interesujących motywów do wykorzystania w pracach malarskich. Ten etap pomógł artyście także opracować koncepcje kompozycji malarskich, co skutkowało minimalną potrzebą wykonywania rysunków wstępnych na podobraziach malarskich. Technika malarska Liu Kanga ukazuje swobodę użycia farby za pomocą pędzli i szpachli malarskich. Charakterystyczne elementy techniki obejmują wzmacnianie kształtów form impastami, ciemnymi i białymi konturami oraz wydrapywaniem świeżej farby twardym narzędziem. W badaniach zwrócono uwagę na to, że białe kontury zwykle były uzyskiwane poprzez celowe eksponowanie białej zaprawy podobrazia, co sugeruje inspirację techniką batiku i stanowi osobisty wkład artysty w styl Nanyang. Najlepszymi przykładami tego stylu w badanej grupie obrazów są O*utdoor painting* (1954) i *Painting kampong* (1954). Artysta zredukował w nich zbędne detale, uprościł formy i zastosował cienko nałożone płaskie plamy kolorystyczne pozbawione światłocienia, natomiast formy zostały podkreślone wyeksponowaną bielą zaprawy i dodatkowo ciemnym konturem. Sposób wykonania tych obrazów wskazuje na dobrą organizację pracy i umiar środków wyrazu.

Jednym z ważnych odkryć podczas badań było udokumentowanie pentimenti oraz odrzuconych kompozycji, które artysta ponownie wykorzystał jako podobrazia malarskie. Praktyka ta miała istotny wpływ na obniżenie jakości niektórych obrazów inspirowanych techniką batiku ze względu na niedostępność białej zaprawy w procesie twórczym. W *Boats* (1956) i *Char Siew seller* (1958) brak białego podłoża artysta zrekompensował białą farbą nakładaną metodą mokre na mokre i mokre na suche w celu odizolowania form i podniesienia kontrastu. Niestety, takie rozwiązanie skutkowało mniej precyzyjnymi podziałami kolorystycznymi, ponieważ biała farba była bardzo często zanieczyszczona innymi kolorami obecnymi na palecie artysty oraz z łatwością mieszała się ze świeżo nałożoną farbą na obrazie. Tak więc tym dwóm dziełom brakuje świeżości i precyzji wykonania, za które cenione są obrazy Liu Kan'a inspirowane batikiem.

Dane uzyskane w wyniku badań mogą pomóc historykom sztuki i konserwatorom w określeniu autentyczności i atrybucji dzieł przypisywanych Liu Kangowi. Szczególne znaczenie ma wyodrębnienie pierwszorzędnych i wtórnych cech malarstwa inspirowanego batikiem. Ponadto, zebrane informacje przyczyniają się do wzrostu wiedzy o materiałach malarskich i technice artysty w latach 50. XX wieku w Singapurze, kiedy rozwijał się styl Nanyang.

8.5. Cykl aktów kobiecych (1927–1954 oraz 1992–1999)

Streszczenie pracy D8: Lizun, D.; Kurkiewicz, T.; Mądry, M.; Szczupak, B.; Rogóż, J. *Evolution of Liu Kang's palette and painting practice for the execution of female nude paintings: the analytical investigation of a genre*. „Heritage" 2022, *5*, 896–935.

Artykuł przedstawia wyniki badań interdyscyplinarnego studium aktów kobiecych autorstwa Liu Kanga. Celem badań było przeanalizowanie ewolucji techniki malarskiej oraz doboru pigmentów użytych w szczególności do opracowania form portretowanych postaci oraz identyfikacja kolorów karnacyjnych.

Tematyka aktów kobiecych towarzyszyła artyście podczas studiów na Xinhua Arts Academy, w trakcie zajęć dydaktycznych na Shanghai Art Academy, gdy przebywał na emigracji w brytyjskich Malajach oraz przez pozostałe lata twórczości w Singapurze. Zaangażowanie we wspomniany gatunek artystyczny zaowocowało licznymi rysunkami, jednakże temat ten nie jest dostatecznie reprezentowany w pracach malarskich ze względu na obowiązującą cenzurę narzuconą przez władze Singapuru. Z tego powodu Liu Kang porzucił tę tematykę w malarstwie na prawie 40 lat (od około 1954 do 1992 roku). W związku z tym badane dzieła malarskie reprezentują dwa okresy 1927–1954 (pierwsza połowa kariery) i 1992–1999 (dojrzałe lata), w których cenzura była mniej dotkliwa i umożliwiała malowanie aktów kobiecych oraz ich prezentowanie na wystawach. Łącznie osiem obrazów wybrano do nieinwazyjnych i mikro-inwazyjnych analiz warstw malarskich. Próbki pobrano głównie z obszarów karnacji portretowanych postaci. W przypadku niedostatecznej ilości materiału badawczego z partii karnacji wsparto się dodatkowymi próbkami warstw malarskich z innych obszarów kompozycji. Interpretacje uzyskanych wyników badań uzupełniono źródłami archiwalnymi w celu wyjaśnienia niektórych aspektów praktyki malarskiej Liu Kanga.

Spoiwo olejne zostało zidentyfikowane we wszystkich badanych próbkach farb. Jasne odcienie karnacji były malowane przy wydatnym użyciu żółcieni żelazowych, chociaż były one czasami zastępowane mieszaniną umbry, czerwieni organicznej oraz czerni kostnej, tak jak w obrazie *Nude* (1992). Natomiast dodatek błękitu kobaltowego do żółcieni i czerwieni żelazowych zarejestrowano w *Nude* (1995). W obrazie *Two nudes* (1996) artysta odszedł od realistycznego sposobu przedstawienia tonacji skóry i zastosował różową farbę na bazie czerwieni żelazowej. Obraz *Beauties at rest II* (1998) reprezentuje zaś bardzo ekspresyjny sposób przedstawienia karnacji z wykorzystaniem żółcieni kadmowej, pomarańczu kadmowego i/lub czerwieni kadmowej lub ich wariantów oraz czerwieni organicznej osadzonej na substracie glinowym. W obrazie *In conversation* (1999) artysta przedstawił karnacje, używając kontrastujących i uzupełniających się kolorów. Tak więc, oprócz żółcieni i czerwieni żelazowych oraz czerwieni organicznej osadzonej na substracie glinowym, artysta zastosował żółcienie chromianowe, ultramarynę i błękit pruski.

Liu Kang bardzo rzadko stosował półtony, chociaż te uzyskane w *Nude* (1927) i *Nude* (1934) sugerują użycie zieleni szwajnfurckiej, zieleni chromianowej lub kobaltowej, ultramaryny lub błękitu kobaltowego, czerwieni organicznej i żółcieni żelazowej. W *Nude* (1992) półtony uzyskano przez zmieszanie szkarłatu alizarynowego, czerwieni żelazowej z żółcienią kadmową lub jej odmianą i czernią kostną, podczas gdy w *Nude* (1995) ultramaryna, czerwień żelazowa, szkarłat alizarynowy osadzony na substracie glinowym i czerń kostna odegrały ważną rolę w uzyskaniu półtonu o chłodnym fioletowym odcieniu.

Jeśli chodzi o prace koncepcyjne, to badania ujawniły istotną rolę studiów rysunkowych w rozwoju idei artystycznych. Rysunki wstępne na podobraziach zostały potwierdzone tylko w *Two nudes* (1996). Niemniej jednak jest prawdopodobne, że artysta przystępował do pracy z określoną koncepcją, którą realizował na podobraziu, zaczynając od nieskomplikowanych pociągnięć pędzla. W artykule przeanalizowano także ewolucję techniki artysty w sposobie przedstawienia kobiecych aktów. Obraz *Nude* (1927) reprezentuje realistyczny styl, który w *Nude* z 1934 i 1940 roku został zastąpiony subiektywną ekspresją, przypominającą wpływy modernistyczne. Oba obrazy charakteryzują się swobodnym wykonaniem oraz redukcją szczegółów i efektów światłocieniowych. Powrót Liu Kanga do tematu aktów w latach 90. XX wieku zainicjował niekonwencjonalną ekspresję artystyczną. W *Nude* (1992) i *Two nudes* (1996) artysta sprowadził sylwetki modelek do uniwersalnych kształtów, posługując się przy okazji ograniczoną paletą barw. W obrazach *Nude* (1995) i *Beauties at rest II* (1998) artysta zastosował żywą kolorystykę w połączeniu z puentylistyczną techniką nakładania farby, która przekształciła się w użycie kontrastujących i uzupełniających się kolorów w obrazie *In conversation* (1999).

Badania przyczyniły się także do odkrycia wcześniejszej wersji obrazu *Beauties at work II* (1998), znanej tylko z archiwalnych fotografii, a zamalowanej przez artystę. Ponadto prawdopodobne użycie farb olejnych marki Royal Talens i Rowney zostało ustalone na podstawie archiwalnych zdjęć artysty w pracowni z lat 90. XX wieku. Ta ważna informacja może pomóc konserwatorom w monitorowaniu procesów niszczenia warstw malarskich z tego okresu.

Przeprowadzone badania po raz pierwszy rzucają światło na paletę kolorów i techniki malarskie artysty w ramach jednego gatunku artystycznego. Uzyskane wyniki mogą umożliwić konserwatorom i historykom sztuki lepsze zrozumienie procesu twórczego artysty.

8.6. Cykl chińskich pejzaży górskich Huangshan i Guilin (1977–1996)

Streszczenie pracy D9: Lizun, D.; Kurkiewicz, T.; Szczupak, B.; Rogóż, J. *Painting materials and technique for the expression of Chinese inheritance in Liu Kang's Huangshan and Guilin landscapes (1977–1996)*. „Materials" 2022, *15*, 7481.

Częste podróże do Chin, które Liu Kang odbywał od lat 70. XX wieku aż do końca swojej artystycznej kariery, stały się źródłem jego twórczej inspiracji i przyczyniły się do powstania odrębnego nurtu malarskiego, który wyraża fascynację górami Huangshan i Guilin. Nurt ten zainicjował nietypowe rozwiązania techniczne w sposobie malowania. W tym kontekście w prezentowanym artykule analizuje się dobór materiałów i technik malarskich artysty na przykładzie 11 obrazów namalowanych w latach 1977–1996. Badaniami objęto podobrazia i warstwy malarskie. Interpretacje badań analitycznych wsparto źródłami archiwalnymi w celu wyjaśnienia niektórych aspektów praktyki malarskiej Liu Kanga.

Uzyskane wyniki wskazują na przeważające użycie płyt pilśniowych bez stosowania warstwy gruntu. Zachowany znak fabryczny na jednym z tych podobrazi wskazuje markę Masonite® Presdwood®. Artysta często stosował ten rodzaj podłoża prawdopodobnie z uwagi na dynamiczną technikę malarską wykorzystującą szpachle i pędzle. Bawełniane i lniane płótna fabryczne były używane rzadziej. Zaobserwowano związek pomiędzy strukturami płócien i zapraw. Gęste płótna bawełniane charakteryzują się jednowarstwową zaprawą składającą się z mieszaniny litoponu i/lub bieli barytowej i cynkowej z dodatkiem bieli ołowiowej. Płótna lniane, mimo zróżnicowanego splotu i gęstości, mają zaprawy dwuwarstwowe o zbliżonym składzie chemicznym. Warstwy dolne są grube i zawierają kredę z dodatkiem litoponu i/lub bieli barytowej i cynkowej oraz bieli ołowiowej i tytanowej. Górne warstwy są cienkie i składają się z tych samych składników co warstwy dolne, jednakże zmieszanych w różnych proporcjach.

Jeśli chodzi o kolorystykę, to należy stwierdzić, że artysta posługiwał się ograniczoną, lecz spójną paletą barw, charakteryzującą się przewagą ultramaryny, żółcieni i czerwieni żelazowych, viridianu i bieli tytanowej. Pozostałe zidentyfikowane pigmenty były stosowane sporadycznie i w niskich koncentracjach, są to: błękit pruski, błękit kobaltowy, błękit ftalocyjaninowy, zieleń ftalocyjaninowa, czerwień naftolowa AS-D, umbra, żółcienie chromianowe, żółcień kadmowa lub jej warianty, żółcień azowa Hansa G, litopon i/lub biel barytowa i biel cynkowa oraz czerń kostna.

Źródła archiwalne pozwalają przypuszczać, że w 1982 roku i w latach 90. artysta preferował farby olejne produkcji Royal Talens, Rowney i Winsor & Newton, w które zaopatrywał się wówczas w dużych ilościach. Liu Kang wykorzystywał także farby ze starych zapasów. W związku z tym jest możliwe, że podczas sesji malarskich mieszał farby różnych producentów wyprodukowane w różnych okresach czasu. Dlatego też przypisanie zidentyfikowanych mieszanin pigmentów do farb określonych producentów nie jest możliwe, natomiast informacje techniczne zawarte w ich katalogach były pomocne w interpretacji badanych mieszanin pigmentów i określeniu tego, czy zostały one uzyskane na palecie artysty, czy też fabrycznie.

Techniki fotograficzne wykonane w VIS i NIR nie potwierdziły obecności wstępnych rysunków kompozycji na podobraziach. Przyczyną takiego wyniku mogła być ograniczona penetracja przez NIR grubych warstw farby lub świadoma decyzja artysty o pominięciu tego etapu procesu twórczego i sprawnym opracowaniu kompozycji na podstawie szkiców i fotografii. Obserwacje powierzchni obrazów oraz mikroskopowe analizy przekrojów warstw malarskich pozwoliły stwierdzić, że technikę malarską artysty charakteryzuje umiejętne manipulowanie farbą w technice mokre na mokre i mokre na suche z przemiennym użyciem pędzli i szpachli skutkującym powstaniem fakturalnej powierzchni malarskich, co jest nietypowe dla Liu Kanga. Opracowanie kompozycji w takiej technice było prawdopodobnie pracochłonne i obejmowało więcej niż jedno posiedzenie, co pozwala na postawienie hipotezy, że artysta malował w pracowni, nie zaś w plenerze. Stworzenie przez artystę obszernego materiału pomocniczego w postaci fotografii i rysunków oraz jego skłonność do ponownego wykorzystania odrzuconych kompozycji potwierdziły tę sugestię. Eteryczny styl badanych obrazów oddaje wyjątkową atmosferę górskich pejzaży, charakteryzujących się surową strukturą majestatycznych skał oraz ciężkimi chmurami, co kontrastuje z delikatną i rzadką roślinnością.

Zebrane w artykule wyniki badań poszerzają wiedzę o stylu i praktyce malarskiej Liu Kanga. Wynika z nich, że artysta powszechnie kojarzony ze stylem Nanyang konsekwentnie podejmował odmienną tematykę malarską, która wyrażała jego nostalgię za Chinami. Choć artysta jest rozpoznawalny głównie w Singapurze i Azji Południowo-Wschodniej, a badany gatunek malarski związany jest z Chinami, to wyniki przeprowadzonych badań wykraczają poza te regiony, przyczyniając się do wzrostu wiedzy o XX-wiecznych materiałach malarskich i ich dostępności w Singapurze.

8.7. Intrygujące cechy praktyki malarskiej artysty oraz związana z nimi problematyka konserwatorska

Streszczenie pracy D10: Lizun, D.; Rogóż, J. *Observations on selected aspects of Liu Kang's painting practice*. "Journal of Conservation Science" 2022, 38, 460-481.

Artykuł ten jako pierwszy przedstawia intrygujące cechy techniki malarskiej Liu Kanga, obejmującej siedem dekad jego działalności artystycznej. Do tych cech należą autorskie retusze, pentimenti, a także ponowne wykorzystanie odrzuconych kompozycji malarskich oraz malowanie na ich odwrociach. Ponieważ Liu Kang nie udzielał informacji na temat technicznych aspektów swojej praktyki malarskiej, eksploracja tych intrygujących cech ekspresji artysty była nastawiona na zrozumienie motywacji jego niekonwencjonalnych decyzji. W tym celu na przykładzie 25 obrazów sklasyfikowano udokumentowane we wcześniejszych artykułach oraz niepublikowane jeszcze cechy procesu twórczego artysty, które mają istotny wpływ na prowenienccje, datowanie, odbiór estetyczny dzieł, a także strategię konserwatorską i ekspozycję. Badania służą potrzebie uzyskania wszechstronnego zrozumienia praktyki malarskiej artysty w celu określenia spójnych wytycznych konserwatorskich, aby umożliwić właściwą prezentację jego prac i uniknąć ich błędnej interpretacji.

Obrazy wyselekcjonowane do badań powstawały w latach 1930–1999 i reprezentowały wszystkie istotne okresy twórczości Liu Kanga. Ponieważ dzieła pochodzące z kolekcji rodziny artysty zachowały się w oryginalnym stanie, a te z kolekcji NGS zostały przekazane przez Liu Kanga, autorstwo retuszy i pentimenti zostało przypisane artyście.

Warstwy malarskie scharakteryzowano za pomocą technik fotograficznych VIS, UVF, NIR, RTI, XRR i cyfrowej mikroskopii optycznej. Interpretacja wyników badań została dodatkowo uzupełniona danymi ze źródeł archiwalnych.

Rezultaty badań jednoznacznie wykazały, że niektóre aspekty praktyki malarskiej artysty prowadzą do błędnego określenia proweniencji obrazów, datowania, interpretacji techniki i stylu malarskiego, a także wpływają na planowane zabiegi konserwatorskie i plany ekspozycyjne. Obecność pentimenti świadczy o dążeniu Liu Kanga do osiągnięcia satysfakcjonujących efektów wizualnych lub o niezdecydowaniu, pomimo zwyczaju opracowywania koncepcji artystycznych w formie szkiców i wykonywania dokumentacji fotograficznej interesujących motywów. Istotnym faktem jest to, że pentimenti czasami zakrywają pierwotne sygnatury i daty, a późniejsze datowanie przez artystę nie zgadza się z rzeczywistym czasem powstania dzieła lub jego korektą. Porównanie badań technicznych obrazów z archiwalnymi fotografiami obrazów oraz rysunkami przygotowawczymi okazało się odpowiednim podejściem badawczym do rozstrzygania tych problemów.

Artysta często zamalowywał wcześniejsze kompozycje lub wykorzystywał ich odwrocia do kolejnych prac malarskich. Te radykalne decyzje miały różne motywacje. W okresie od początku lat 30. do końca lat 40. XX wieku decyzje o zamalowaniu wcześniejszych kompozycji wynikały z ograniczeń finansowych oraz utrudnionej dostępności materiałów artystycznych. W przypadku obrazów dwustronnie malowanych zebrany materiał badawczy sugeruje, że tego typu realizacje malarskie są charakterystyczne tylko dla wczesnej kariery w Paryżu (1929–1932) oraz okresu emigracji w brytyjskich Malajach (1937–1945) i były spowodowane trudnościami finansowymi artysty. Wykonanie nowych kompozycji na odwrociach starych obrazów sugeruje, że Liu Kang starał się nie zamalowywać przedstawień malarskich, z których był zadowolony. Praktyka malowania na wcześniej odrzuconych dziełach w latach 1950–1990 wynikała przede wszystkim z praktycznych względów, a nie koniecznych oszczędności. Najczęściej powodem zamalowywania wcześniejszych kompozycji był ich zły stan zachowania, tak jak w przypadku obrazu przedstawiającego tancerkę balijską. Z powodu rozległych ubytków, zarejestrowanych w XRR, artysta wykorzystał tę kompozycję do namalowania obrazu *Char Siew seller* (1958). Jeśli jednak kompozycja, pomimo zniszczeń, była dla artysty wartościowa, to usiłował on retuszować nawet rozległe ubytki warstwy malarskiej, tak jak w przypadku obrazu *Batik workers* (1954). Ponadto możliwy jest także emocjonalny czynnik, który mógł odpowiadać za niechęć artysty do pierwotnych wersji obrazów *Chinese bridge over river* i *Beauties at rest II* (1998), które poddane zostały radykalnym przemalowaniom. Niechęć mogła wynikać z rozczarowania odbiorem pracy malarskiej przez publiczność lub nieudanej sprzedaży.

W artykule podjęto dyskusję nad zakresem i etyką zabiegów konserwatorskich dotyczących retuszy i przemalowań autorstwa Liu Kanga. Zwrócono także uwagę na rolę badań porównawczych charakteru pisma artysty oraz konieczność potwierdzenia autorstwa retuszy i przemalowań w celu zmniejszenia ryzyka nieprawidłowego datowania i niezamierzonego usunięcia lub zakrycia autorskich warstw malarskich. Przeprowadzono krytyczną dyskusję na temat potencjalnych wyzwań związanych z konserwacją i ekspozycją obrazów dwustronnie malowanych na przykładzie obrazu *Village* i *Slope* z 1931 roku. Badania wykazały także wpływ ponownego wykorzystania podobrazi na jakość obrazów inspirowanych techniką batiku.

Omówione mniej znane aspekty procesu twórczego Liu Kang'a mogą uświadomić konserwatorom i historykom sztuki jego niekonwencjonalny proces twórczy oraz zachęcić ich do dalszych badań w tej dziedzinie.

8.8. Podsumowanie rezultatów badań

Streszczenie pracy D11: Lizun, D.; Rogóż, J. *Overview of materials and techniques of paintings by Liu Kang made between 1927 and 1999 from the National Gallery Singapore and Liu family collections*. „Heritage" 2023, 6, 3271–3291.

Artykuł podsumowuje kompleksowe badania techniki i technologii malarskiej Liu Kanga zaprezentowane w serii publikacji (D1–D10). Zebrane informacje dają spójny pogląd na warsztat artysty poprzez wyodrębnienie zasadniczych cech techniczno-technologicznych dla jego kluczowych okresów stylistycznych oraz pozwalają prześledzić ewolucję doboru materiałów i techniki malarskiej na przestrzeni jego twórczości. Badaniom nieinwazyjnym i mikroinwazyjnym poddano 97 obrazów namalowanych w latach 1927–1999 pochodzących z kolekcji National Gallery Singapore i rodziny artysty.

Badania ujawniły kilka kluczowych aspektów praktyki malarskiej Liu Kanga. Preferowanymi przez artystę podobraziami malarskimi były fabryczne płótna lniane o zróżnicowanej gęstości z olejnymi zaprawami. Fabryczne płótna bawełniane były typowe dla okresu szanghajskiego. Zaprawy klejowe lub emulsyjne były stosowane przez artystę wyłącznie w okresie paryskim i szanghajskim. Płótno zagruntowane prawdopodobnie przez artystę zostało zidentyfikowane tylko w obrazie *Nude* (1927). Oprócz podobrazi płóciennych artysta sporadycznie stosował niezagruntowane płyty pilśniowe. Częste malarstwo plenerowe, typowe dla okresu paryskiego i szanghajskiego, charakteryzuje się stosowaniem małych podobrazi malarskich, ale w miarę rozwoju kariery Liu Kang zaczął chętniej wykorzystywać większe formaty.

Paleta kolorów stosowanych przez artystę była oszczędna, jednak nie ma pewności, czy wynikało to z dostępności materiałów, kłopotów finansowych, czy też wyrażało zamierzoną estetykę. Niemniej jednak badania wykazały ewolucję palety kolorystycznej Liu Kanga w trakcie jego kariery. Artysta powszechnie stosował viridian, ultramarynę, błękitu pruski, żółcienie chromowe i chromianowe, żółcienie kadmowe i ich warianty, żółcienie i czerwienie żelazowe oraz czerwienie organiczne. Natomiast bardzo sporadycznie używał błękitu kobaltowego ceruleum, fioletu kobaltowego, błękitu manganowego oraz błękitu i zieleni ftalocyjaninowych. Rola bieli ołowiowej na palecie artysty została zredukowana w latach 70. XX wieku, natomiast wzrosło znaczenie bieli tytanowej w latach 80. i 90. XX wieku. Artysta zaprzestał używania żółcieni kobaltowej i zieleni szwajnfurckiej w latach 50. XX wieku.

Proces koncepcyjny poprzedzał właściwą pracę malarską. Artysta skupiał się wówczas na opracowywaniu kompozycji za pomocą rysunków, szkiców akwarelowych lub na fotograficznym dokumentowaniu wybranych motywów. Stosowanie przez Liu Kanga rysunków wstępnych na podobraziach pozostaje stosunkowo nieznane. Jednym z powodów takie postępowania może być fakt, że gruba warstwa malarska skutecznie ograniczała penetrację użytego w trakcie badań promieniowania z zakresu bliskiej podczerwieni. Jednakże rysunki przygotowawcze i fotografie umożliwiły artyście sprawne określenie kompozycji malarskiej na podobraziu za pomocą kilku pociągnięć pędzla z pominięciem etapu rysunku przygotowawczego.

Wyniki badań ujawniły zróżnicowaną technikę malarską, która odzwierciedlała doświadczenia i inspiracje artystyczne nabyte w Paryżu, Szanghaju, Malajach i ostatecznie w Singapurze oraz w trakcie różnych podróży artystycznych. Artysta swobodnie manipulował farbą za pomocą pędzli i szpachel. Mieszaniny kolorystyczne nakładał drobnymi dotknięciami lub pociągnięciami narzędzia, przechodzącymi w złożone światłocieniowe modelowanie form, które wyewoluowało w płaskie plamy kolorystyczne, a u schyłku kariery, w puentylistyczne i impastowe wykończenie w technice mokre na mokre lub mokre na suche. Artysta wcześnie wyrażał zainteresowanie efektami optycznymi uzyskanymi poprzez eksponowanie białego koloru zaprawy. Jednakże od lat 50. upodobanie to stało się elementem rozpoznawczym jego techniki malarskiej inspirowanej batikiem. Ponadto badania wykazały, że Liu Kang czasami odchodził od wypracowanej konwencji malarskiej stylu Nanyang i chętnie eksperymentował z nowymi środkami artystycznego wyrazu, zachowując jednak konserwatywną postawę w doborze materiałów malarskich i unikał eksperymentowania z nowymi typami farb artystycznych.

Praktyka artystyczna Liu Kanga charakteryzuje się także niekonwencjonalnymi rozwiązaniami, takimi jak retusze, pentimenti, a także ponowne wykorzystanie odrzuconych kompozycji malarskich oraz malowanie na ich odwrociach. Słaba jakość retuszy wykonanych przez artystę mogła wynikać z postępującej choroby oczu, na którą cierpiał od lat 80. XX wieku. Pentimenti mogą sugerować, że artysta zmieniał koncepcję swojego dzieła w trakcie pracy, mimo że wykonywał obszerne prace przygotowawcze, takie jak rysunki czy dokumentację fotograficzną interesujących motywów. Ograniczenia finansowe, zróżnicowana dostępność materiałów artystycznych, zły stan zachowania obrazów, a także temperament artysty odpowiadały za jego decyzję o pozostawieniu dzieł w stanie nieskończonym lub o ich odrzuceniu i ponownym wykorzystaniu jako podobrazia malarskie.

Zaprezentowane w artykule informacje w sposób spójny przedstawiają praktykę malarską Liu Kanga, umożliwiając dalsze pogłębianie tej wiedzy poprzez korzystanie z odniesień do szczegółowych zagadnień poruszonych w odrębnych publikacjach autora. Wyniki badań mogą pomóc historykom sztuki w ewaluacji techniki malarskiej artysty, a konserwatorom w diagnozowaniu stanu zachowania oraz w planowaniu zabiegów konserwatorskich. Ponadto, przedstawione informacje stanowią podstawę do przyszłych badań skoncentrowanych na praktyce malarskiej innych współczesnych Liu Kangowi artystów z Singapuru i Azji Południowo-Wschodniej.

9. Omówienie wyników prac konserwatorskich wskazanych jako dzieło doktorskie

Prace badawcze umożliwiły zrozumienie techniki malarskiej artysty oraz wyjaśnienie przyczyn obecności modyfikacji malarskich oraz niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł. Tym samym możliwe było poprawne zdiagnozowanie stanu zachowania i poprawne przeprowadzenie zabiegów konserwatorskich dzieł artysty wytypowanych przez kuratorów NGS na stałą ekspozycję. Pracom konserwatorskim poddane zostały następujące dzieła Liu Kanga: *Malay man* (1942), *Kampong scene* (1951), *Batik workers* (1954) i *Liu Hai Su tenth trip to Mt Huanghshan* (1989). Zabiegi konserwatorskie były wykonane przeze mnie w latach 2014–2021. Przedłożone cztery dokumentacje konserwatorskie omawiają typową dla dzieł artysty problematykę dotyczącą ich aspektu wizualnego:

- obszerne przemalowania warstw malarskich,
- nieprofesjonalne uzupełnienia ubytków warstw malarskich,
- zniekształcenia podobrazi wynikające z obecności grubych warstw malarskich powstałych przez powtórne wykorzystanie wcześniejszych kompozycji lub niewłaściwe warunki przechowywania,
- zanieczyszczenia powierzchniowe warstw malarskich oraz ich odwroci.

Zastosowane rozwiązania konserwatorskie wykorzystywały kombinację działań prewencyjnych i inwazyjnych. W związku z tym częstymi zabiegami były: poprawa naciągu płócien, instalacja osłon na odwrociach obrazów, a także oczyszczanie powierzchniowe, konsolidacja odspojonych warstw malarskich, nawilżanie w celu usunięcia deformacji płócien, a w wyjątkowej sytuacji dublaż z przekładką w celu trwałego ustabilizowania podobrazia o nieregularnej strukturze.

Osobnym problemem były retusze i przemalowania wykonane przez artystę. W wielu przypadkach należało uznać integralność aktualnych kompozycji malarskich z autorskimi poprawkami, których jakość diametralnie ustępowała stylowi prac malarskich. W związku z tym podjęte rozwiązania brały pod uwagę aspekt historyczny ingerencji artysty i tylko w bardzo szczególnych przypadkach podjęto decyzję o wykonaniu ich korekty kolorystycznej po uprzednim zabezpieczeniu warstwą werniksu, wypełnieniu ubytku i imitacji faktury. Ta problematyka konserwatorska została dokładniej przedstawiona w publikacji D10, która obszernie omawia wpływ elementów praktyki malarskiej Liu Kanga na strategie konserwatorskie. Praktyczna implementacja wymienionych rozwiązań została przedstawiona w załączonych dokumentacjach konserwatorskich do obrazów Liu Kanga: *Malay man* (1942), *Batik workers* (1954) i *Liu Hai Su tenth trip to Mt Huanghshan* (1989). Warto zaznaczyć, że ostatni z obrazów został namalowany na dwóch podobraziach płóciennych naciągniętych osobno na nieklinowane krosna. Po ukończeniu pracy miejsce styku płócien artysta połączył bibułą naklejoną na warstwę malarską, na którą ponownie nałożył farbę w sposób mniej staranny i odbiegający stylem od oryginalnej kompozycji. Po przedyskutowaniu problemu z kuratorem postanowiono nie ingerować w fakturę wtórnego połączenia, natomiast działanie konserwatorskie ograniczono do korekty kolorystycznej za pomocą delikatnego retuszu.

Innym aspektem skomplikowanej praktyki artystycznej Liu Kanga, oprócz lokalnych uzupełnień warstw malarskich, są pentimenti oraz kompleksowe przemalowania skutkujące całkowitą zmianą stylu kompozycji. Pentimenti często zakrywa oryginalne sygnatury i daty. Natomiast wtórne datowanie obrazów przez artystę jest niezgodne z faktycznym czasem ich powstania, przyczyniając się do błędnej interpretacji oraz proweniencji dzieł. Dlatego też rezultaty kompleksowych badań materiałów i techniki malarskiej artysty umożliwiają zrozumienie jego praktyki malarskiej, zapobiegając błędnemu uznaniu pentimenti, przemalowań oraz retuszy za warstwy renowacyjne innego autorstwa niż Liu Kanga i mogą ustrzec przed ich nieumyślnym usunięciem. W ustaleniu prawidłowego datowania obrazów pomocna okazała się fotografia w VIS i NIR, obrazowanie fałszywym kolorem w podczerwieni, cyfrowa mikroskopia, studia porównawcze z rysunkami przygotowawczymi, a także szczegółowe badania struktury podobrazi malarskich i zapraw, które posiadają cechy charakterystyczne dla różnych okresów artystycznych Liu Kanga. Rezultaty tych badań zostały zaprezentowane w publikacji D6 na przykładzie obrazu *Climbing the hill*, wtórnie datowanego przez artystę w latach 90. na rok 1937, a faktycznie namalowanego w 1948 roku. Ponadto publikacja wyjaśnia przyczyny wtórnego i nieprawidłowego datowania obrazów przez Liu Kanga. Natomiast problem kompleksowych przemalowań skutkujących całkowitą zmianą stylu kompozycji został szczegółowo omówiony w dwóch publikacjach (D8 i D10) dotyczących obrazów *Beauties at rest II* (1998) i *Chinese bridge* (1974). Wyniki kompleksowych badań oraz ich interpretacje dostarczają obszernych informacji na temat budowy technicznej obrazów oraz uzupełniają wiedzę na temat praktyki malarskiej artysty, umożliwiając prawidłową interpretację jego niekonwencjonalnych rozwiązań stylistyczno--technicznych w kontekście możliwych prac konserwatorskich i prawidłowej ekspozycji dzieł.

10. Dokumentacje konserwatorskie

10.1. Dokumentacja konserwatorska obrazu olejnego na płótnie *Malay man* (1942)

Section: Paintings		**Heritage Conservation Centre** Condition & Treatment Report	**Cons ID:** 245238
Title: Malay Man		**Museum:** NGS	**Accession no:** 2003-03244
Artist: Liu Kang	**Dating**: 1942	**Project**: NGS opening	**Project period**:
Curator(s):	**Conservator(s):** Damian Lizun	**Date started**: 13/02/2014	**Date completed**: 08/04/2014

Section A: Description	
Dimensions: Without frame: 94 x 73 cm. With frame: 98.5 x 76.5 cm.	**Artefact image:** 
Primary support: Linen canvas.	
Ground / preparatory layer: Commercial ground layer.	
Paint layer: Oil.	**Surface coating:** Unvarnished.
Auxiliary support: Before treatment and after treatment – wooden strainer.	**Attachment of primary support to auxiliary support:** Before and after treatment – staples.
Framing: Before and after treatment – commercial frame.	**Others (attachments/ labels/ previous repairs):**

Section B: Condition	
Date: 13/02/2014	**Time spent (hrs):** 79
Condition rating: ☐ CR1 Good to go; no processing time required ☐ CR2 <8 hours of processing time required ☐ CR3 8 to 24 hours of processing time required ☐ CR4 >24 to 40 hours of processing time required ☒ CR5 >40 to 120 hours of processing time required ☐ CR6 >120 hours of processing time required	
Primary support (front): Severe undulations.	**Primary support (back):** Severe undulations, surface dirt and water marks.
Ground/ preparatory layer: Delamination and losses.	
Paint layer: Surface dirt. The artist's retouchings executed without the filling material to reconstruct the primer resulted in visible differences between the thickness of the original paint layers and their compensation. Moreover, low-quality colour matching was executed by the artist with oil paints which additionally discoloured over time. The poor application manner of the retouchings, by means of brush strokes incompatible with the surrounding paint application style, additionally reduced the aesthetic properties of the painting.	
Surface coating: None.	
Auxiliary support: Stable.	
Frame: Stable.	
Signature, labels, inscriptions: **Signature:** Chinese character "Kang", followed by date "1942" painted with dark paint in the bottom-right corner. **Inscription:** None.	
Pest infestation / mould: None.	
Other observations (if any): None.	

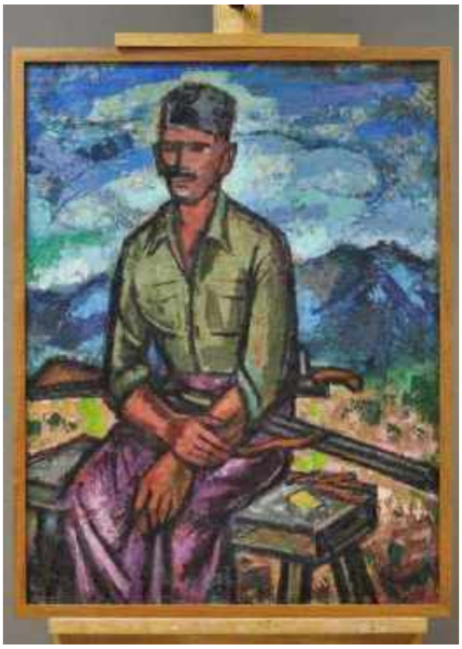
Before treatment images:	
 Fig. 1 Painting before treatment photographed in a normal light.	 Fig. 2 Painting before treatment photographed in a UV light. The image does not show any overpaints.
 Fig. 3 Back of the painting before treatment photographed in a raking light. The image shows severe canvas deformations.	 Fig. 4 Detail of the back of the painting photographed in a raking light. The image shows severe canvas deformations.

Fig. 5 Detail of the back of the painting photographed in a normal light. The image shows water marks.

Fig. 6 Detail of the painting before treatment photographed in a normal light. The arrows indicate the artist's retouchings.

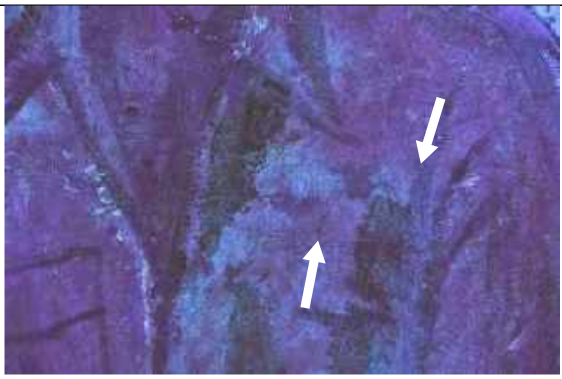


Fig. 7 Detail of the painting before treatment photographed in a UV light. The arrows indicate the artist's retouchings.

Fig. 8 Detail of the painting before treatment photographed in a normal light. The arrow indicate the artist's retouchings executed directly on the canvas without the filling material.

Section D: Treatment proposal

Aim of treatment:

The visual examination of the painting revealed two major issues: severe deformations of the textile painting support and artist's low quality retouchings executed over the paint losses.

The canvas was loose and undulated. Based on the evident water marks on the reverse side of the painting it was concluded that deformations probably were caused by the direct contact with water which accelerated dimensional changes of the textile and ground layers. Therefore, it was crucial to reduce or remove the canvas undulations by means of humidification treatment combined with locally applied pressure and heat. If the results of the treatment are unsatisfactory, then lining of the painting onto new linen canvas with an interleaf should be considered.

Most of Liu Kang's retouches are intrusive elements of the painting. However, despite the arguable quality of the retouching work, these amendments are a legitimate part of the history of the artwork. As for the treatment, the considered professional standards support the notion that the artist's interventions should be preserved as long as they do not endanger the original paint. However, as continued discolouration of Liu Kang's retouched areas increases the risk of further reduction of the aesthetic properties of the painting, the considered approach was to infill and inpaint the retouched

areas of very low quality and which cause the most visually damaging effects. On the other hand, the retouched areas that appear convincing or less distracting should be left untreated.

Treatment proposal	**Est. time (hrs)**
Unstretching.	1
Cleaning the front and back of the painting.	4
Removal of the undulations by means of humidification, heat and pressure treatment.	8
Consolidation.	8
Inlays.	4
Infilling.	8
Strip lining.	5
Stretching.	8
Inpainting.	30
Treatment reporting.	10
Total time:	**86**
Alternatively	
Unstretching.	1
Cleaning the front and back of the painting.	20
Inlays.	4
Removal of the undulations by means of lining.	10
Infilling.	8
Stretching.	1
Inpainting.	30
Treatment reporting.	10
Total time:	**84**

Section E: Treatment		
Date	**Treatment and materials**	**Actual time (hrs)**
13/02/2014	Paint layer was secured with Japanese tissue and 4% water solution of methyl cellulose.	2
13/02/2014	Painting was unstretched and put flat, face down on the working surface.	1
13/02/2014	Back of the painting was vacuumed and surface dirt removed with soft erasers.	8
19/02/2014	Canvas deformations were treated by means of mild humidification on moist blotters and glass slabs (ineffective).	8
26-27/02/2014	Canvas deformations were treated by means of mild humidification combined with heat and suction provided by miniature suction unit (ineffective).	8
11/03/2014	Inlays	5
18-19/03/2014	Lining onto a new linen canvas with mylar interleaf and Beva film.	8
20/03/2014	Removal of the Japanese tissue facing.	2

20/03/2014	Surface dirt removal from the paint layer with 3% deionised water solution of tri-ammonium citrate.	2
24/03/2014	Infilling and texturing with a white putty prepared by hand – 12% weight ratio of calcium carbonate and Mowiol 4-88 (a polyvinyl alcohol).	4
25/03/2014	Stretching.	1
26-28/03/2014	Inpainting with Gamblin Conservation Colours.	20
01-08/04/2014	Treatment reporting.	10
	Total time:	**79**

During and after treatment images:

Fig. 9 Image of the painting after facing with a Japanese tissue.

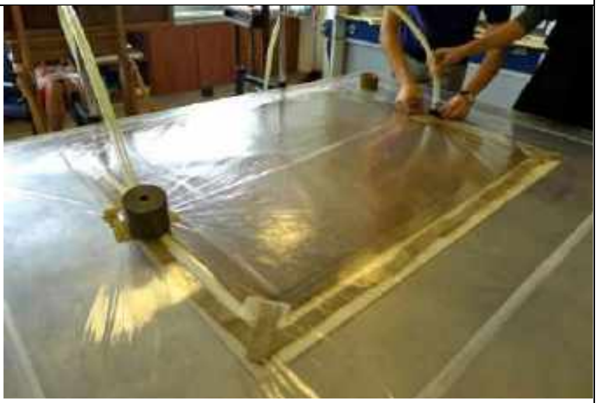


Fig. 10 Painting during lining with the Mylar interleaf and Beva film. Painting was placed face down onto a 3 mm foam to protect the paint layer's texture.

Fig. 11 Image showing the preparation of the linen lining canvas with 3 %methyl cellulose.

Fig. 12 Image showing the painting during the lining onto a linen canvas with Beva film.


Fig. 13 Detail of the painting after infilling.


Fig. 14 Detail of the painting after inpainting.


Fig. 15 Detail of the painting after infilling.


Fig. 16 Detail of the painting after inpainting.

Fig. 17 Back of the painting after treatment.

Fig. 18 Painting after treatment.

Storage & display:

As the painting was selected for gallery display, the recommended ambient temperature is 21°C +/-2°C and RH range 55 +/-5%, and light level 200 lux with UV exposure of no more than 75 µW/lumen. Regular condition checks should be conducted by the museum maintenance team.

10.2. Dokumentacja konserwatorska obrazu olejnego na płótnie *Kampong scene* (1951)

Section: Paintings		**Heritage Conservation Centre** Condition & Treatment Report	**Cons ID:** 342522
Title: Kampong scene		**Museum:** NGS	**Accession no:** 2003-03245
Artist: Liu Kang	**Dating**: 1951	**Project**: NGS rotation	**Project period**:
Curator(s):	**Conservator(s):** Damian Lizun	**Date started**: 31/05/2017	**Date completed**: 19/07/2017

Section A: Description	
Dimensions: Without frame: 61 x 74.5 cm. With frame: 71 x 75 x 2.5 cm.	**Artefact image:** 
Primary support: Linen canvas.	
Ground / preparatory layer: Commercial ground layer.	
Paint layer: Oil.	**Surface coating:** Unvarnished.
Auxiliary support: Before treatment – wooden strainer. After treatment – new wooden strainer.	**Attachment of primary support to auxiliary support:** Before treatment – nails. After the treatment – staples
Framing: Before treatment – no frame. After treatment – no frame.	**Others (attachments/ labels/ previous repairs):**

Section B: Condition	
Date: 31/05/2017	**Time spent (hrs):** 40
Condition Rating: ☐ CR1 Good to go; no processing time required ☐ CR2 <8 hours of processing time required ☐ CR3 8 to 24 hours of processing time required ☒ CR4 >24 to 40 hours of processing time required ☐ CR5 >40 to 120 hours of processing time required ☐ CR6 >120 hours of processing time required	
Primary support (front): Undulations.	**Primary support (back):** Undulations and surface dirt.
Ground/ preparatory layer: Good.	
Paint layer: Surface dirt.	
Surface coating: None.	
Auxiliary support: Unstable. Loose joints	
Frame: None.	
Signature, labels, inscriptions: **Signature:** Chinese character "Kang", followed by English "Liu Kang" and date "1951" painted with dark paint in the bottom-left corner. **Inscription:** None.	
Pest infestation / mould: None.	
Other observations (if any): None.	

Before treatment images:

Fig. 1 Painting before treatment photographed in a normal light.

Fig. 2 Painting before treatment photographed in a UV light. The image does not show any overpaints.

Fig. 3 Painting before treatment photographed in a raking light. The image shows severe canvas deformations.

Fig. 4 Back of the painting before treatment photographed in a raking light. The image shows severe canvas deformations.

Fig. 5 Back of the painting photographed in a normal light.

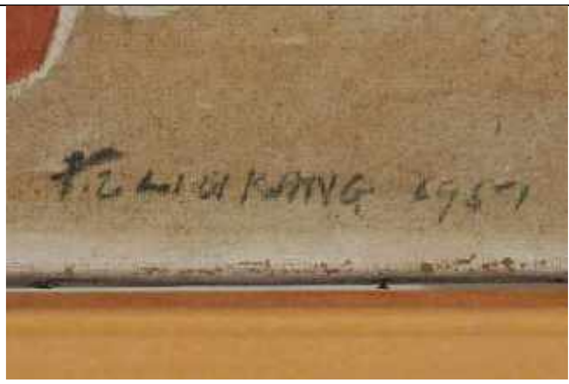


Fig. 6 Detail of the painting before treatment photographed in a normal light. The image shows the artist's signature and date.

Section D: Treatment proposal
Aim of treatment: The aim of the treatment was to remove the canvas undulations, replace the unstable strainer with a new auxiliary structure, surface dirt removal from the front and back of the painting and reinforcement of the tacking margins with strip lining.

Treatment proposal	Est. time (hrs)
Unstretching.	1
Removal of the undulations.	8
Clean the front and back of the painting.	20
Strip lining.	5
Stretching.	1
Treatment reporting.	5
Total time:	**40**

Section E: Treatment		
Date	**Treatment and materials**	**Actual time (hrs)**
31/05/2017	Painting was unstretched and put flat, face down on the working surface.	1
01/06/2017	Canvas deformations were removed by means of mild humidification on moist blotters and weights.	8
12-13/06/2017	Front and back of the painting were cleaned with a soft brush and vacuum cleaner. Ingrained dirt on the paint layer was removed with 2.5 % water solution of tri-ammonium citrate.	20
19-21/06/2017	Strip lining with linen canvas and Beva film.	5
27/06/2017	Stretching.	1
18-19/07/2017	Treatment reporting.	5
	Total time:	**40**

During treatment images:

 **Fig. 7 Detail of the painting during the cleaning tests conducted in the sky area.**	 **Fig. 8 Detail of the painting during the cleaning tests conducted in the sky area.**
 **Fig. 9 Detail of the painting during the cleaning tests conducted in the sky area.**	 **Fig. 10 Detail of the painting during the cleaning tests conducted in the sky area.**

After treatment images:

 **Fig. 11 Painting after treatment.**	 **Fig. 12 Back of the painting after treatment.**

Storage & display:

As the painting was selected for gallery display, the recommended ambient temperature is 21°C +/- 2°C and RH range 55 +/-5%, and light level 200 lux with UV exposure of no more than 75 μW/lumen. Regular condition checks should be conducted by the museum maintenance team.

10.3. Dokumentacja konserwatorska obrazu olejnego na płótnie *Batik workers* (1954)

Section: Paintings	**Heritage Conservation Centre** Condition & Treatment Report		**Cons ID:** 367563
Title: Batik workers		**Museum:** NGS	**Accession no:** P-0197
Artist: Liu Kang	**Dating**: 1954	**Project**: NGS rotation	**Project period**:
Curator(s):	**Conservator(s):** Damian Lizun	**Date started**: 04/01/2018	**Date completed**: 20/02/2018

Section A: Description	
Dimensions: Without frame: 88.5 x 69 cm. With frame: 94.5 x 75 x 2.5 cm.	**Artefact image:** 
Primary support: Linen canvas.	
Ground / preparatory layer: Commercial ground layer.	
Paint layer: Oil.	**Surface coating:** Unvarnished.
Auxiliary support: Before treatment – stretcher without keys. After the treatment – stretcher with keys.	**Attachment of primary support to auxiliary support:** Before and after treatment – staples.
Framing: Before treatment – none. After treatment – frame.	**Others (attachments/ labels/ previous repairs):**

Section B: Condition

Date: 05/01/2018	**Time spent (hrs):** 81

Condition rating:

☐ CR1 Good to go; no processing time required
☐ CR2 <8 hours of processing time required
☐ CR3 8 to 24 hours of processing time required
☐ CR4 >24 to 40 hours of processing time required
☒ CR5 >40 to 120 hours of processing time required
☐ CR6 >120 hours of processing time required

Primary support (front):	**Primary support (back):**
Minor distortions of the canvas. Loose canvas.	Water marks.

Ground/ preparatory layer:
Multiple losses, overpainted by the artist.

Paint layer:
Surface dirt, paint losses within the areas of the ground layer losses.

Surface coating:
None.

Auxiliary support:
Missing 8 keys.

Frame:
None.

Signature, labels, inscriptions:
Signature: Chinese character “Kang” followed by “1954” date scarped in the fresh paint in the bottom-left corner.
Inscription: “LIU KANG BATIK WORKERS 1954, 88.5 x 69 cm. P 0197”, handwritten with a black marker on the back of the top member of the stretcher.

Pest infestation / mould:
None.

Other observations (if any):
None.

Before treatment images:

Fig. 1 Painting before treatment photographed in a normal light.

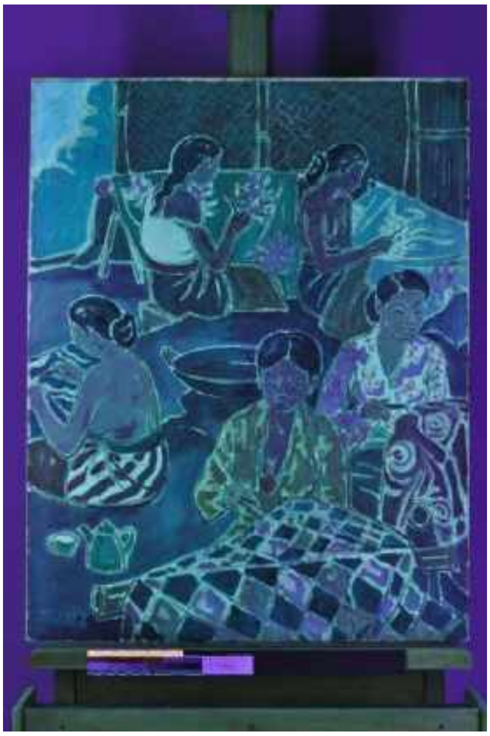


Fig. 2 Painting before treatment photographed in a UV light. Non-fluorescent areas reveal extensive artist-made overpaints.

Fig. 3 Painting before treatment. Transmitted light image shows the losses of the ground and paint layer.

Fig. 4 Back of the painting before treatment. Normal light image shows the water marks.

Fig. 5 Detail of the painting before treatment photographed in a raking light shows the ground and paint layer losses.

Fig. 6 Detail of the painting before treatment photographed in a raking light shows the ground and paint layer losses.

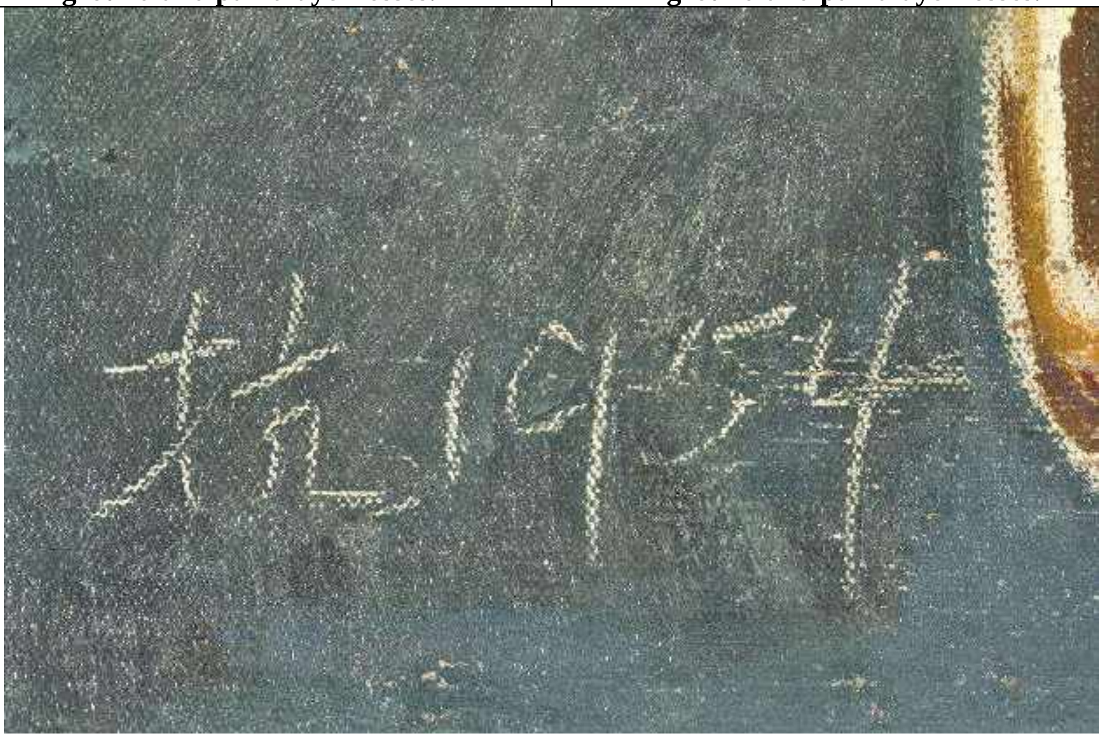


Fig. 7 Detail of the painting before treatment photographed in a normal light shows the artist's signature and date.

Section D: Treatment proposal
Aim of treatment: To remove minor deformations, clean the front and back and address the extensive losses of the ground layer as well as the artist-made discoloured overpaints. The artist's overpaints cover the areas of paint and ground layer losses. The overpaints were applied without infilling. Upon discussion with the curator, the decision was made to address the most disturbing artist's repairs by protecting them with a coat of varnish, followed by infilling and inpainting. The areas which do not require infilling but show disturbing discoloured artist's overpaint and retouching should be corrected by inpainting.

Treatment proposal	Est. time (hrs)
Unstretching.	1
Cleaning front and back of the painting.	5
Flattening the deformations.	4
Infilling.	10
Making new stretcher keys.	1
Stretching.	2
Inpainting.	20
Framing.	4
Treatment reporting.	8
Total time:	**55**

Section E: Treatment		
Date	**Treatment and materials**	**Actual time (hrs)**
04/01/2018	Painting was unstretched.	1
05/01/2018	Front and back of the painting were cleaned with a soft brush and vacuum cleaner. Ingrained dirt on the paint layer was removed with 2.5 % water solution of tri-ammonium citrate.	5
08/01/2018	Canvas deformations were removed by means of mild humidification on moist blotters.	4
15/01/2018	Selected most disturbing artist's overpaints were protected with Larapol A81 at 12% in Shellsol A100.	1
17/01/2018	The selected areas were infilled with a white putty – 12% weight ratio of calcium carbonate and Mowiol 4-88 (polyvinyl alcohol).	10
29/01/2018	New stretcher keys were cut in beech wood.	4
30/01/2018	Painting was stretched over the original stretcher.	2
01-08/02/2018	Inpainting was executed with Gamblin Colours.	40
12/02/2018	Painting was framed into a new frame.	4
20/02/2018	Treatment reporting.	10
	Total time:	**81**

During treatment images:

Fig. 8 Painting after infilling.

Fig. 9 Detail of the painting after infilling.

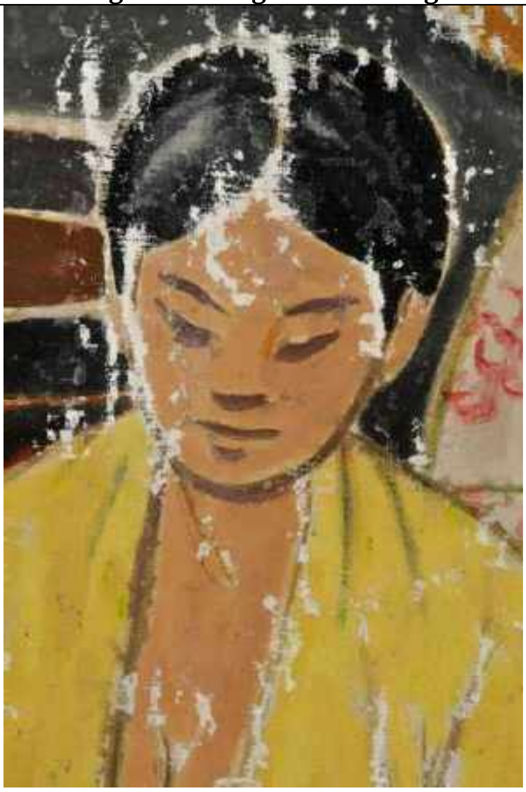


Fig. 10 Detail of the painting after infilling.

Fig. 11 Detail of the painting after infilling.

Fig. 12 Detail of the painting after infilling.

After treatment images:

Fig. 13 Painting after inpainting in a new frame.

Fig. 14 Back of the painting after treatment.

Fig. 15 Detail of the painting after treatment.

Fig. 16 Detail of the painting after treatment.

Fig. 17 Detail of the painting after treatment.

Fig. 18 Detail of the painting after treatment.

Storage & display:
As the painting was selected for gallery display, the recommended ambient temperature is 21°C +/- 2°C and RH range 55 +/-5%, and light level 200 lux with UV exposure of no more than 75 µW/lumen. Regular condition checks should be conducted by the museum maintenance team.

10.4. Dokumentacja konserwatorska obrazu olejnego na płótnie *Liu Hai Su tenth trip to Mt Huanghshan* (1989)

Section: Paintings	**Heritage Conservation Centre** Condition & Treatment Report		**Cons ID:** 410025
Title: Liu Hai Su tenth trip to Mt Huanghshan		**Museum:** NGS	**Accession no:** 2003-03268
Artist: Liu Kang	**Dating**: 1989	**Project**: NGS rotation	**Project period**:
Curator(s):	**Conservator(s):** Damian Lizun	**Date started**: 06/09/2021	**Date completed**: 19/11/2021

Section A: Description	
Dimensions: Without frame: 126 x 170 cm With frame: 149 x 194 x 2.5 cm	**Artefact image:** 
Primary support: Linen canvas stretched over two individual strainers.	
Ground / preparatory layer: Commercial ground layer.	
Paint layer: Oil.	**Surface coating:** Unvarnished.
Auxiliary support: Before treatment – 2 strainers. Each strainer stretched with a commercially made linen canvas and then assembled together with metal plates and screws. After the treatment – no changes made to the structure	**Attachment of primary support to auxiliary support:** Before and after treatment – staples.
Framing: Before and after treatment – frame.	**Others (attachments/ labels/ previous repairs):**

Section B: Condition	
Date: 06/09/2021	**Time spent (hrs):** 26
Condition rating: ☐ CR1 Good to go; no processing time required ☐ CR2 <8 hours of processing time required ☐ CR3 8 to 24 hours of processing time required ☒ CR4 >24 to 40 hours of processing time required ☐ CR5 >40 to 120 hours of processing time required ☐ CR6 >120 hours of processing time required	
Primary support (front): Good.	**Primary support (back):** Good.
Ground/ preparatory layer: Good.	
Paint layer: The unprofessional, the artist-made repair in the area of the vertical joint of the canvases. The repair made of untextured putty and paper tissue was finished with the discoloured oil paint.	
Surface coating: None.	
Auxiliary support: Good.	
Frame: None.	
Signature, labels, inscriptions: **Signature:** Chinese characters “Kang”, followed by “1989” date painted with dark-brown paint in the bottom-left corner. **Inscription:** None.	
Pest infestation / mould: None.	
Other observations (if any): None.	

Before treatment images:

Fig. 1 Painting before treatment photographed in a normal light.

Fig. 2 Painting before treatment photographed in a UV light. Non-fluorescent areas reveal artist-made vertical overpaints in the centre of the composition.

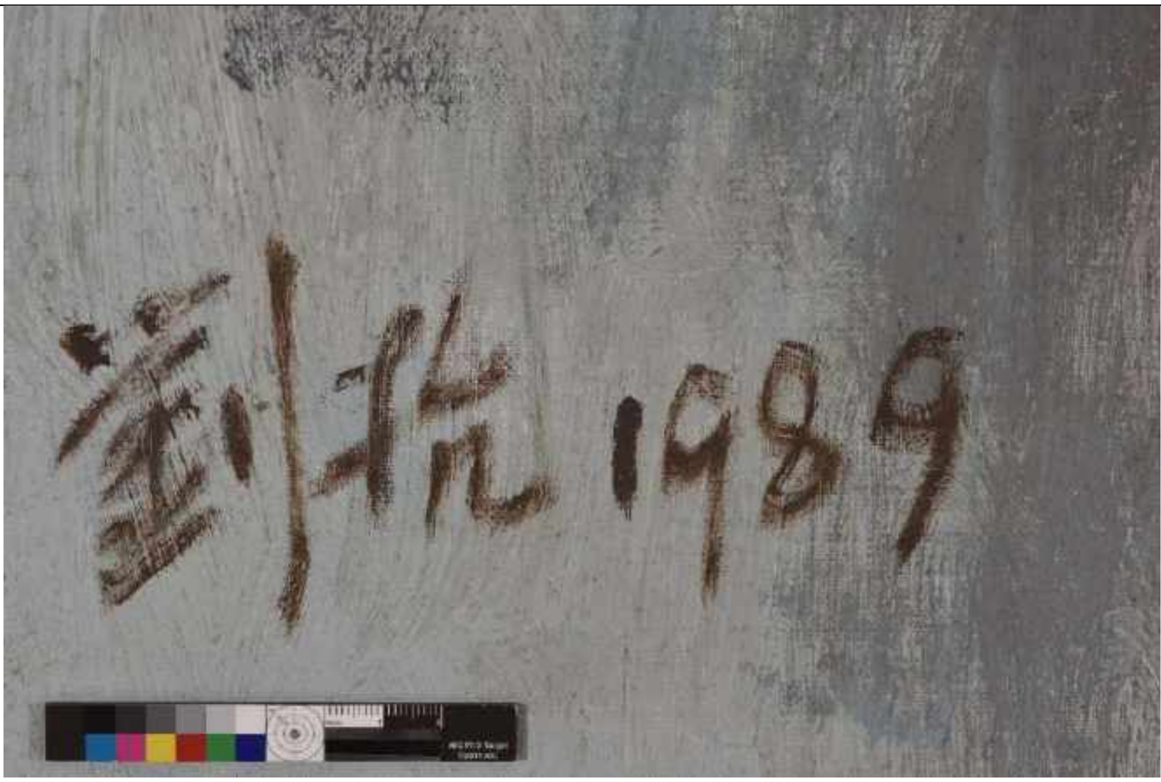


Fig. 3 Detail of the painting before treatment photographed in a normal light. The image shows the artist's signature and date.

Fig. 4 Detail of the painting before treatment photographed in a raking light. The image shows the unprofessional, vertical infill.

Fig. 5 Detail of the painting before treatment photographed in a UV. The image shows the unprofessional, vertical infill seen as non-fluorescent vertical line.

Fig. 6 Detail of the painting before treatment photographed in a normal light showing discoloured artist's retouching in the area of the vertical repair.

Fig. 7 Detail of the painting before treatment photographed in a raking light showing poor texture of the artist's infill in the area of the vertical repair.

Fig. 8 Detail of the painting before treatment photographed in normal light showing discoloured artist's retouching in the area of the vertical repair.

Fig. 9 Detail of the painting before treatment photographed in a raking light showing poor texture of the artist's infill in the area of the vertical repair.

Fig. 10 Detail of the painting before treatment photographed in a normal light showing discoloured artist's retouching in the area of the vertical repair.

Fig. 11 Detail of the painting before treatment photographed in a raking light showing poor texture of the artist's infill in the area of the vertical repair.

Section D: Treatment proposal
Aim of treatment: Upon discussion with the curator, the decision was made to preserve the vertical, artist-made repair, and conduct a minor inpainting to re-integrate the original paint with the artist's overpaint. The artist-made repair should be protected with a coat of reversible varnish, providing a base for further conservation intervention. There was no intention reduce the texture of the artist's infill.

Treatment proposal	Est. time (hrs)
Cleaning the front and back of the painting	4
Varnishing of the artist's repairs	4
Inpainting	10
Treatment reporting	8
Total time:	**26**

Section E: Treatment		
Date	**Treatment and materials**	**Actual time (hrs)**
06-13/09/2021	Front and back of the painting were cleaned with a soft brush and vacuum cleaner. Ingrained dirt on the paint layer was removed with 2.5 % water solution of tri-ammonium citrate.	4
23/09/2021	The artist's repairs were protected with a coat of Larapol A81 at 12% in Shellsol A100.	4
05-12/10/2021	Inpainting was executed with Gamblin Colours	10
19/11/2021	Treatment reporting	8
	Total time:	**26**

After treatment images:

Fig. 12 Painting after treatment.

Fig. 13 Detail of the painting photographed in a normal light, after minor inpainting.

Fig. 14 Detail of the painting photographed in a normal light, after minor inpainting.

Fig. 15 Detail of the painting photographed in a normal light, after minor inpainting.

Fig. 16 Detail of the painting photographed in a normal light, after minor inpainting.

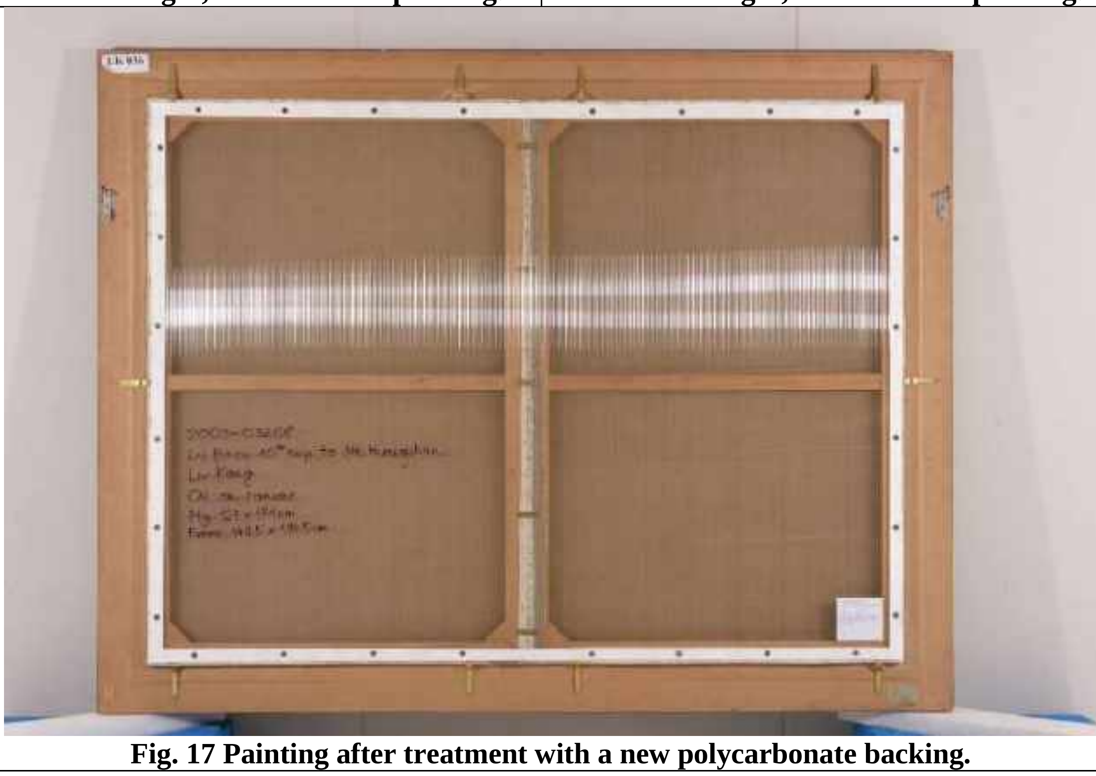


Fig. 17 Painting after treatment with a new polycarbonate backing.

Storage & display:
As the painting was selected for gallery display, the recommended ambient temperature is 21°C +/-2°C and RH range 55 +/-5%, and light level 200 lux with UV exposure of no more than 75 µW/lumen. Regular condition checks should be conducted by the museum maintenance team.

11. Streszczenie pracy doktorskiej w języku polskim

Tytuł: Interdyscyplinarne badania materiałów malarskich i techniki w obrazach singapurskiego artysty Liu Kanga (1911–2004)

Słowa kluczowe: Liu Kang, podobrazia malarskie, pigmenty, przemalowania, pentimenti, obrazy dwustronnie malowane, Shanghai Art Academy, styl Nanyang, IRFC, X-RAY, RTI, MA-XRF, PLM, SEM-EDS, FTIR

Praca doktorska podejmuje zagadnienie techniki i technologii malarskiej jednego z najwybitniejszych singapurskich artystów Liu Kanga (1911–2004). Ponad siedemdziesięcioletnia kariera artystyczna Liu Kanga wykazuje silne wpływy modernizmu, a także tradycyjnego chińskiego malarstwa tuszem. Oba te źródła inspiracji znalazły się w zakresie jego zainteresowań podczas studiów artystycznych w dwóch wielkich stolicach kultury Wschodu i Zachodu początku dwudziestego wieku – Szanghaju i Paryżu. Artysta studiował w Akademii Artystycznej Xinhua w Szanghaju (1926–1928) w okresie istotnych reform społecznych oraz debaty podejmowanej w kręgach artystycznych nad ożywieniem pogrążonego w konserwatyzmie chińskiego malarstwa. Dalszą edukację artystyczną Liu Kang kontynuował w Académie de la Grande Chaumière na Montparnassie (1929–1932), a kilkuletni pobyt w Paryżu zainicjował jego fascynację przede wszystkim twórczością Matisse'a, a także Cézanne'a, Gauguina i van Gogha, do których twórczości nawiązywał w trakcie swojej późniejszej kariery. Wyrazem uznania dla talentu Liu Kanga w trakcie pobytu w Paryżu było dwukrotne przyjęcie jego obrazów na Salon d'Automne w latach 1930 i 1931.

Jednym z największych osiągnięć artystycznych Liu Kanga jest jego udział w rozwoju stylu malarskiego Nanyang, który był praktykowany przez chińskich malarzy-migrantów w Singapurze od późnych lat 40. do 60. XX wieku. Koncepcja stylu została oparta na zobrazowaniu aspektów życia lokalnych społeczności Azji Południowo-Wschodniej za pomocą środków wyrazu asymilujących wpływy szkoły paryskiej oraz chińskiego tradycyjnego malarstwa tuszem. W historii stylu Nanyang Liu Kang ma szczególne miejsce, głównie dzięki wprowadzeniu stylistycznej innowacji nawiązującej do techniki batiku. Mimo że styl ten z biegiem czasu stracił na swojej atrakcyjności, artysta często do niego wracał w swoich późniejszych pracach malarskich. Jego twórczość, jako całość, jest stylistycznie zróżnicowana za sprawą nieustannych poszukiwań nowych źródeł inspiracji, podejmowania porzuconych wcześniej tematów, eksperymentowania z nowymi technikami malarskimi, co skutkowało niezamierzonymi efektami wizualnymi.

Bibliografia dotycząca twórczości Liu Kanga, artysty uznawanego powszechnie za ikonę malarstwa singapurskiego i współtwórcę regionalnego stylu, jest stosunkowo skromna i zawiera się w kilku dysertacjach i opracowaniach zbiorowych w większości omawiających jego działalność w kontekście innych lokalnych twórców lub stylu Nanyang. Inne materiały źródłowe obejmują liczne katalogi wystaw, artykuły prasowe, wywiady oraz dokumenty telewizyjne. Ponadto, żaden z autorów nie podjął się zadania scharakteryzowania warsztatu malarskiego artysty w sposób koherentny lub omówienia wybranych aspektów jego techniki i używanych materiałów.

Głównym celem badań było stworzenie spójnego poglądu na warsztat artysty poprzez wyodrębnienie zasadniczych cech techniczno-technologicznych dla jego kluczowych okresów stylistycznych oraz prześledzenie ewolucji doboru materiałów i techniki malarskiej na przestrzeni jego twórczości. Ponadto istotnym zadaniem było wyjaśnienie przyczyn obecności modyfikacji malarskich oraz niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł artysty. Konieczne zatem było szczegółowe rozpoznanie rodzajów i sposobu przygotowania podobrazi malarskich, struktury i chemicznej kompozycji zapraw oraz warstw malarskich, a także określenie roli studiów przygotowawczych w procesie twórczym artysty.

Przedmiotem badań uczyniono 97 obrazów Liu Kanga z kolekcji National Gallery Singapore oraz rodziny artysty w Singapurze namalowanych w okresie od 1927 do 1999 roku. Obrana metodyka dała pierwszeństwo badaniom nieinwazyjnym, których wyniki określiły zakres kolejnych technik analitycznych. Zakres technik nieinwazyjnych objął rejestrację obrazów za pomocą światła widzialnego, fluorescencji wzbudzonej ultrafioletem, reflektografii w ultrafiolecie, bliskiej podczerwieni, fałszywej podczerwieni, obrazowania z transformacją odbicia i rentgenografii. Ponadto warstwy malarskie były analizowane przy użyciu mikroskopii cyfrowej oraz rentgenowskiej analizy fluorescencyjnej. W następnym etapie pobrano 152 próbki włókien podobrazi płóciennych oraz 448 próbek warstw malarskich i zapraw do szczegółowych badań analitycznych, stosując mikroskopię polaryzacyjną, skaningowy mikroskop elektronowy ze spektrometrem dyspersji energii promieniowania rentgenowskiego oraz spektroskopię w podczerwieni z transformatą Fouriera stosując technikę osłabionego całkowitego wewnętrznego odbicia. Istotnym elementem metodologii były badania materiałów archiwalnych z kolekcji rodziny artysty oraz studia katalogów i reklam materiałów artystycznych z okresów odpowiadających aktywności malarskiej Liu Kanga. Zebrane w ten sposób informacje były pomocne w interpretacji wyników badań analitycznych, ale także umożliwiły częściowe rozpoznanie dostępności materiałów artystycznych w trzech głównych miejscach działalności malarskiej Liu Kanga – Paryżu, Szanghaju i Singapurze.

Rozprawę doktorską stanowi jedenaście artykułów naukowych oraz cztery dokumentacje konserwatorskie. Artykuły zestawiono w kolejności odpowiadającej głównym okresom stylistycznym artysty oraz jego cyklom tematycznym:

- okres paryski (1929–1932),
- okres szanghajski (1933–1937),
- okres emigracji na Półwyspie Malajskim i poszukiwanie nowego stylu (1937–1949),
- udział w rozwoju stylu Nanyang (1950–1960),
- cykl aktów kobiecych (1927–1954 oraz 1992–1999),
- cykl chińskich pejzaży górskich Huangshan i Guilin (1977–1996).

Intrygujące cechy praktyki malarskiej artysty oraz związaną z nimi problematykę konserwatorską zaprezentowano w kolejnym artykule. Cykl zamyka publikacja podsumowująca rezultaty wszystkich badań i charakteryzująca technikę i technologię malarską Liu Kanga na przestrzeni całego okresu jego pracy twórczej.

Zabiegi konserwatorskie zostały wykonane na czterech obrazach wytypowanych przez National Gallery Singapore na stałą wystawę. Zastosowane rozwiązania konserwatorskie wykorzystywały kombinację działań prewencyjnych i inwazyjnych. Istotną rolę w przeprowadzeniu działań konserwatorskich odgrywało kompleksowe zrozumienie techniki malarskiej artysty w trakcie całej jego kariery artystycznej, wyjaśnienie przyczyn obecności modyfikacji malarskich oraz niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł z kolekcji NGS.

Badania ujawniły kilka kluczowych aspektów praktyki malarskiej Liu Kanga. Preferowanymi przez artystę podobraziami malarskimi były fabryczne płótna lniane o zróżnicowanej gęstości z olejnymi zaprawami. Fabryczne płótna bawełniane były typowe dla okresu szanghajskiego. Zaprawy klejowe lub emulsyjne były stosowane przez artystę wyłącznie w okresie paryskim i szanghajskim. Oprócz podobrazi płóciennych artysta sporadycznie stosował niezagruntowane płyty pilśniowe. Częste malarstwo plenerowe typowe dla okresu paryskiego i szanghajskiego charakteryzuje się stosowaniem małych podobrazi malarskich, ale w miarę rozwoju kariery Liu Kang zaczął chętniej wykorzystywać większe formaty.

Paleta kolorów używanych przez artystę była oszczędna. Artysta powszechnie stosował viridian, ultramarynę, błękitu pruski, żółcienie chromowe i chromianowe, żółcienie kadmowe i ich warianty, żółcienie i czerwienie żelazowe oraz czerwienie organiczne. Natomiast bardzo sporadycznie używał błękitu kobaltowego ceruleum, fioletu kobaltowego, błękitu manganowego oraz błękitu i zieleni ftalocyjaninowych. Rola bieli ołowiowej na palecie artysty została zredukowana w latach 70. XX wieku, natomiast wzrosło znaczenie bieli tytanowej w latach 80. i 90. XX wieku. Artysta zaprzestał używania żółcieni kobaltowej i zieleni szwajnfurckiej w latach 50. XX wieku.

Źródła archiwalne udokumentowały, że w latach 80. i 90 XX wieku artysta posługiwał się między innymi farbami olejnymi produkcji Royal Talens i Rowney, w które zaopatrywał się wówczas dużych ilościach. Liu Kang wykorzystywał także farby ze starych zapasów. W związku z tym jest możliwe, że podczas sesji malarskich mieszał farby różnych producentów wyprodukowane w różnych okresach.

Proces koncepcyjny poprzedzający właściwą pracę malarską obejmował opracowywanie kompozycji za pomocą rysunków, szkiców akwarelowych lub w fotograficznym dokumentowaniu wybranych motywów. Stosowanie przez Liu Kanga rysunków wstępnych na podobraziach pozostaje stosunkowo nieznane prawdopodobnie z powodu ograniczonej penetracji NIR grubych warstw malarskich. Jednakże rysunki przygotowawcze i fotografie umożliwiły artyście sprawne określenie kompozycji malarskiej na podobraziu za pomocą kilku pociągnięć pędzla i z pominięciem etapu rysunku przygotowawczego.

Wyniki badań ukazały zróżnicowaną technikę malarską, która odzwierciedlała doświadczenia i inspiracje artystyczne nabyte w Paryżu, Szanghaju, Malajach i ostatecznie w Singapurze oraz w trakcie różnych podróży artystycznych. Artysta nakładał farbę drobnymi dotknięciami lub pociągnięciami narzędzia, przechodzącymi w złożone światłocieniowe modelowanie form, które wyewoluowało w płaskie plamy kolorystyczne, a u schyłku kariery, w puentylistyczne i impastowe wykończenie w technice mokre na mokre lub mokre na suche. Artysta wcześnie wyrażał zainteresowanie efektami optycznymi uzyskanymi poprzez eksponowanie białego koloru zaprawy. Jednakże od lat 50. upodobanie to stało się elementem rozpoznawczym jego techniki malarskiej inspirowanej batikiem. Ponadto badania wykazały, że

Liu Kang czasami odchodził od wypracowanej konwencji malarskiej stylu Nanyang i chętnie eksperymentował z nowymi środkami artystycznego wyrazu, zachowując jednak konserwatywną postawę w doborze materiałów malarskich i unikał eksperymentowania z nowymi typami farb artystycznych.

Praktyka artystyczna Liu Kanga charakteryzuje się także niekonwencjonalnymi rozwiązaniami, takimi jak retusze, pentimenti, a także ponowne wykorzystanie odrzuconych kompozycji malarskich oraz malowanie na ich odwrociach. Słaba jakość retuszy wykonanych przez artystę mogła wynikać z postępującej choroby oczu, na którą cierpiał od lat 80. XX wieku. Pentimenti mogą sugerować, że artysta zmieniał koncepcję swojego dzieła w trakcie pracy, mimo że wykonywał obszerne prace przygotowawcze, takie jak rysunki czy dokumentację fotograficzną interesujących motywów. Ograniczenia finansowe, zróżnicowana dostępność materiałów artystycznych, zły stan zachowania obrazów, a także temperament artysty odpowiadały za decyzję artysty o pozostawieniu dzieł w stanie nieskończonym lub o ich odrzuceniu i ponownym wykorzystaniu jako podobrazia malarskie.

Prace badawcze umożliwiły zrozumienie techniki malarskiej artysty oraz wyjaśnienie przyczyn obecności modyfikacji malarskich oraz niekonwencjonalnych rozwiązań stylistyczno-technicznych wpływających na estetykę dzieł. Tym samym możliwe było poprawne zdiagnozowanie stanu zachowania i poprawne przeprowadzenie zabiegów konserwatorskich dzieł artysty wytypowanych przez kuratorów National Gallery Singapore na stałą ekspozycję.

Dodatkowym osiągnięciem badawczym jest częściowe udokumentowanie dostępności materiałów malarskich w trzech ważnych ośrodkach działalności artystycznej Liu Kanga: w Paryżu, Szanghaju i Singapurze. Wyniki badań mogą pomóc historykom sztuki w ewaluacji techniki malarskiej artysty, a konserwatorom w diagnozowaniu stanu zachowania oraz w planowaniu zabiegów konserwatorskich. Zebrane wyniki badań mogą być użyteczne w studiach nad autentycznością prac przypisywanych artyście. Ponadto, przedstawione informacje stanowią podstawę do przyszłych badań skoncentrowanych na praktyce malarskiej innych współczesnych Liu Kangowi artystów z Singapuru i Azji Południowo-Wschodniej.

12. Streszczenie pracy doktorskiej w języku angielskim

Title: An interdisciplinary investigation of the painting materials and technique of Singapore artist Liu Kang (1911–2004).

Key words: Liu Kang, painting supports, pigments, hidden paintings, pentimenti, double-sided paintings, Shanghai Art Academy, Nanyang style, IRFC, X-RAY, RTI, MA-XRF, PLM, SEM-EDS, FTIR

The aim of the doctoral thesis is to elucidate the painting materials and techniques of a renowned modern Singaporean artist Liu Kang (1911–2004). His painting practice which spans over seven decades was strongly influenced by Modernists' artworks and Chinese painting traditions. Liu Kang expressed these artistic inspirations during his studies in two major East and West art centres – Shanghai and Paris. Liu Kang gained art education at the Xinhua Art Academy in Shanghai (1926–1928) during the national art reformation movement, which aimed at the revival of Chinese painting practices by introducing artistic ideas from the School of Paris. He continued his artistic education at the Académie de la Grande Chaumière in Montparnasse (1929–1932). Liu Kang's stay in Paris initiated his fascination with the works of Matisse, Cézanne, Gauguin, and van Gogh, whose art he alluded to throughout his career. Liu Kang's early artistic achievements in Paris were publicly recognised in 1930 and 1931, when he exhibited at the Salon d'Automne.

One of Liu Kang's main artistic accomplishments was his contribution to the creation and development of the Nanyang painting style in the 1950s. The Nanyang style is associated with paintings that express a consciousness of regional identity amongst the migrant Chinese painters in Singapore, stemming from an erosion of ties with China, especially after the start of communist rule in 1949. The painting style reflects an eclectic amalgamation of two artistic traditions, the School of Paris and Chinese ink painting, representing Southeast Asian subject matter. The additional aspect of the style is the batik-inspired stylistic innovation, which successfully accommodated Liu Kang's preference for the exposed colour of white ground. Besides having a vital role in developing the Nanyang style, Liu Kang repeatedly departed from his established artistic way to search for new sources of inspiration and to experiment with various forms of expression. These explorations triggered unconventional painting approaches, which accentuated some inconsistencies in the artist's oeuvre.

The literature relating to Liu Kang's oeuvre is limited and includes academic dissertations and studies about his professional activity in the context of other Singapore artists or the Nanyang style. Other sources comprise various exhibition catalogues, press releases, interviews and TV documentaries. Moreover, none of the authors have discussed the artist's painting techniques comprehensively or analysed the peculiarities of his working practice.

The main aim of the research comprised an overview of the artist's preferential painting supports and pigments and an outline of the evolution of his working methods throughout his career. Moreover, it was crucial to identify and categorise some intriguing technical features of his paintings, which define the less known and mysterious side of his oeuvre. Therefore, it was important to identify the types and methods of preparation of the painting supports, the structure and chemical composition of the ground and paint layers, as well as to determine the role of preparatory studies in the artist's creative process.

The research focused on 97 of Liu Kang’s paintings from the National Gallery Singapore (NGS) and Liu family collections created on canvas and hardboard between 1927 and 1999. Research strategy prioritised non-invasive techniques. Their results guided further micro-invasive analytical techniques. The non-invasive techniques involved the photography of the paintings in visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR), near-infrared (NIR) and infrared false-colour (IRFC) imaging. Moreover, X-ray radiography (XRR) and reflectance transformation imaging (RTI) were conducted. Paint layers were analysed with a digital microscopy and X-ray fluorescence (XRF). The following step involved the extraction of 152 fibre samples from the textile supports and 448 ground- and paint-layer samples for detailed identification employing polarised microscopy (PLM) and field-emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS), followed by total reflectance–Fourier transform infrared spectroscopy (ATR-FTIR). When necessary, the interpretation of the analytical data was cross-referenced with contemporary colourmen catalogues. The archival sources further expanded the knowledge of Liu Kang’s painting practice, whereas his drawings and watercolours shed light on the development of the compositions from the initial concepts to the completed artworks. The thesis was conducted in a series of publications focusing on Liu Kang’s major artistic phases and special artistic subjects as follows:

- Paris period (1929–1932),
- Shanghai period (1933–1937),
- period of emigration to Malaya and the quest of developing his own painting style (1937–1949),
- contribution to the Nanyang style (1950–1960),
- artistic subject of female nudes (1927–1954 and 1992–1999),
- artistic subject of Huangshan and Guilin mountains (1977–1996).

The intriguing technical features of Liu Kang’s painting practice and conservation issues relating to them are presented in a dedicated research article. The final publication presents the research results, which characterises painting materials and techniques throughout Liu Kang’s oeuvre.

The systematic multidisciplinary approach revealed a few key aspects of Liu Kang’s painting practice. Commercially prepared linen canvases of varied densities with oil-based grounds were the artist’s preferred painting supports. Commercially prepared cotton canvases were the norm during the Shanghai period. Absorbent and semi-absorbent grounds occurred only in paintings originating from Paris and Shanghai. Besides textile supports, the artist occasionally used unprimed hardboards resembling Masonite boards. Additionally, Liu Kang's frequent outdoor painting sessions in Paris and Shanghai led to the use of small-sized painting supports, but as his career progressed, he began to favour larger formats.

The palette of colours is economical, but it evolved over time. The artist relied on viridian, ultramarine, Prussian blue, Cr- and Cd-containing yellows, yellow and red Fe-containing earth pigments and organic reds. The artist introduced—very briefly— cobalt blue, cerulean blue, cobalt violet, manganese blue, phthalocyanine blue and green. However, their low usage suggests some hesitation in giving these pigments a more pronounced role in the painting process. Although lead white was continuously present in the mixtures with other pigments until the 1990s, it was superseded by titanium white in highlights. Hence, the role of titanium white in Liu Kang's paintings evolved from a possible commercial admixture characteristic of his early practice to the most frequently employed white pigment in the 1980s and consistently used thereafter. He withdrew cobalt yellow and emerald green in the 1950s.

According to the archival sources, the artist used oil paints from Royal Talens and Rowney, among other manufacturers, in the 1980s and 1990s. It can be inferred that he may have preferred bulk purchases of paint tubes to avoid interruption to the artistic process. In addition, it is conceivable that, during the painting sessions, the artist mixed the paints of different brands. Hence, the attribution of the identified pigment mixtures to the specific colourmen brand(s) should be made very carefully.

Small-scale sketching on paper with pencil, crayon, charcoal, pastel, pen and watercolour was an integral part of Liu Kang's development of the artistic ideas prior to painting. The comparative studies of these drawings with the final paintings revealed a distinctive conceptual work of the artist who attempted to design the most satisfactory compositions. Liu Kang's practice of making preparatory underdrawings on the painting supports remains relatively unknown. One reason could be that thickly applied paint effectively limits the visibility of the underdrawings in NIR. On the other hand, preliminary sketching studies enabled the artist to establish the composition on the painting support with effortless brushwork and skip the underdrawing stage.

The study revealed variations in his paint application techniques, from small dabs, short or long directional and parallel strokes that sometimes juxtaposed with the exposed ground, to fluid brushwork that evolved into broad application or pointillist finish, impasted wet-on-wet or wet-on-dry execution with both brushes and palette knives. Liu Kang expressed early interest in the optical effects achieved by exposing of the white ground. However, since the 1950s this predilection has become a hallmark of his batik-inspired painting technique. Moreover, the study demonstrated that the artist occasionally departed from established painting convention of the Nanyang style and explored different means of artistic expression, although he remained conservative in his choice of painting materials and avoided experimentation with new paint formulations.

Distinctive features of the artist's working practice are the retouchings, revisions and recycling of former compositions. Liu Kang habitually retouched the paint losses in his paintings; however, a worsening eye condition might have impacted the colour accuracy of these amendments. Minor and major revisions may indicate that, despite extensive drawing studies and photography preceding the painting, the artist's concept of the final composition evolved, and in some cases, changes were made in very distinct stages. Financial constraints, changes in availability of art materials, the poor condition of the paintings or a shift in Liu Kang's personal taste resulted in an unfinished state of artwork, or a rejection of the completed artwork, leading to their being recycled.

The interdisciplinary study of Liu Kang's painting practice allowed to identify and categorise some intriguing technical features of his paintings, which define the less known and mysterious side of his oeuvre. Thus, it was possible to diagnose the condition correctly and to conduct the conservation treatments of his artworks selected by the curators for the permanent display at the National Gallery Singapore.

Another accomplishment in research involves partially documenting the availability of painting supplies in three crucial locations where Liu Kang engaged in his artistic pursuits, namely Paris, Shanghai, and Singapore.

The obtained results may be of great value to conservators and art historians who further explore Liu Kang's painting materials and technique. In particular, the knowledge gained from this comprehensive research may be useful in the dating of undocumented paintings and authenticating works attributed to him. In addition, the presented information sets a foundation for future research focusing on the painting practices of other modern Singapore and Southeast Asian artists.

13. Literatura

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EXAMINATION OF PAINTING TECHNIQUE AND MATERIALS OF LIU KANG'S SEAFOOD AND HIDDEN SELF-PORTRAIT

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Abstract

This paper is a part of an ongoing research that aims to present the painted oeuvre of pioneering Singapore artist Liu Kang (1911 – 2004) through the lens of conservation science instruments. The study concentrates on the painting Seafood from the National Gallery Singapore collection. The painting was created in 1932 and represents Liu Kang's early artistic period, "Paris". The painting was studied using complementary examination techniques. The imaging methods, including digital microscopy, NIR, XRR and RTI, revealed a hidden painting underlying the existing composition. XRR and NIR provided strong evidence that the image underneath is a portrait of a man while RTI revealed its texture. A comparative stylistic study of the hidden portrait was conducted with two other of Liu Kang's self-portraits from the same period. The study exposed some similarities, leading to the conclusion that the hidden painting is Liu Kang's self-portrait. Results of these imaging techniques initiated a further in-depth study to characterise and compare the pigments used in the creation of Seafood and that of the hidden self-portrait. The pigments of these two paintings were identified by means of IRFC, SEM-EDS, FTIR, PLM and XRF. Additionally, the in-depth study increased our understanding of both pictures and contributed to the growing body knowledge about Liu Kang's "Paris" period.

***Keywords**: IRFC; X-RAY; RTI; SEM-EDS; FTIR; Liu Kang; Hidden painting; Lefranc paints*

Introduction

Liu Kang (1911 – 2004), on graduating from Xinhua Arts Academy in Shanghai, moved to Paris in an attempt to assimilate the artistic essence of the Western masters. According to his travel documents, which were shared by the Liu family, he arrived in France in February 1929 and stayed there until April 1932. During that time, he was drawn to Impressionist, Post-Impressionist and Fauvist masters, whose works influenced his own [1]. His career took off in 1930 and 1931 with the annual art exhibition Salon d'Automne, where he exhibited his paintings. The painting *Seafood* (1932), from the National Gallery Singapore collection, represents that period in his artistic carrier (Fig. 1).

The analysed case study is *Seafood*, an oil-on-canvas painting measuring 46 × 55cm. The painting is a straightforward still life, depicting the main subject – a red lobster on a white plate – in the centre. A green fruit placed near the lobster breaks this almost-centrist

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composition and subtly pulls some attention away from the lobster. The tilted tabletop, with the flattening and merging of planes, manifest the influence of Paul Cézanne's still lifes, while the implementation of strong, dark contour lines to delineate objects is reminiscent of Paul Gaugin's artistic style. Although it is a static composition, it exudes great spontaneity, in the paint application, and power, which is expressed in the vivid red colour of the lobster and enhanced by its strong contrast to the white plate. The palette is limited to five colours – red, white, green, brown and black – and all have subtle tonal nuances across the painting. The painting is signed, with a Chinese character Kang (抗), and dated in the Western style (1932); that is, horizontally in the bottom-left corner.

Fig. 1. Liu Kang, *Seafood*, 1932, oil on canvas, 46 × 55cm. Gift of the artist's family. Collection of National Gallery Singapore. The white arrows indicate the sampling areas

Already at first glance, *Seafood* possesses some intriguing paint features that do not correlate to the final composition. Several bold, curved and dark paint strokes and patches are visible on the brown tabletop and white plate. On the one hand, these features blend with the existing elements, enriching the overall tonality and adding some spontaneity. On the other hand, some other features cause a visible disturbance, creating an impression of an uneven table surface. To obtain more information about the artist's technique and the materials he used, the painting was investigated for the first time by means of non- and micro-invasive methods. Initial close inspection revealed the existence of an underlying painting scheme. While this was an interesting discovery, further imaging methods brought to light a much more exciting finding – the portrait of a man. At that point, a comprehensive investigation was initiated to fully identify the composition details of the portrait and understand the artist's choice of materials for both paintings.

Although it is unknown what brand of colours Liu Kang used during his stay in Paris, Liu family records show that the artist had some interest in Lefranc paints as he had preserved and brought home two pages from the October 1928 Lefranc catalogue, which contains a list of oil colours (*fines*) and their prices (Fig. 2). While that may not be a compelling evidence to draw firm conclusion about the brand of colours that the artist preferred, authors of this study reviewed Lefranc catalogues from 1928 to 1934 and will make some references in relation to certain pigments.

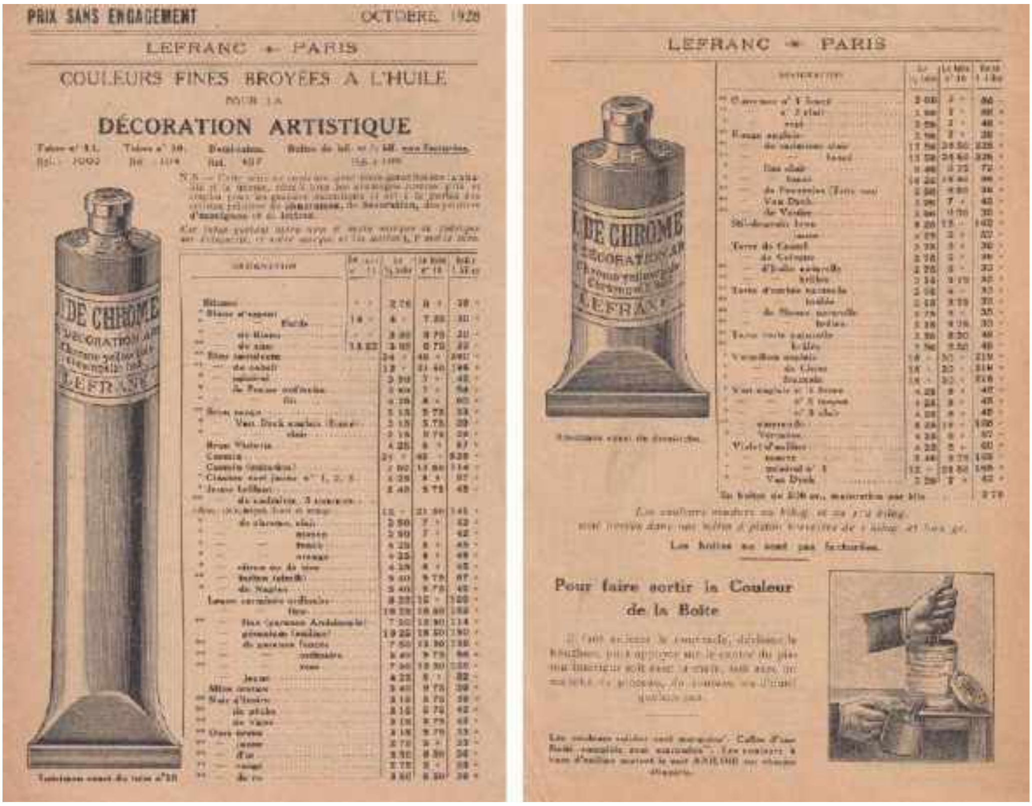

Fig. 2. Oil colours (*fines*) listed in a Lefranc catalogue, Paris, October 1928.
Detail showing two pages of the catalogue that Liu Kang preserved and brought home.
Liu Kang Family Collection. Images courtesy of Liu family

Materials and Methods

Technical photography

The technical images were acquired according to the workflow described by *A. Cosentino* [2-4]. A Nikon D90 DSLR modified camera with a sensitivity of between about 360 and 1100nm was used. The camera was calibrated with X-Rite ColorChecker Passport. Visible and ultraviolet fluorescence (UVF) photography at 365nm were taken with X-Nite CC1 and B+W 415 filters coupled together. For near-infrared (NIR) imaging at 1000nm Heliopan RG1000 filter was used while Andrea "U" MK II filter was used for reflected ultraviolet photography (UVR).

The illumination system for visible and NIR photography consisted of two 500W halogen lamps while two lamps equipped with eight 40W 365nm UV fluorescence tubes were used for UVF and UVR photography.

The American Institute of Conservation Photo Documentation (AIC PhD) target was used for the images' white balance and exposure control. Further processing of the photographs including false-colour infrared imaging (IRFC) was carried out with Adobe Photoshop CC according to the standards set out by the American Institute of Conservation [5].

High-resolution Digital Microscopy

The paint layer was examined with a Keyence VHX-6000 digital microscope, using universal zoom lenses coupled with a high-speed camera. Observations were conducted with a magnification range of 20 – 50×. For analysis, a built-in Keyence software – VHX-H2M2 and VHX-H4M – was used .

Reflectance Transformation Imaging

Reflectance Transformation Imaging (RTI) and further processing of the images using Adobe Photoshop, RTIBuilder and RTIViewer software were carried out according to the workflow proposed by the Cultural Heritage Imaging [6-8].

X-ray Radiography

The painting was digitally X-ray radiographed (XRR) using a Siemens Ysio Max Digital X-ray System with a detector size 35 × 43cm and high pixel resolution (over 7 million pixels) in the detector face. The X-ray tube operated at 40kV and 0.5-2mAs. The four images were first processed with an X-ray medical imaging software, iQ-LITE, then exported to Adobe Photoshop CC for final alignment and merging.

X-ray Fluorescence

Portable X-ray fluorescence (XRF) spectroscopy analysis was performed with Thermo Scientific™ Niton™ XL3t 970 spectrometer with a GOLDD+ detector, and an Ag anode X-ray tube with a 6 – 50kV voltage and up to 200μA current. A mining mode with four elemental ranges and measurement duration of 50s each (total acquisition time of 200s) was activated to achieve better sensitivity for light elements. The spectra were collected from a 3mm diameter spot size. The instrument was supported on a tripod. The acquired spectra were collected and interpreted using Thermo Scientific™ Niton Data Transfer (NDT™) 8.4.3 software, which allowed the elemental characterisation of the analysed spots. The XRF instrument was used for the acquisition of spectra from one area where sampling was not safe.

Scanning electron microscope with energy dispersive spectroscopy

The cross-sections of the paint samples 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 60Pa vacuum, with 20kV beam acceleration, at 50–60 intensity spot and a working distance of 10mm. The distribution of chemical elements was mapped using the Bruker Esprit 2.0 processing 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. Measurements were carried out in the spectral range of 4000–600cm^{-1}, at a resolution of 4cm^{-1}, averaging 64 scans. The elaboration of spectra was done using Bruker Opus 7.5 software.

Optical Microscopy and Polarized Light Microscopy

Optical microscopy (OM) of samples was performed in visible and ultraviolet reflected light on a Leica DMRX polarized microscope with a magnification range of 40 – 200×. Polarized light microscopy (PLM) was carried out in visible transmitted light at magnifications of 100 – 400× using the methodology developed by *P. Mactaggart and A. Mactaggart* [9]. The OM and PLM images were taken with a Leica DFC295 digital camera coupled with the microscope.

Staining test

The iodine test was conducted with a fresh KI_3 solution on the cross-section of the paint layer to determine the presence of starch [10].

Samples

A total of 15 micro-samples of the paint layer were taken from the areas of existing losses. Samples for cross-section structure observation and analysis were embedded in a fast-curing acrylic resin, ClaroCit (supplied by Struers), and fine polished. Samples for PLM were mounted with Cargille Meltmount nD = 1.662.

Results and Discussion

The surface painting: Seafood

Ground layer

The technical photography of the painting's surface followed by analyses of the cross-sections of the paint layer revealed that *Seafood* was painted on the underlying composition without the application of an intermediate ground.

Brown

The parts painted with different shades of brown are imaged yellow-green in the IRFC, suggesting the use of ferrous pigment(s) (Fig. 3).

Fig. 3. IRFC image of *Seafood*

The purple hue that is mostly visible on the tabletop has its source in an underlying green paint, which will be investigated later. Two samples, light brown (sample 4b) and dark brown (sample 13), were investigated with SEM-EDS and PLM. A strong Fe-signal from both samples, detected with SEM-EDS, can be attributed to brown iron oxide, which is confirmed with PLM (anisotropic brown particles with a high refractive index). The high content of Pb, Cr and Ca indicated the presence of chrome yellow (lead chromate), which was confirmed with PLM observation (anisotropic particles between crossed polarized filters have the shape of tiny rods with a high refractive index). Presence of Ca may relate to chalk (calcium carbonate) added commercially to chrome yellow to obtain a lighter shade or to improve the handling properties of the paint. Chalk can also appear as a by-product in the production of chrome yellow [11]. It is uncertain if a mix of iron oxide and chrome yellow from the dark brown paint (sample 13) was obtained by the artist or commercially prepared. Ochres can be commercially enhanced by a small addition of chrome yellow [12, 13], usually extended with barium white (barium sulphate), kaolin, gypsum (calcium sulphate) and calcium chromate [12]. The detection of Ca- and P-signals suggested a small admixture of bone black later confirmed with PLM (anisotropic grey and black particles).

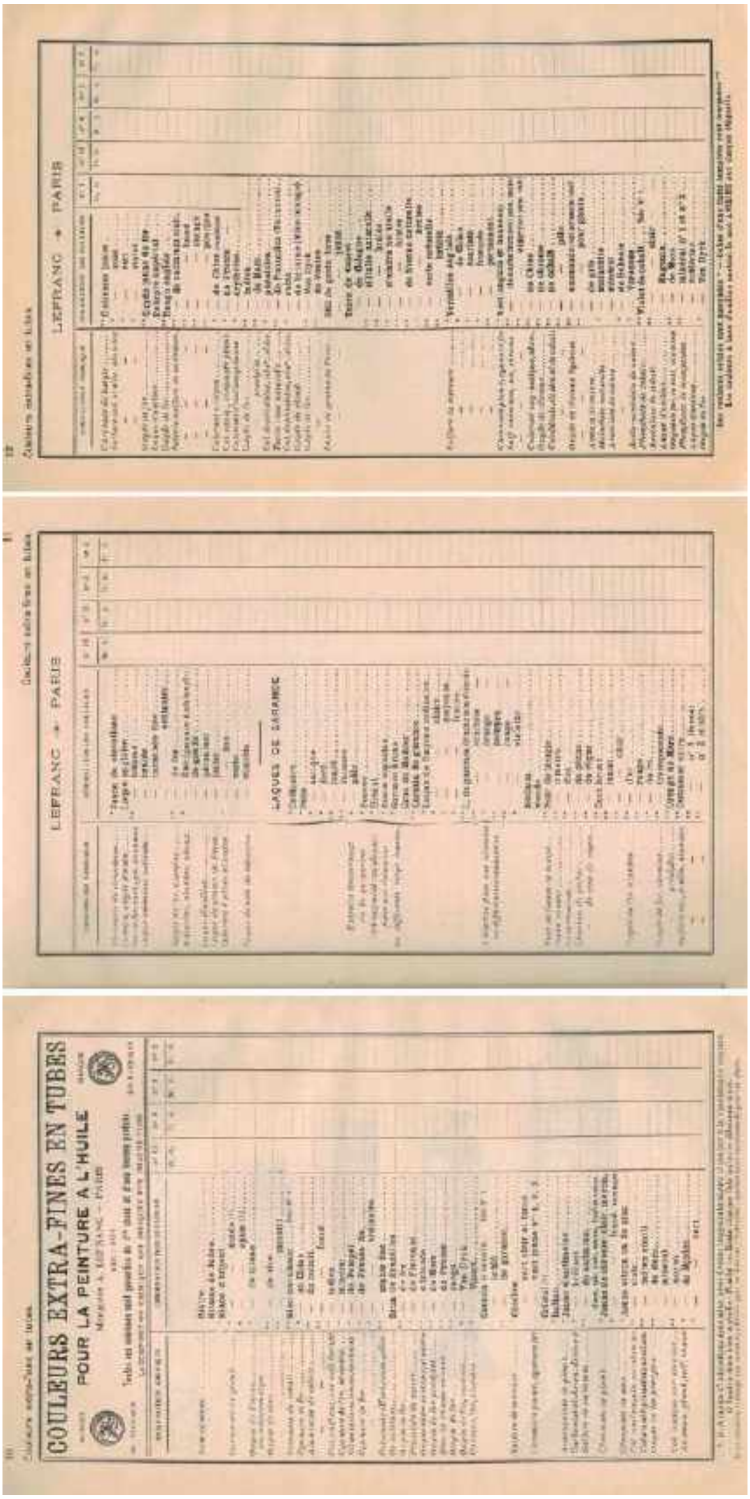

Fig. 4. Oil colours (*extra-fines*) listed in the catalogue of Lefranc, Paris 1930.
Detail showing carmines, range of madder lakes, Hansa red, Hansa yellow, strontium yellow, emerald green and Scheele's green as being available

Pinpointing the source of the other elements, such as Mg, Al, Si, P, K, Zn and As, is difficult, however they coincide naturally with iron oxides [13]. Traces of Sr found in the light brown paint (sample 4b) may indicate a common impurity of barium white [14, 15] rather than strontium yellow (strontium chromate). However, it is worth noting that strontium yellow was listed in the Lefranc catalogues of oil paints (*extra-fines*) as *chromate de strontiane* (Fig. 4), and its chemical composition was confirmed in the recent analysis of the set of Lefranc oil paints from the early 1930s [16].

Green

Light, green fruit was imaged violet in IRFC, indicating a presence of a complex paint mixture, while the dark, green background appears dark purple in the IRFC, suggesting a probable use of Cr- and/or Co-containing green pigment (Figs. 1 and 3). SEM-EDS of both samples 7 and 3 detected a similar set of elements, but with different concentrations and excluded the presence of cobalt.

Light green (Figs. 5a and b) is characterised by strong Pb-, Ba-, Cr- and S-signals, suggesting a presence of viridian (hydrated chromium oxide), chrome yellow and barium white. Viridian was observed with PLM by large particles, with a rough surface and high refractive index. Chrome yellow was observed with PLM and confirmed with FTIR by peaks at 625, 847cm^{-1} (CrO_4^{2-} symmetric stretching), 1034, 1059, 1104, 1146cm^{-1} [17]; however, the confirmation of the presence of barium white was hampered by overlapping signals for chrome yellow. Barium white was in common use as an extender, among others, for viridian [18] and chrome yellow [12]. The presence of chalk, which is probably an admixture to chrome yellow, was confirmed with FTIR by peaks at 872 and 1410cm^{-1}. The concomitant presence of Cu and As elements evidenced the use of emerald green (copper acetoarsenite) and/or Scheele's green (copper arsenite). *Vert Veronese* (emerald green), *vert de Scheele* (Scheele's green) and its variant, *vert minérale*, appeared in the Lefranc catalogues of oil paints (*extra-fines*) (Fig. 4). Emerald green was confirmed with FTIR by the detection of the As-O stretch at 818cm^{-1} and ester group stretching peak at 1569cm^{-1}[19]. The PLM observation could not make any attribution, probably due to an insufficient quantity of the pigment in question in the sample. The SEM-EDS detection of Fe, as well as the PLM observation of very few sporadic brown and blue particles, allowed the identification of the brown iron oxide and Prussian blue (dark blue, isotropic particles with a low refractive index that appear dark greenish with a Chelsea filter). Prussian blue (hydrated iron hexacyanoferrate) is known for its very high tinting strength, achieved with at low concentration of pigment. Thus, the FTIR was able to detect a weak absorption peak at 2097cm^{-1}, attributable to C≡N stretching [20]. These analyses are in agreement with the IRFC imaging, as a purple representation of viridian combined with a grey blue representation of emerald green and a dark blue representation of Prussian blue can produce violet.

Dark green (Figs. 5c and d) contains a high concentration of Cr and PLM observation allowed the identification of a good deal of viridian particles in the paint sample. The detection of strong Cu- and As-signals with SEM-EDS suggests the use of Scheele's or emerald green however the PLM observation of the paint sample was inconclusive. Nevertheless, as emerald green was detected in sample 7, it is more likely that it is present in the dark green paint. Ba and S could be attributed to the barium white extender for viridian. The Fe-signal detected with SEM-EDS correlates with the dark brown particles observed on the cross-section of the paint, suggesting the presence of brown iron oxide, later confirmed with PLM. Other elements like Ca, Pb and Cr could be linked with iron oxide or Cr-containing yellow pigment(s) not identified with PLM. These findings are consistent with the IRFC imaging, as a purple colour is determined by a high content of viridian in the analysed paint.

As emerald green and viridian were detected in both, light and dark green mixtures, it is difficult to ascertain whether these two pigments were deliberately mixed by artist or emerald green was commercially adulterated with viridian [21].

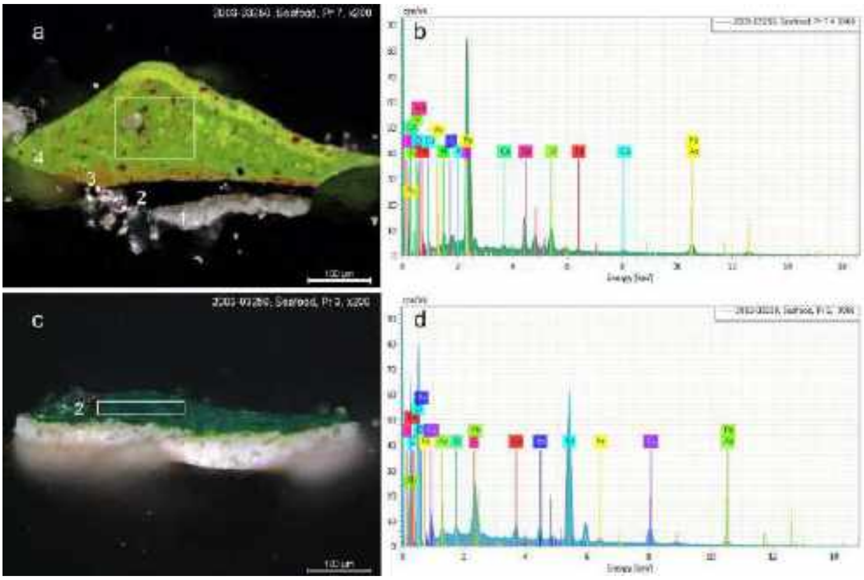

Fig. 5. Cross-sections and corresponding SEM-EDS spectra of green layers from samples 7 (a, b) and 3 (c, d). The SEM-EDS quantitative elemental analysis shows that the intensity of the green colour in both samples is determined by the presence of chrome yellow and viridian rather than the emerald green. The cross-section of sample 7 shows no evidence of an intermediate ground layer between the two painted compositions (layers 2 and 3)

Red

The red paint used for painting of the lobster is not uniform and is characterised by different hues of red, which gradually turns brown in the shadows and yellow in the highlights (Fig. 1). A microscopic observation of the lobster's surface and paint sample cross-section (sample 21) revealed a wet-in-wet paint application (Figs. 6 and 8a). The cross-section of the paint sample shows two layers (red and purple) without a clear division between them. The upper red consists of clusters of not properly mixed colours of dark red, red and orange. The PLM allowed the preliminary identification of the organic red pigment, due to its unique low refractive index. FTIR measurements, although very challenging due to interfering signals of the oil binder and other inorganic components, confirmed alizarin crimson by typical absorption bands at 606, 669, 1249, 1387, 1552, 1591, and 1627cm^{-1} (Fig. 7a) [22]. Moreover, the presence of Hansa red was confirmed by absorption peaks at 753, 1256, 1297, 1345, 1448, 1467, 1502, 1560 and 1621cm^{-1} (Fig. 7b). In addition, the PLM observation of crystalline sublimates and FTIR detection of peaks at 750, 1353 and 1518cm^{-1} confirmed the presence of Hansa yellow (Fig. 7a). SEM-EDS, FTIR and PLM identified also lead white (lead carbonate), barium white, chrome yellow and chalk present in the paint mixture. A co-location of Cr- and Ca-signals, visible in the SEM-EDS elemental distribution maps, suggests that chalk was an admixture to chrome yellow (Fig. 6).

Although these results require further investigation, Lefranc's catalogues give some insight into the availability of natural and synthetic madder pigments. According to Lefranc's description of the chemical composition of the pigments, there were available madder lakes derived from *purpurine (tri-oxy- anthraquinone)* along with different pink colours containing chrome yellow, anthraquinone and azo pigments. In addition, Lefranc listed *jaune permanent moyen*, which contains Hansa yellow (*colorant azoïque sur alumine*) and *rouge de Chine vermillonné* containing Hansa red (*colorant azoïque*) (Fig. 4). Although occurrences of Hansa yellow are relatively limited in artworks prior to 1950, the recent analysis of early-20th century Lefranc lake and synthetic organic pigments provided evidence that azoic dyes, like Hansa yellow and Hansa red, were added as a component to other paints [23].

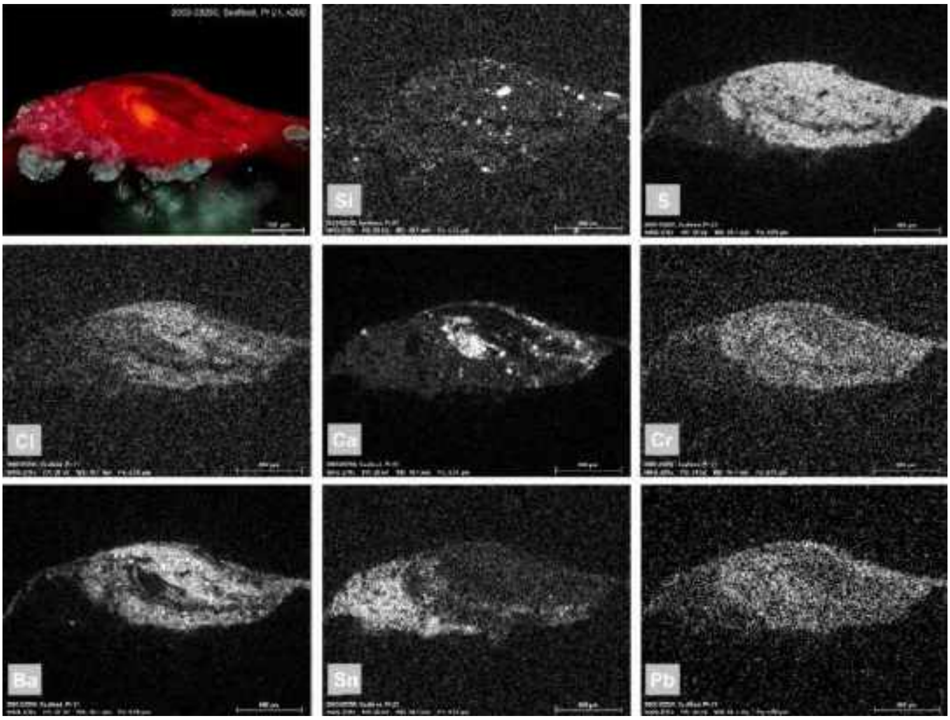

Fig. 6. Microscopy image of the cross-section of sample 21, photographed in visible light, and SEM-EDS maps showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. A high concentration of Sn relates to the presence of a tin-based substrate in the paint

For the bottom purple layer, PLM allowed the detection of an organic red pigment while the FTIR analysis revealed the presence of brazilwood (absorption bands 669, 1024 and 1562cm^{-1}) [24] and alizarin crimson (1118 and 1540cm^{-1}) [21] (Fig. 7c). In addition, starch grains were observed with PLM by round particles with a distinct extinction cross, which was visible in polarized light (Fig. 8c).

The presence of starch was positively confirmed with the iodine test and FTIR measurements showing peaks at 993, 1074, 1381, 1641, 2930, 2965 and 3317cm^{-1} (Fig. 7c) [25]. The occurrence of starch in the bottom layer correlates with the high concentration of Sn, detected with SEM-EDS (Fig. 6), suggesting the presence of a tin-based substrate in the paint. Tin is described in the literature as a complexing ion, commonly associated with cochineal lake pigments to produce intense red hues [26, 27].

Meanwhile, starch is known as a substrate or an inert additive, used to obtain a lighter shade of the organic red pigment and improve its handling properties [27, 28]. Tin was also employed as a substrate for the brazilwood pigment; such a combination was encountered in Vincent van Gogh's paintings [29]. Brazilwood, as a cheap type of organic red, was often added to other types of lakes to reduce the cost of manufacturing [29]. The SEM-EDS detection of other elements in the purple layer, like Pb, Ba, Ca, Al and S, is difficult to interpret due to their weak signal; however, it is known that lead white, barium white, chalk and kaolin may occasionally accompany the organic red pigment [25, 27]. Lefranc listed *carmin de cochenille* and *laque anglaise* containing *carmin* and *oxyde d'etain* (tin oxide) (Fig. 4) in its catalogues. Moreover, it is known that Lefranc natural organic pigments were commonly modified with synthetic ones [22], therefore more analyses are needed to identify the content of the purple paint.

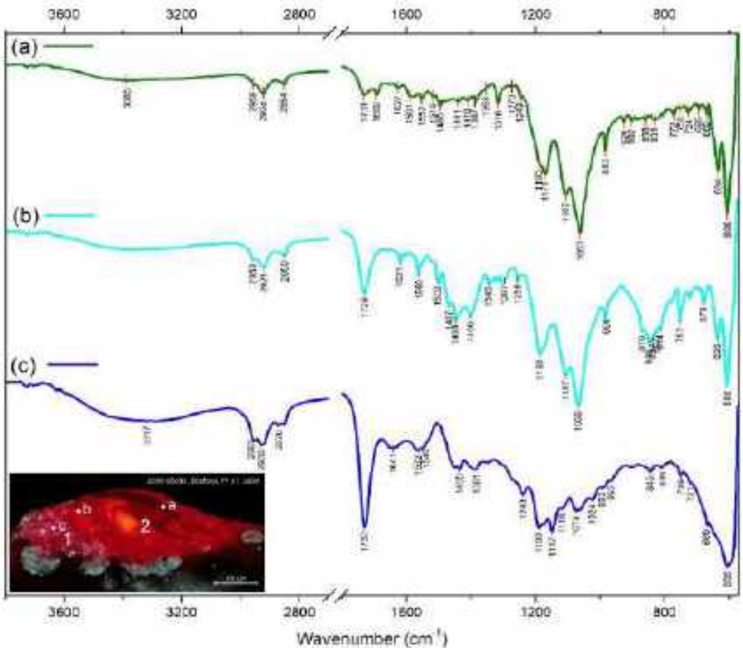

Fig. 7. µFTIR spectra from sample 21: (a) layer 2 contains alizarin crimson and Hansa yellow, among other pigments; (b) layer 2 contains Hansa red, among other pigments; (c) layer 1 contains brazilwood, alizarin crimson and starch

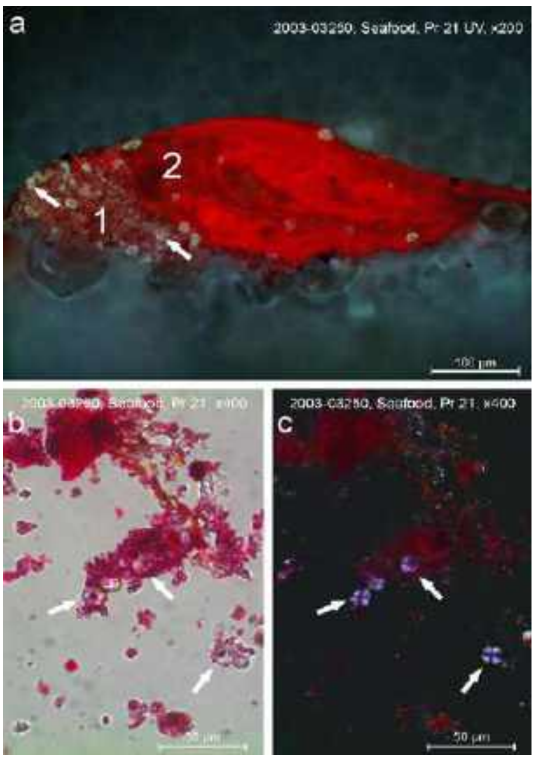

Fig. 8. Microscopy images showing (a) cross-section of sample 21, photographed in UV; (b) PLM pigment dispersion from layer 1 in plane light; (c) polarized light. Round, blue-fluorescing particles of starch are visible in (a) layer 1. Individual particles of starch were detected in (b) plane and (c) polarized light

The analysis of sample 21 revealed a very interesting aspect of Liu Kang's palette as he used two different types of red. One is composed of alizarin crimson, Hansa red and Hansa yellow with possible artist's admixture of chrome yellow; the second is a mixture of alizarin crimson and brazilwood on tin and starch substrate.

White

The UVR photography of the painting was very effective, given a preliminary indication that the plate was painted with lead white (Fig. 9).

Zinc white (zinc oxide) and titanium white (titanium dioxide), being strong absorbers, appear dark in UVR, and only the lead white among the white pigments reflects UV and appears white [5]. The SEM-EDS analysis of paint samples 22 and 10b, taken from the rim and bottom of the white plate, revealed a high concentration of Pb. The absorption bands in the FTIR spectra of sample 10b at 681, 853, 1040 and 1398cm^{-1} are characteristic of lead white [30]. The SEM-EDS detection of Ba in sample 22 could be related to barium white, a common extender for lead white [31]. In both samples, the high content of Ca recorded with SEM-EDS, together with apparent absorption bands at 713, 872 and 1398cm^{-1} in the FTIR spectra of sample 10b, indicates an admixture of chalk. It is worth noting that the 1398cm^{-1} band, attributed to the antisymmetric stretching of CO_3^{2-} is assigned to the lead white as well as chalk. The presence of chalk is additionally confirmed by PLM observation (circular coccoliths). Other trace elements, like Si, Mg, Cr and Al, are considered as contaminants. Liu Kang used drying oil as a binder, and this is confirmed with FTIR in the sample 10b by peaks at 1173, 1730, 2852 and 2922cm^{-1} [32].

Fig. 9. The UVR image of *Seafood* indicates that the plate was painted with lead white showing a strong UV reflectance

Black

Liu Kang used black paint extensively, with no hesitation, to enhance and isolate various forms from each other (Fig. 1). The elemental analysis of the sample taken from the shadow area beneath the table (sample 6b) recorded a high concentration of Ca and P, which can be attributed to bone black. A small concentration of Cr was attributed to viridian with PLM, while a concomitant presence of Cu and As suggested emerald green. Both green pigments can be considered as contamination from the artist's brush.

A summary of the identified materials from the *Seafood* is given in Table 1.

Table 1. Pigments detected in the painting *Seafood* by SEM-EDS, FTIR and PLM
*Major elements are given in bold, minor elements in plain type and trace elements in brackets

Sample	Colour/ stratigraphy layer	SEM-EDS detected elements*	SEM-EDS possible assignment	FTIR	PLM identification
4B	Light brown	**C, O, Pb**, Fe, Ca, Al, Si, Ba, Cr, (Sr, K, Mg, P)	Brown iron oxide, chrome yellow, chalk, bone black, barium white		Brown iron oxide, chrome yellow, chalk, bone black
13	Dark brown	**C, O, Fe**, Pb, Si, Ca, Cr, Al, (Ba, Zn, K, P, Na, Mg)	Brown iron oxide, chrome yellow, chalk, bone black, barium white		Brown iron oxide, chrome yellow, chalk, bone black
7	Light green	**C, Pb, O, Ba**, Cr, S, Al, As, Cu, (Ca, Fe, Si, P)	Viridian, chrome yellow, barium white, chalk, emerald green, brown iron oxide, Prussian blue	Chrome yellow, chalk, emerald green, Prussian blue, oil	Viridian, chrome yellow, brown iron oxide, Prussian blue
3	Dark green	**O, C, Cr,** Cu, Pb, Ba, As, Ca, Fe, S, (Si)	Viridian, emerald green, barium white, brown iron oxide, possible traces of Cr-containing yellow pigment(s)		Viridian, brown iron oxide,
21	Red	**O, Ba, Pb, S**, Sn, Ca, Cr, (Cl, Si, Na, Sr, Al, P)	Lead white, chrome yellow, chalk, barium white, tin substrate	Lead white, chrome yellow, chalk, barium white, alizarin crimson, Hansa red, Hansa yellow, oil	Chrome yellow, organic red, Hansa yellow
	Purple	**C, O**, Sn, Pb, (Ba, Ca, Si, Al, S, Cl)	Tin substrate	Brazilwood, alizarin crimson, starch, oil	Organic red, starch
10B	White	**Pb, C, O**, Ca, (Si, Mg, Cl, Na, Al)	Lead white, chalk	Lead white, chalk, oil	Lead white, chalk
22	White	**Pb, C, O**, Ca, (Si, Cl, Na, Ba, Mg, Cr, Al)	Lead white, barium white, chalk		Lead white, chalk
6B	Black	**O, C, Ca**, P, Pb, Zn, (Cu, Na, Si, Cr, Ba, As, K, Mg, Al, Sr)	Bone black, viridian, emerald green		Bone black, viridian

Hidden painting beneath Seafood

Pictorial composition

Racking light photography and digital microscopy of the paint surface of *Seafood*, revealed some anomalies. The most obvious are the brushstrokes of different colours that are visible through the very thinly applied brown paint of the table (Fig. 10a and b). This feature can be explained by the lack of an intermediate ground layer between the two compositions and, possibly, the decreasing hiding power of the upper paint layer [33, 34]. Severely cracked paint of the *Seafood* allowed to see different colours beneath (Fig. 10c and d). Moreover, some areas of the different paint scheme were not completely covered with the current painting (Fig. 10e and f). Additionally, by tracing the texture details in the racking light the existence of a portrait painting in a vertical orientation was revealed (Fig. 11a).

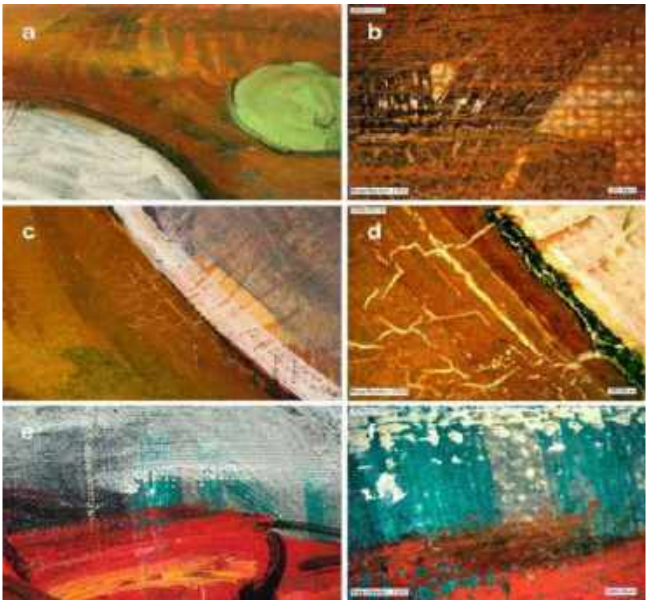

Fig. 10. Details showing: (a, b) individual brushstrokes of different colours visible through a very thin paint layer; (c, d) yellow paint of the earlier composition visible through cracks; (e, f) areas of earlier composition not completely covered with the current painting

Fig. 11. Detail of the centre of *Seafood*, rotated at 90° clockwise and photographed in: (a) racking light and (b) NIR RTI. Racking light photography reveals the existence of a portrait painting in vertical orientation, while NIR RTI specular enhancement shows the surface texture with the reduced distraction of pictorial elements in *Seafood*

Subsequent NIR and transmitted NIR photography immediately unveiled a head-and-shoulders portrait view of a man wearing a collared shirt and suit jacket (Fig, 12a and b).

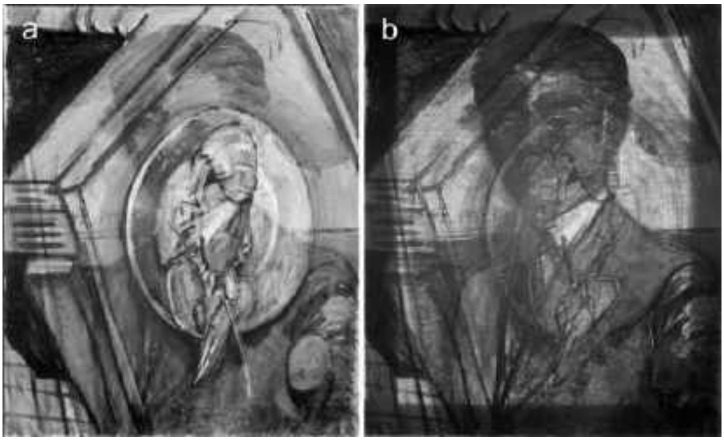

Fig. 12. Images of the painting *Seafood* rotated at 90° clockwise photographed in:
(a) NIR and (b) transmitted NIR. Both photography techniques revealed a detailed portrait view of a man

His face is in the focal point and captured in ¾ view. The face details, along with the individual brushstrokes, are more legible in transmitted NIR, which provides good contrast and reduces interference from the upper composition. NIR sensitivity to carbon-based pigments, suggests that a dark paint containing carbon was used extensively for enhancing the shapes of the portrait painting. Carbon may also be present in the paint used for outlining in the upper composition, which obscures the visibility of the portrait underneath. Straight horizontal lines painted behind the subject's shoulders suggest an unknown background feature. In addition, the transmitted NIR showed the existence of thin white lines delineating the subject's suit jacket (Fig. 13).

Fig. 13. Details of the portrait imaged by means of transmitted NIR photography,
showing thin white lines delineating the subject's suit

The lines were probably achieved by scratching into wet paint with a sharp tool. This additional technique of artistic expression was found in another painting by Liu Kang, *Nude* from 1936 [35]. Transmitted NIR photography also unveiled Liu Kang's signature, in the horizontal orientation, painted in the corner between the subject's right shoulder and his head. It consisted of the Chinese character Kang (抗) followed by a partially legible date written in the Western style (1932) (Fig. 14).

Fig. 14. Detail of Liu Kang's signatures from the portrait beneath *Seafood*

The NIR-RTI photography technique was engaged to enhance the texture of the underlying portrait. Liu Kang applied short and multidirectional paint strokes with a small brush to define the shapes of eyes, nose, forehead and left ear, indicating an advanced paint build-up (Fig. 11b). Although a conventional RTI provides an improved view of the surface texture, replacing visible light with an infrared reduces the distraction from the pictorial elements in the upper paint layer due to the penetrative ability of the infrared [36]. Hence, the overall legibility of the paint texture of both *Seafood* and the underlying portrait was improved.

The acquired data was enriched by the XRR (Fig. 15), which appears as a positive image of the NIR.

Fig. 15. The XRR image of *Seafood* rotated at 90° emphasises the brushwork and reveals rather a sketchy handling of paint in the area of the face. The lack of the X-ray absorption in the centre of the forehead suggests very little or no paint in that area

The XRR additionally emphasised the brushwork and revealed a rather sketchy handling of the paint in the area of the face, which can be attributed to a young man with an oval face and a comb-over hairstyle. A strong X-ray absorption signal corresponds to the impastos recorded with the NIR-RTI. Intriguingly, there is a lack of X-ray absorption in the centre of forehead correlating with the transmitted NIR image, suggesting that this part of the painting was probably unfinished. In addition, below the horizontal background lines recorded with the NIR, the XRR revealed highly absorbent brushstrokes, which break the uniformity of space behind the subject.

Fig. 16. Liu Kang's self-portraits: (a) *Self-portrait in Paris*, 1931, oil on canvas, 61 × 46cm; (b) *Self-portrait*, 1931, oil on canvas, 55 × 46cm. Liu Kang Family Collection. Images courtesy of Liu family

Knowing that the topic of self-portraits was explored by Liu Kang in Paris, a direct correlation of the hidden portrait was made with two self-portraits that were executed in 1931 and belonging to Liu family. The first, *Self-portrait in Paris*, is an oil-on-canvas painting, measuring 61 x 46cm. It features Liu Kang in a half-length self-portrait and ¾ face view (Fig. 16a). The second, *Self-portrait,* is also an oil-on-canvas painting measuring 55 x 46cm. It presents a head-and-shoulders portrait of Liu Kang captured in a full-face view (Fig. 16b).

The style of the revealed painting is entirely in accord with two other self-portraits. Both the revealed portrait and *Self-portrait* (Fig. 16b) are characterised by tight composition and a thin application of paint. Furthermore, the subject's ¾ face view and body position in the revealed portrait strongly resemble those in the *Self-portrait in Paris* (Fig. 16a). Based on the similarities in the style and composition in the three paintings, it is hypothesised that the portrait hidden beneath *Seafood* is another of Liu Kang's self-portraits.

Dating of self-portrait and reason behind its repainting

The stylistic similarity of the hidden painting with the two other self-portraits, as well as the partial legibility of its date, provides some evidence that the analysed painting was executed between 1930 and 1932. Based on the results from transmitted NIR and XRR photography (Figs. 12 and 15), it can be concluded that Liu Kang considered his work as completed as he signed and dated it. However, among his three self-portraits, this one (underneath *Seafood*) could have been unsuccessful, hence chosen by the artist for painting over with *Seafood* in 1932. The examination of the cross-sections of the paint layers revealed a clear stratigraphy and an absence of dirt between the layers corresponding to the *Seafood* and underlying self-portrait (Figs. 5a and 18d). These findings, combined with the distinct brushstrokes detected in the self-portrait (Figs. 11b and 15), strongly support the hypothesis that the time between the execution of both the self-portrait and *Seafood* was relatively short, but sufficient for the paint on the self-portrait to dry before it was painted over. The practice of reusing earlier, unwanted paintings was – and still is – a common practice among artists, and it is known that two of Liu Kang's paintings from 1930 and 1936 were also executed on discarded compositions [35]. Archival photograph of Liu Kang in his rented room in Paris shows wall filled with unstretched paintings (Fig. 17). Based on this evidence, a conclusion can be drawn that Liu Kang's practice of reusing stretchers or strainers and unwanted paintings could have been measures to save on art materials so that he could continue with his painting studies.

Fig. 17. Liu Kang in his rented room in Paris in 1931 with wall tightly filled with paintings. Liu Kang Family Collection. Images courtesy of Liu family

Ground layer

SEM-EDS measurements combined with FTIR and PLM observations indicated that the composition of the ground layer (samples 10b, 19 and 22) is probably a mixture of lead white, barium white and chalk. Drying oil was used as a binder and exhibits typical peaks at 1173, 1731, 2851 and 2925cm^{-1} [32].

Face

Concerning the paints and technique used for painting the face, the examination of the cross-sections, reveal that the flesh colour was achieved by the application of a yellow base tone, followed by darker paints. Yellow paint was found in the sample taken from the chin (sample 28), illustrated in Figure 18a and b. A similar yellow tone followed by brown, applied wet-in-wet, was observed in the cross-section of paint taken from the area between the nose and the right eye (sample 22), illustrated in the Figure 18c and d (layers 1, 2). However, a flesh tone on the cheek was achieved by a direct application of brown paint over the ground (sample 43), illustrated in Figure 18e and f.

Based on the SEM-EDS and PLM analysis, the yellow underpaint primarily involves a mixture of yellow iron oxide and lead white. A weak, SEM-EDS signal from P, Ca, Ba and Cr can suggest traces of bone black, barium white and/or barium yellow. Some contaminants, like Cr-containing green, were identified in sample 22 (layer 1). The brown and yellow layers have a similar elemental composition; however, the PLM allowed the observation of an admixture of organic red in the sample 43. The detection of red iron oxides corresponds to the yellow-green colour in the IRFC image of the examined areas (Fig. 3).

Vivid red lips (sample 10b) can be seen in visible light through a thinly applied white paint of the current composition (Fig. 1). Based on the SEM-EDS and FTIR analysis, the red paint probably contains a complex mixture of lead and barium whites, chalk and bone black. FTIR measurements detected anthraquinone derivative peaks at 939 and 1276cm^{-1}, indicating a possible use of alizarin crimson, while peaks at 752 and 1504cm^{-1} indicated a presence of Hansa yellow [37]. Liu Kang used drying oil as a binder; this is confirmed with FTIR by peaks at 1733, 2852 and 2918cm^{-1} [32].

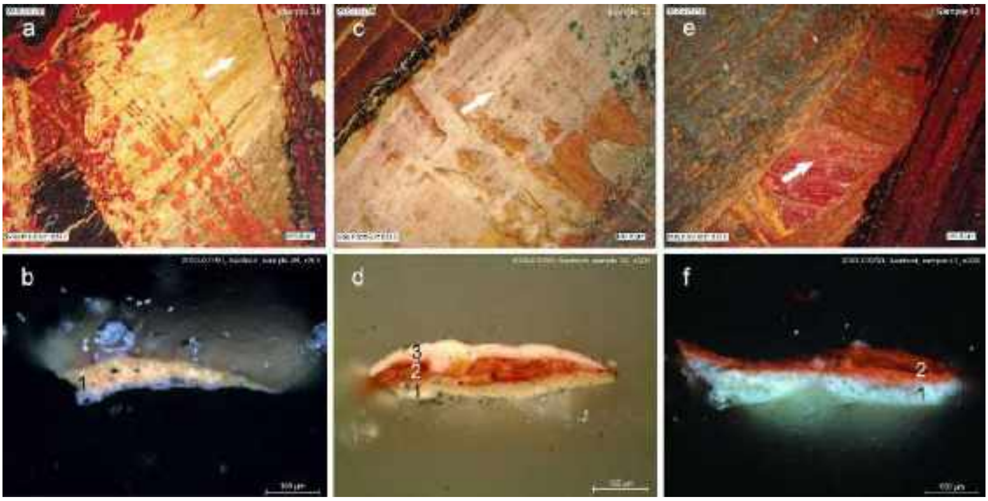

Fig. 18. Sampling sites and relevant cross-sections showing the structure of the paint layer in the area of the subject's face. The white arrows indicate the sampling sites. The microphotographs relate to: (a, b) sample 28 from chin; (c, d) sample 22 from the area between the nose and right eye; (e, f) sample 43 from cheek. Sample 22 contains a white top layer (layer 3) relating to the white plate in *Seafood*. This sample shows no evidence of an intermediate ground layer between the two painted compositions

Garment

The man's garment was assessed based on the fragments of the original composition that were not completely covered with the current painting.

The vivid, dark green colour found in the area of the suit's jacket lapels turns purple in the IRFC image (Fig. 19a and b) This observation is in agreement with the SEM-EDS and PLM identification of viridian probably in combination with lead white, bone black and barium white or barium yellow (sample 19).

The thick, black brushstrokes defining the folds of the suit's jacket contain mainly bone black and viridian, which were identified with SEM-EDS and PLM. Admixtures of lead and barium whites and/or lithopone (mixture of zinc sulphide and barium sulphate) and/or barium yellow are suspected in the black paint, based on the SEM-EDS analysis. The weak Sr-signal may be associated with the presence of strontium sulfate impurity in barium white [31, 38]. The identification of viridian could be in agreement with the warm hue of the black paint imaged in IRFC.

The bottom part of the suit's jacket appears darker, with a green-blue hue. The SEM-EDS and PLM of sample 20 confirmed the prominent use of viridian and bone black with some admixtures of ultramarine and brown iron oxide, which is consistent with the IRFC as green-blue turns purple. The paint mixture also contains Pb and Ba elements, and that could be assigned to lead and barium whites.

Background

In terms of the background colours of the self-portrait, exposed passages of green, blue and red colours were investigated.

Light green was found mainly in the top-right and top-left quarters in the background of the self-portrait (Fig. 1). The SEM-EDS and PLM analyses of the green paint (sample 40) revealed that it was predominantly made of viridian with an admixture of brown iron oxide and brightened with lead and barium whites. The result is consistent with the IRFC as green was imaged purple (Fig.19c and d).

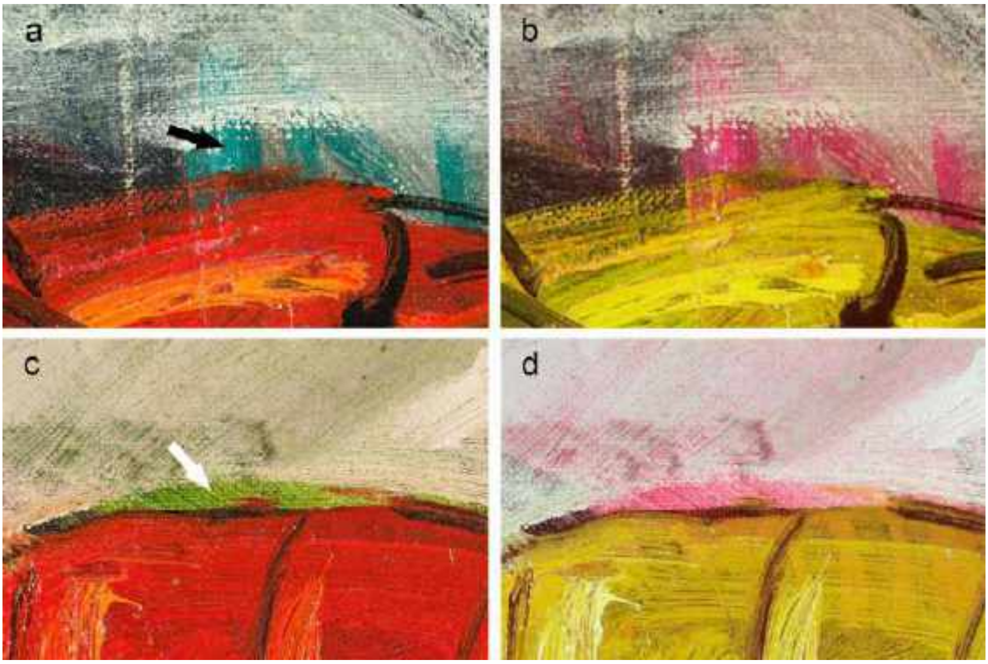

Fig. 19. Detail of *Seafood* photographed in visible light, showing green paint corresponding to the garment (a); background (c) of the self-portrait beneath; and (b, d) IRFC images of the same areas. The arrows indicate the extraction areas for sample 19 and 40

Grey-blue colour is largely visible in the bottom-left quarter of the background (Fig. 1). SEM-EDS combined with PLM of the grey paint (sample 11b) allowed for the identification of ultramarine and bone black with an admixture of viridian and brightened with lead and barium whites, which is agreeable with the grey-purple imaging of the area in IRFC (Fig. 3).

Red paint was recorded along the top edge of the self-portrait (Fig. 1), and it turned yellow in the IRFC (Fig. 3). In general, there was little distinction between the red and yellow pigments in the IRFC as they appeared as various shades of yellow. The XRF elemental analysis of spot 9 on the red paint detected the presence of Fe corresponding to the iron oxide, while Pb- and Cr-signals can be attributed to lead white and/or chrome yellow. Although a Ba-signal was not recorded, the trace of S could correspond to barium white; however, this assumption cannot be confirmed with only XRF analysis.

A summary of the identified materials from the self-portrait is given in Table 2.

Table 2. Pigments detected in the hidden self-portrait by SEM-EDS, FTIR, XRF and PLM.

Sample/ spot	Colour/ stratigraphy layer	SEM-EDS detected elements*	SEM-EDS, XRF possible assignment	FTIR	PLM identification
22	Brown	**C, O, Pb**, Zn, Ba, Cr, Ca, Si, Fe, K, Al, (Na, S, Mg, P)	Iron oxide, lead white and/or chrome yellow, barium white and/or lithopone, Cr-containing yellow pigment(s)		
	Yellow	**C, Pb, O,** Ca, (Si, Fe, Al, Cr, Ba, Na, Mg)	Yellow iron oxide, lead white, barium white and/or barium yellow, Cr-containing green pigment		
	White (ground layer)	**Pb, C, O, Ba**, Ca, (Si, S, Na, Al)	Lead white, barium white, chalk		
28	Yellow	**Pb, C, O**, Ca, Si, Fe, (Al, Ba, Cr, Mg, P)	Yellow iron oxide, lead white, barium white and/or barium yellow, bone black		Yellow iron oxide, lead white
43	Brown	**C, O, Ba, Pb**, S, Si, Fe, Al, Cl, (Ca, P, K, Mg, Na)	Red iron oxide, lead white, barium white, bone black		Red iron oxide, organic red, lead white
10B	Red	**Pb, C, O,** Ca, Ba, Si, (Fe, Al, Sr, Mg, P)	Lead white, barium white, chalk, bone black, traces of iron oxide	Lead white, barium white, chalk, bone black, alizarin crimson, Hansa yellow, oil	
	White (ground layer)	**Ba, C, O, S**, Pb, Sr, (Ca, Si, Al)	Lead white, barium white, chalk	Lead white, barium white, chalk, oil	
19	Green	**C, Pb, O, Cr**, Ca, Ba, (Si, P, Na, Mg, Al, S)	Viridian, lead white, bone black, barium white or barium yellow		Viridian, lead white, bone black
	White (ground layer)	**Pb, Ba, C, O, S**, Sr, (Cr, Ca, Si, Zn, Mg, P, Al)	Lead white, barium white, chalk		
45	Black	**O, Pb, Ca**, C, P, Ba, Cr, Si, Zn, Al, Na, (S, Fe, K, Mg, Cl, Sr)	Bone black, viridian, lead white, barium white and/or lithopone and/or barium yellow		Bone black, viridian
20	Green-blue	**C, O, Cr**, Pb, Ca, Ba, P, (S, Si, Na, Al, Fe, Mg, Zn)	Viridian, bone black, ultramarine, brown iron oxide, lead white, barium whites		Viridian, bone black, ultramarine, brown iron oxide
40	Green	**C, O, Pb**, Ba, Cr, Ca, Si, S, Fe, (Al, Na, Zn)	Viridian, brown iron oxide lead white, barium white		Viridian, brown iron oxide, lead white
11B	Grey-blue	**C, Pb, O**, Ba, Ca, Si, Al, S, Na, (Cr, P, K)	Ultramarine, bone black, viridian, lead white, barium white		Ultramarine, bone black, viridian, lead white
9	Red	**** XRF Detected elements:** Pb, Fe, Cr, Ca, S	Iron oxide, lead white and/or chrome yellow, barium white		

*Major elements are given in bold, minor elements in plain type and trace elements in brackets.

Conclusions

The combination of complimentary non- and micro-invasive techniques provided important technical information about the painting *Seafood* and explained the nature of its intriguing paint features. Technical photography played an important role in the process of understanding the artwork and the artist's way of handling the paint. Transmitted NIR, NIR-RTI and XRR significantly expanded the field of research and permitted the visualisation of Liu Kang's self-portrait hidden behind *Seafood*. The revealed self-portrait is probably a part of the artist's exploration of this topic as it complements two other self-portraits on canvas from 1931. Based on the acquired data, the hidden self-portrait was executed between 1930 and 1932. It can be deduced that Liu Kang considered it as a completed artwork by signing and dating it. However, among his three self-portraits, this one could have been the most unsuccessful and hence chosen for repainting with *Seafood* in 1932. This decision could have been primarily driven by materials shortage. As the archival photographs suggest, Liu Kang was saving on auxiliary supports, therefore the practice of reusing unwanted paintings could have been motivated by the financial constraints.

IRFC imaging assisted at the tentative identification of the pigments and sampling for the SEM-EDS, FTIR, PLM and XRF measurements. The binding medium for the ground layer and the paints for the self-portrait and *Seafood* is drying oil. The analysis of the paint samples gave an insight into the pigments used by Liu Kang in both paintings, contributing to a still-growing database of his painting materials. The majority of identified pigments are consistent across the two artworks and include viridian, alizarin crimson, iron oxides, chrome yellow, Hansa yellow, bone black, lead and barium whites. In both paintings, viridian appears to be the preferred green pigment. Lead white is a primary white and the main component of the ground layer. Admixtures of Prussian blue and emerald green were detected in the *Seafood* while ultramarine appears in the self-portrait only. The FTIR analysis of red paint revealed that Liu Kang used two different types of red in *Seafood*. One is composed of alizarin crimson, Hansa red and Hansa yellow with the artist's admixture of chrome yellow. The second is a mixture of alizarin crimson and brazilwood on tin and starch substrate. These very interesting findings require further analysis to precisely identify the components of the red paints, and it would involve comparisons with the reds from Liu Kang's other paintings from the same period. Some ambiguity still remains in the interpretation of the XRF data acquired from the red paint from the background of the self-portrait. Ultimately, the results obtained from the complementary analytical techniques employed in this study may aid art historians in the evaluation of Liu Kang's early career. Further research on the revealed self-portrait should focus on the investigation of the partially legible date and the technological and stylistic comparisons with two other self-portraits belonging to Liu family.

Abbreviations

UVF: ultraviolet fluorescence; UVR: reflected ultraviolet; NIR: near-infrared; IRFC: infrared false-colour; RTI: reflectance transformation imaging; XRR: X-ray radiography; XRF: X-ray fluorescence; SEM–EDS: scanning electron microscope with energy dispersive spectroscopy; FTIR: Fourier transform infrared spectroscopy; OM: optical microscopy; PLM: polarized light microscopy.

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RESEARCH ARTICLE

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A preliminary study of Liu Kang's palette and the discovery and interpretation of hidden paint layers

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Abstract

This paper presents an overview of the results from the ongoing study on the materials and painting technique of the pioneering Singapore artist—Liu Kang. The paintings *Zuo La Lu* and *Nude*, which represent two of Liu Kang's early and distinct artistic phases—Paris and Shanghai—were investigated for the first time using a combination of non- and micro-invasive techniques. The aim of this study was to identify the main pigments used by the artist and to add to the existing research on the artist's painting methods. The results show that the majority of pigments used in both paintings are similar and include Prussian blue, ultramarine, viridian, strontium yellow, chrome yellow, cadmium yellow, iron oxides, lead, zinc and barium whites, bone black and organic red. Particularly interesting is the predominance of lead white in *Zuo La Lu* and zinc white in *Nude*. A comparison of the ground layers also indicates the presence of a lead white admixture in *Zuo La Lu* while its absence in *Nude* may point to a characteristic difference between two artistic phases, possibly determined by the availability of materials. The imaging methods revealed hidden compositions: the view of a canal house behind *Zuo La Lu,* and a mystery outdoor view behind *Nude*. Although these investigative methods permitted some visualisation of the discarded compositions, it remains difficult to determine their details.

Keywords: Liu Kang, IRFC, MA-XRF, SEM–EDS, Pigment identification, Hidden painting

Introduction

Liu Kang was born in Yongchun, Fujian province, China, in 1911. He graduated from Xinhua Arts Academy in Shanghai in 1928. He stayed in Paris from 1928 to 1933, during which time he went on painting trips across Europe to assimilate the artistic essence of the Western masters. In 1933, he taught at the Shanghai Academy of Fine Art. He moved to Malaya in 1937 when the Sino-Japanese War broke out, and moved to Singapore in 1942. Liu Kang was active as an artist, educator and cultural commentator for about 60 years in Singapore. When he died in 2004, he was regarded as a pioneering Singapore artist who had profoundly influenced generations of Singapore artists [1].

During his formative years in Paris, Liu Kang formulated modernist art concepts before he found his own approach to painting, influenced by Impressionist, Post-Impressionist and Fauvist styles [2]. In an essay from 1980, Liu Kang made a reference to his stay in Paris: "As for myself, I have loved Vincent van Gogh and Paul Gauguin, and have also been infatuated with Henri Matisse. They have inclined me to adopt an optimistic and open-minded approach [3]."

In an 1981 interview, he said: "One of the first things I saw when I arrived in Paris was the 60th-anniversary exhibition works by Matisse. The impact was powerful and lasting [4]."

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Liu Kang's early explorations met with some success and his works were exhibited at Salon d'Automne in 1930 and 1931.

After returning to China, Liu Kang taught Western art at the Shanghai Academy of Fine Art and he was also at the centre of the Chinese modern art movement. He felt a strong need to search for and develop his own manner of painting, one that would bear the mark of his Chinese ethnicity. He combined Chinese ink technique with the colourful tones of Post-Impressionist works. Bands of bright, raw colours and quick, bold strokes characterised his works from that time onwards. The use of dark lines to delineate objects also became a dominant feature in his work [2].

Although there is an extensive literature on Liu Kang's works, none of these discussions included technical examination. Two paintings from the National Gallery Singapore, *Zuo La Lu* (1930) and *Nude* (1936), are amongst very few works from Liu Kang's Paris and Shanghai periods that have survived the Second World War. They exemplify the artist's early explorations of the Western painting style and his attempts at bridging East and West.

Zuo La Lu is an oil-on-canvas painting measuring 46 × 55 cm (Fig. 1). It is an outdoor scene depicting a townhouse behind a wall and some shrubs at Emile Zola Street. The palette of colours is characterised by different hues of blue, brown and green. Although the painting style is expressive, it betrays some attention to detail in the characterisation of the house.

Nude is a studio work painted in oils on a canvas measuring 46 × 54.5 cm (Fig. 2). The painting shows a female model sitting in front of a simple backdrop. The colour block division of the background hints at the influence of the Post-Impressionists. The use of a broad brown line around the model's body betrays the influence of Chinese ink painting, a style that would later become Liu Kang's trademark [5]. This rapidly executed painting reveals the decisive use of a few strong colours.

Fig. 1 Liu Kang, *Zuo La Lu*, 1930, oil on canvas, 46 × 55 cm. Collection of National Gallery Singapore. Image courtesy of National Heritage Board. White arrows indicate sampling areas

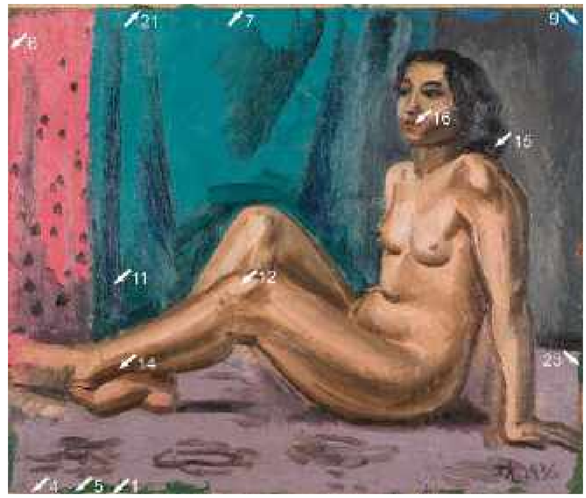

Fig. 2 Liu Kang, *Nude*, 1936, oil on canvas, 46 × 54.5 cm. Gift of the artist's family. Collection of National Gallery Singapore. Image courtesy of National Heritage Board. White arrows indicate sampling areas

As these two works represent different dates, genres and painting methods, they were selected to study the artist's painting materials. The paintings were investigated for the first time using a combination of in situ analytical non-invasive methods, and the results guided further micro-invasive techniques to characterise the pigments in detail.

Methods

Technical photography

High-resolution technical photography was conducted according to the workflow proposed by Cosentino [6–8]. A Nikon D90 DSLR modified camera with a sensitivity of between about 360 and 1100 nm was used with following filter sets:

a. X-Nite CC1 coupled with B + W 415, for visible, raking, transmitted light photography and ultraviolet fluorescence (UVF) photography at 365 nm;
b. Heliopan RG1000, for near-infrared (NIR) photography at 1000 nm with an additional aim of infrared false-colour imaging (IRFC);
c. Andrea "U" MK II for reflected ultraviolet photography (UVR). The lighting system was composed of

Table 1 Pigments detected in the painting *Zuo La Lu* by SEM–EDS and PLM

Samples	Colour/stratigraphy layer	Location	SEM–EDS detected elements[a]	SEM–EDS possible assignment	PLM identification
1	White	Ground layer	**O**, **C**, **Ca**, Pb, Zn, Na, (Si, Al, Mg)	Calcium carbonate, lead white, zinc white	Calcium carbonate, lead white, zinc white
4	Blue	Street name sign	**Pb**, **C**, **O**, Ca, Ba, (Fe, Na, Al, Si, Mg)	Prussian blue, lead white, barium white	Prussian blue, lead white
13	Blue	Sky	**Pb**, **C**, **O**, **Ca**, (Zn, Mg, Na, Si, Al)	Prussian blue, ultramarine, lead white, zinc white	Prussian blue, ultramarine, lead white, zinc white
8	Green	Shrubs above the fence	**C**, **O**, **Cr**, Cd, S, Pb, Ba, Al, Zn, (Ca, Fe, Mg, Na, Cl, Si)	Ultramarine, viridian, Prussian blue, lead white, cadmium yellow or light cadmium yellow, zinc white, barium white or lithopone	Ultramarine, viridian, Prussian blue, lead white, cadmium yellow
	Yellow cluster		**O**, **Pb**, **C**, **Ca**, Cr, S, (Al, Ba, Zn, Mg, Si)	Chrome-containing yellow(s) and green(s)	
	Green cluster		**O**, **C**, **Pb**, **Ca**, **Cr**, Ba, (S, Al, Cd, Fe, Si)	Chrome-containing yellow(s) and green(s), traces of cadmium yellow	
7	Yellow	Wooden blinds	**O**, **C**, **Pb**, **Si**, Fe, Al, Ca, Sr, As, (Ba, K, Cr, P, Na, Mg)	Yellow iron oxide, chrome yellow, barium white, gypsum, kaolin, strontium yellow, possible other chrome-containing yellow(s)	Yellow iron oxide, chrome yellow, strontium yellow
19	Brown	House wall	**C**, **Pb**, **O**, Ca, Fe, Si, Al, As, (Ba, P, Na, Sr, Zn, Cr, Mg)	Brown iron oxide, strontium yellow, bone black	Brown iron oxide, strontium yellow
5	Red	Tile from the roof of the smaller house	**O**, **C**, **Pb**, **Ca**, Cr, P, Al, Fe, (Si, As, Zn, Na, Cl, Ba, Mg)	Red iron oxide, chrome yellow, possible other chrome-containing yellow(s)	Red iron oxide, chrome yellow
6	Black	Tree branch	**O**, **Pb**, **C**, **Fe**, **Ba**, Ca, S, Na, Si, (K, Al, P, Zn)	Prussian blue, bone black, lead white, barium white	Prussian blue, bone black, lead white

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

two 500 W halogen lamps as an illumination source for visible, raking, transmitted light and NIR photography. Two lamps equipped with eight 40 W 365 nm UV fluorescence tubes were used for UVF and UVR photography.

The camera was calibrated with the X-Rite ColorChecker Passport. The American Institute of Conservation Photo Documentation Target (AIC PhD Target) was used for images white balance and exposure control. The images were further processed by Adobe Photoshop CC in accordance with the standards described by the American Institute of Conservation [9].

Reflectance transformation imaging

Reflectance transformation imaging (RTI) was carried out according to the workflow proposed by the Cultural Heritage Imaging [10]. The images were processed using Adobe Photoshop, followed by RTIBuilder and RTIViewer software, proposed by the Cultural Heritage Imaging [11, 12].

X-ray radiography

The digital X-ray radiography (XRR) was carried out at the radiology department of the Singapore General Hospital using a Siemens Ysio Max Digital X-ray System with a 35 × 43 cm detector that delivers high-pixel resolution images (over 7 million pixels). 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.

Macro X-ray fluorescence

The elemental mapping of the entire surface of the paintings was conducted with a macro X-ray fluorescence (MA-XRF) scanner, the M6 Jetstream from Bruker Nano GmbH. The instrument consists of a 30 W Rh-target microfocus X-ray tube, with a maximum voltage of 50 kV and a maximum current of 600 μA. The instrument is equipped with a 30 mm^2 active area XFlash Silicon Drift Detector with an energy resolution of < 145 eV for Mn Kα. A detector is mounted on an X–Y–Z motorised stage

Table 2 Pigments detected in the painting *Nude* by SEM–EDS and PLM

Sample	Colour/ stratigraphy layer	Location	SEM–EDS detected elements[a]	SEM–EDS possible assignment	PLM identification
1	White	Ground layer	**C**, **O**, **Ca**, **Zn**, Ba, S, (Na, Cr, Si, Al)	Calcium carbonate, zinc white, barium white	Calcium carbonate, zinc white
4	Violet	Violet fabric	**C**, **Zn**, **O**, Na, (Si, Ca, Al, Fe, Ba, S, Cr)	Ultramarine, yellow iron oxide, zinc white, barium white	Ultramarine, yellow iron oxide, organic red
9	Blue	Top-right corner	**C**, **Zn**, **O**, Na, Cr, Ba, S, Ca, Si, Al	Ultramarine, viridian, zinc white, barium white	Ultramarine, viridian, zinc white
11	Blue	Shadow of the fold	**C**, **O**, Ba, Zn, Cr, Na, S, Si, Al, (Ca, Fe, K)	Ultramarine, viridian, yellow iron oxide, zinc white, barium white	Ultramarine, viridian, yellow iron oxide, zinc white
5	Green	Bottom-left corner	**C**, **O**, **Zn**, Cr, Ba, Pb, Na, Ca, S, (Si, Al, Fe, Sr)	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow, possible extenders such as: barium white, gypsum, kaolin or other chrome- containing yellow(s)	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow
7	Green	Curtain	**C**, **O**, **Zn**, Ba, Cr, Na, S, (Sr, Ca, Si, Al)	Viridian, ultramarine, strontium yellow, zinc white, barium white, possible other chrome-containing yellow(s)	Viridian, ultramarine, strontium yellow, zinc white
21	Green	Top edge	**C**, **O**, **Ba**, Zn, Cr, Ca, Pb, S, Fe, Si, Na, (Al, Cd, Sr, K)	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow, possible extenders such as: barium white, gypsum, kaolin or other chrome- containing yellow(s), traces of cadmium yellow	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow
23	Green	Right edge	**O**, **C**, **Cr**, **Ba**, Zn, Ca, S, (Si, Na, Pb, Fe, Sr, Al)	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow, possible extenders such as: barium white, gypsum, kaolin or other chrome- containing yellow(s)	Viridian, ultramarine, Prussian blue, strontium yellow, zinc white, chrome yellow
12	Yellow	Model's knee	**C**, **Zn**, **O**, Na, (Si, Fe, Al)	Yellow iron oxide, zinc white	Yellow iron oxide, zinc white
14	Brown	Shadow from model's calf	**C**, **Zn**, **O,** Fe, Na, Si, (Al, Ba, Ca, S, Cr, Pb, Sr, Mg, As)	Brown iron oxide, chrome yellow strontium yellow, bone black	Brown iron oxide, chrome yellow strontium yellow
6	Pink	Curtain	**C**, **Zn**, **O**, Na, Ba, (Sr, S, Si, Fe, Pb, Al, Ca, Mg, Cr, Cl)	Strontium yellow, yellow iron oxide, zinc white, barium white, chrome yellow	Organic red, strontium yellow, yellow iron oxide, zinc white, chrome yellow
16	Red	Model's lips	**C**, **O**, **Ba**, S, Sr, Zn, Cl, (Ca, Si, Na, Pb, Fe)	Red iron oxide, strontium yellow, zinc white, barium white	Red iron oxide, organic red, strontium yellow, zinc white
15	Black	Model's hair	**C**, **O**, **Zn**, Si, (Na, Ca, Ba, Fe, Cr, S, P, Al)	Bone black, ultramarine, viridian, yellow iron oxide, zinc white, barium white	Bone black, ultramarine, viridian, yellow iron oxide, zinc white

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

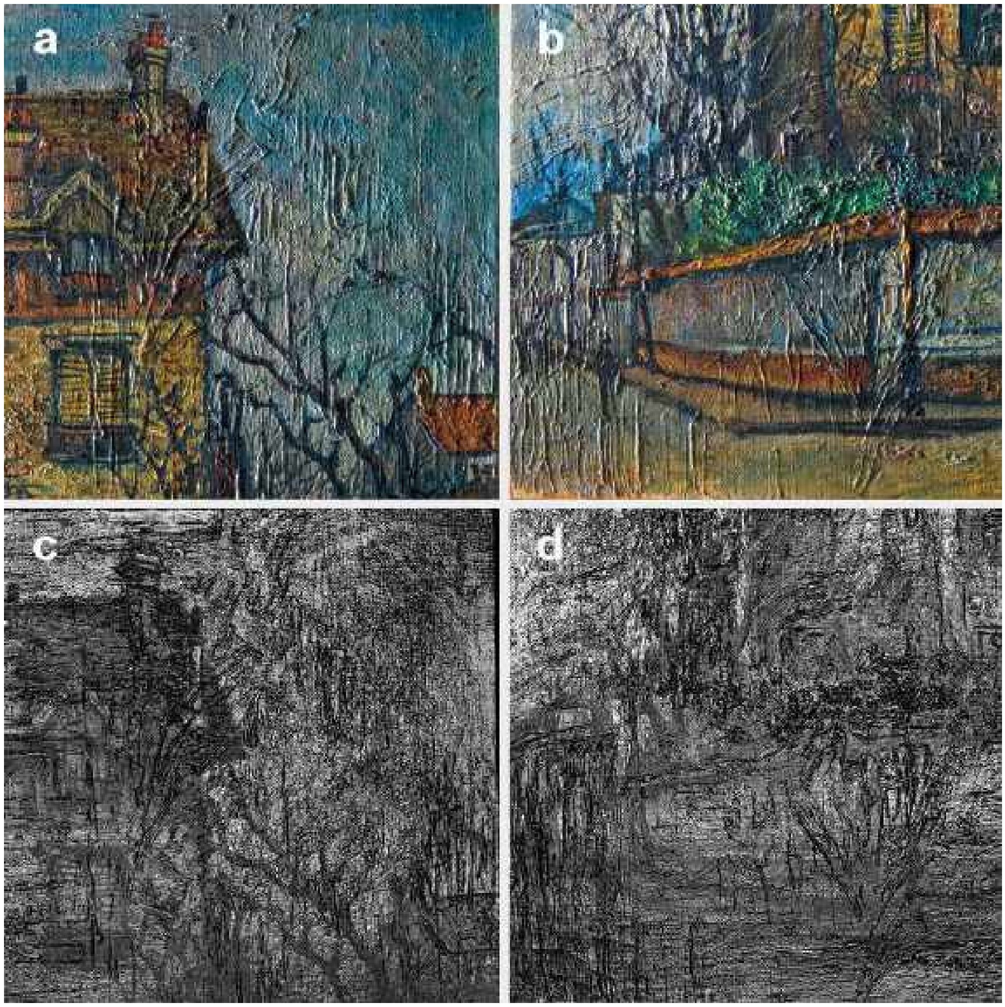

Fig. 3 Details of *Zuo La Lu*: **a**, **b** photographed in raking light; **c**, **d** photographed by RTI technique. Both imaging techniques reveal texture details corresponding to the earlier painted composition

with a maximum scanning range of 80 × 60 × 9 cm. The instrument offers an adjustable spot size from 100 to approximately 500 μm [13]. The elemental distribution maps of the paintings were collected with a dwell time of 10 ms/pixel, a pixel size of 300 μm and an anode current of 599 μA. The acquired spectra were collected and analysed using Bruker's M6 software, which allows the elemental distribution maps to be produced.

Optical microscopy and polarized light microscopy

Optical microscopy (OM) of the samples was carried out in visible and ultraviolet reflected light on the Leica DMRX polarized microscope at magnifications of ×40, ×100 and ×200 equipped with Leica DFC295 digital camera. Polarized light microscopy (PLM) was carried out using the methodology developed by Peter and Ann Mactaggart [14].

Scanning electron microscope with energy dispersive spectroscopy

All samples (powdered paint samples and cross-section) were mounted on high purity carbon tapes and examined with a scanning electron microscope (SEM) Hitachi SU5000 SEM, coupled with energy dispersive X-ray spectroscopy (EDS), Bruker XFlash 6|60. In SEM, the backscattered electron mode was used in 60 Pa vacuum, with 20 kV beam acceleration, at 50–60 intensity spot and a working distance of 10 mm. The distribution of chemical elements was mapped using Qantax Esprit processing software.

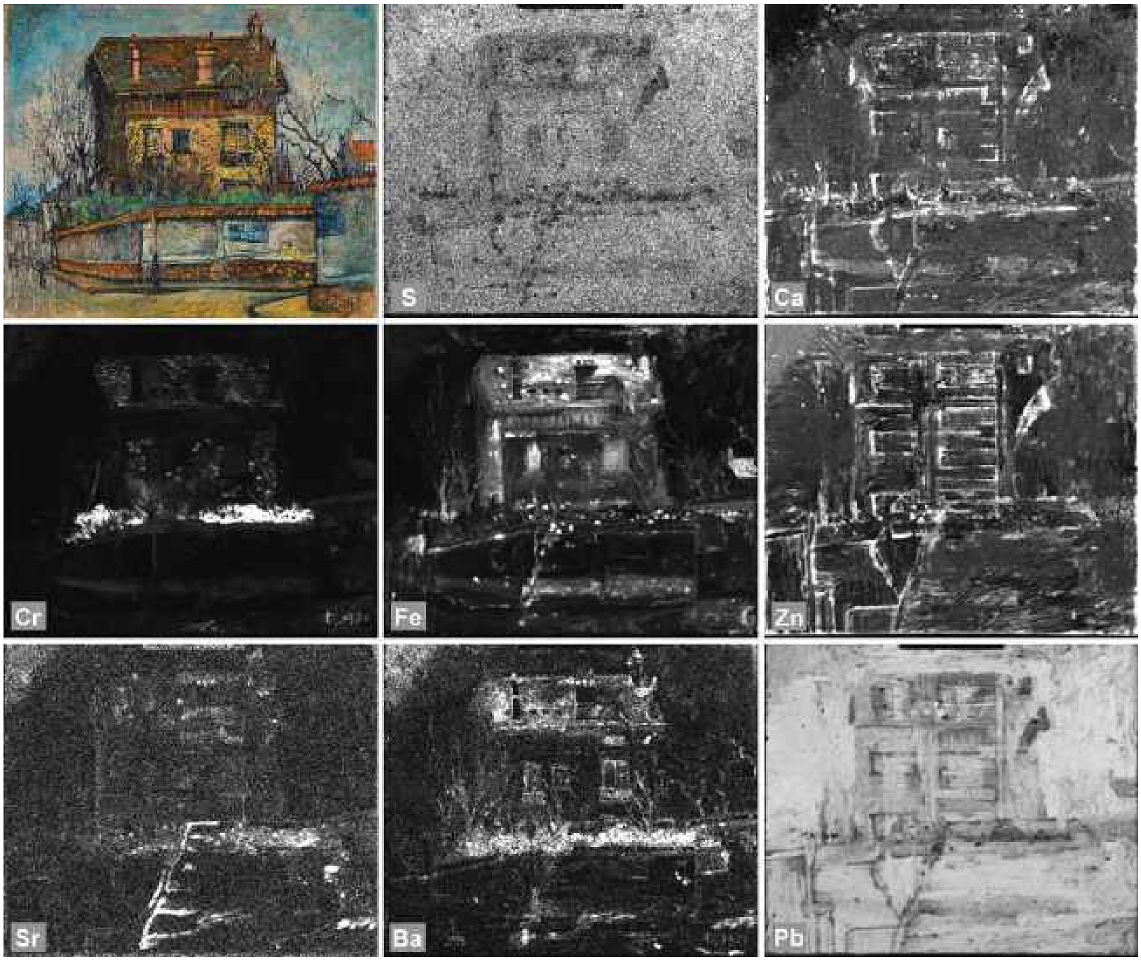

Fig. 4 Visible light image and MA-XRF maps of *Zuo La Lu* showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element; white equals high intensity, black means low intensity. Distribution maps of Ca, Zn and Pb reveal the hidden composition rotated at 90° anticlockwise

Samples

Based on the preliminary non-invasive investigation, eight micro-samples from *Zuo La Lu* and thirteen samples from *Nude* were analysed for this study.

Samples of the paint for cross-section structure observation and analysis were embedded in a fast-curing acrylic resin ClaroCit (supplied by Struers) and polished with abrasives down to grade 4000. The mounting medium for PLM pigment dispersion was Cargille Meltmount nD = 1.662.

A summary of the identified materials is given in Tables 1 and 2.

Results and discussion

Hidden painting beneath *Zuo La Lu*

The raking light and RTI examination revealed the presence of impastos that do not correspond to the present paint scheme. The impastos was evident in the areas of sky, house, fence and road in the bottom-left corner of the painting (Fig. 3). Subsequent MA-XRF scanning revealed the underlying view of a canal house painted in vertical orientation (Fig. 4). The hidden composition is visualised in the Pb, Zn and Ca distribution maps. Interestingly, the Zn and Ca maps appear as a negative image of the Pb distribution, indicating that the Zn- and Ca-signals source is the ground layer blocked locally by the Pb-containing paint of an underlying painting. This observation finds confirmation in the upper part of the underlying painting where what was probably the sky colour has a high concentration of Pb-containing pigment corresponding to the heavy impastos imaged in XRR. The XRR additionally revealed expressive brushstrokes that are much more visible than in the RTI, suggesting an attempt to imitate van Gogh's style (Fig. 5). The primary source of contrast in the radiographic image was the thickness variations of paint layer which

Fig. 5 Visible light (**a**) and XRR image (**b**) of *Zuo La Lu* rotated at 90° clockwise. XRR reveals the hidden painting of canal house

is rich in heavy metal, applied over a thinner ground of a similar chemical composition [15].

Hidden painting beneath *Nude*

A visual examination of the painted edges of *Nude* revealed the presence of green and blue paint to be unrelated to the final image (Fig. 6). An examination of the painting's surface with the raking light and RTI pointed out the impastos and other expression effects that do not correlate to the final composition. The underlying paint layer is characterised by marks probably achieved by scratching into wet paint with a palette knife, the end of a brush handle or any sharp tool. In the area of the feet, the marks have a form of crossed lines, like a net or garden fence. In the area of the model's left calf, small circles were scratched. Additionally, thick impastos were noticed in the area of the breast and the adjacent green background (Fig. 7). The XRR of *Nude* remains inconclusive; however, it suggests that the unveiled composition was painted in the horizontal orientation and that there might be shrubs or other greenery on the left side of the painting, where the scratching marks were noticed (Fig. 8). Similarly to *Zuo La Lu*, the thickness variations in the hidden paint layer play a role in the absorption of X-rays and rendering the X-ray image. This observation finds confirmation in the MA-XRF distribution map of Pb (Fig. 9) compared with XRR. A strong Pb-signal from the underlying composition corresponds to the impastos recorded with RTI and XRR. However, the Pb-signal from the model's face does not correlate with the thick brushwork recoded with raking light photography, RTI and XRR (Fig. 10), suggesting that the Pb-containing paint was applied at an earlier stage of the painting and covered with a thick application of a Zn-containing paint. Consequently, this assumption is supported by the Zn map, which appears as a negative image of the Pb distribution in the area of model's face (Fig. 9).

The underlying composition partially visible in the Pb distribution map is also not sufficiently recorded in the distribution maps for other elements present. However, some paint fragments along the painting turnover edges provide limited information about the pigment composition and will be discussed in the next chapter.

Ground layer

SEM–EDS measurements combined with PLM observations indicated that the composition of the ground layer in both paintings differs. In *Zuo La Lu*, the ground layer probably consists of a mixture of calcium carbonate (coccoliths were visible in normal and polarized light), lead white (particles appear greenish and show hexagonal angles in normal light), and zinc white (small particles appear yellow in normal light). The ground layer in *Nude* probably involves calcium carbonate with the addition of zinc white and barium white based on the co-location of Ba and S in the sample examined with SEM–EDS.

Blue and violet paints

In *Zuo La Lu*, the dark blue colour from the street sign and light blue from the sky were analysed. An IRFC

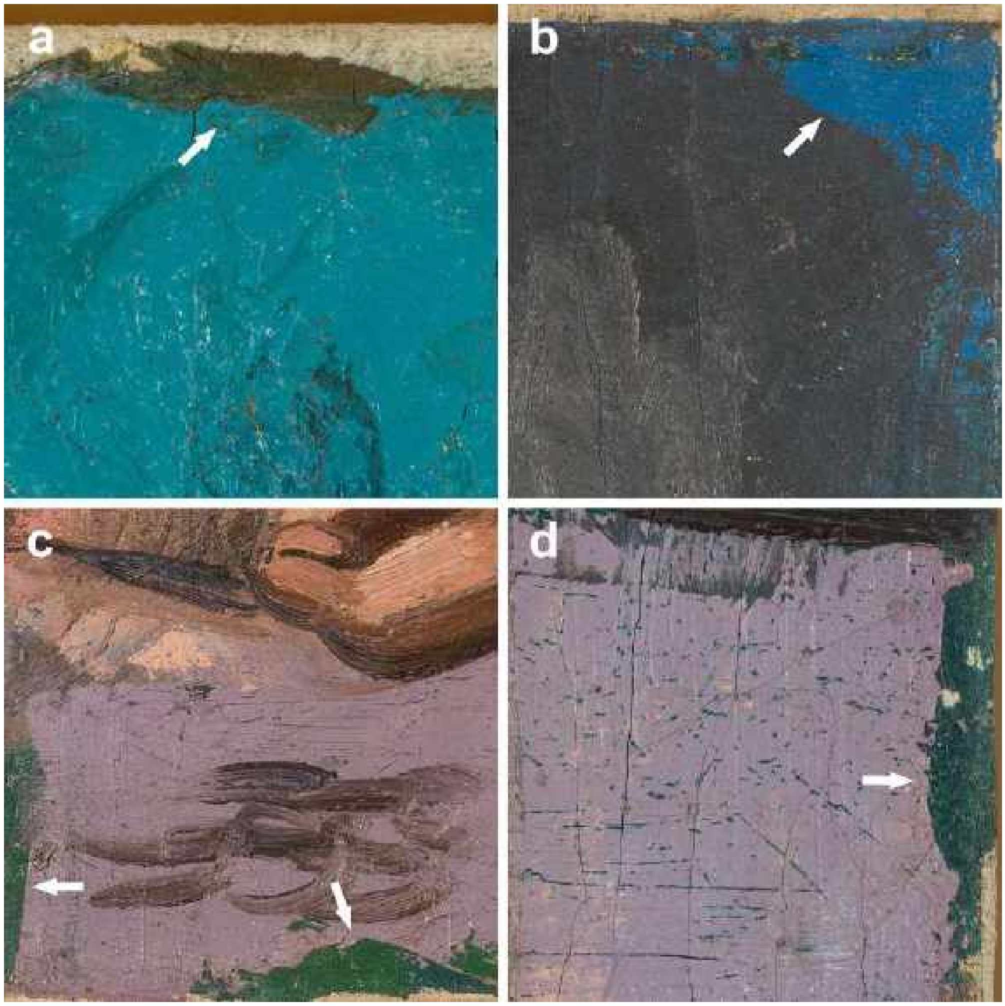

Fig. 6 Details of *Nude* showing paint fragments corresponding to the earlier painted composition: **a** green at the top edge; **b** blue at the top-right corner; **c** green at the bottom-left corner; **d** green at the right edge

(Fig. 11) was very effective, with preliminary indication that the painted areas contain Prussian blue. This pigment is known for its strong absorption of infrared; thus the blue street sign appears dark blue in IRFC imaging. Moreover, Prussian blue has very high tinting strength, so a low concentration of pigment is needed to achieve a blue shade. An MA-XRF scan of the area (Fig. 12) and a SEM–EDS analysis of the paint sample confirmed a small concentration of Fe, which was further identified with PLM as Prussian blue (particles appear greenish with Chelsea filter) (Fig. 13). An SEM–EDS analysis also recorded a signal of Pb, Ca and Ba, suggesting the use of lead white, chalk and barium white in the paint mixture.

The blue sky was imaged violet in an IRFC (Fig. 11), suggesting the use of a complex paint mixture. The SEM–EDS recorded traces of elements characteristic for Prussian blue and ultramarine, confirmed with PLM (ultramarine particles appear red with Chelsea filter). The MA-XRF was not able to visualise ultramarine due to the low atomic number of the element content of this pigment; its concentration was below the detection limit of the instrument. The final result seems to be consistent with the IRFC imaging as the purple and dark blue representation of ultramarine and Prussian blue can produce violet when combined. The brighter tone of the blue sky was achieved by adding lead and zinc whites identified by SEM–EDS and PLM.

In *Nude*, a blue paint from top-right corner turns purple in the IRFC image (Fig. 14), suggesting the use of ultramarine or cobalt blue. MA-XRF detected a Cr-signal (Fig. 9), which could be related to the use of Cr-containing yellow or green pigment(s). SEM–EDS combined with PLM allowed the identification

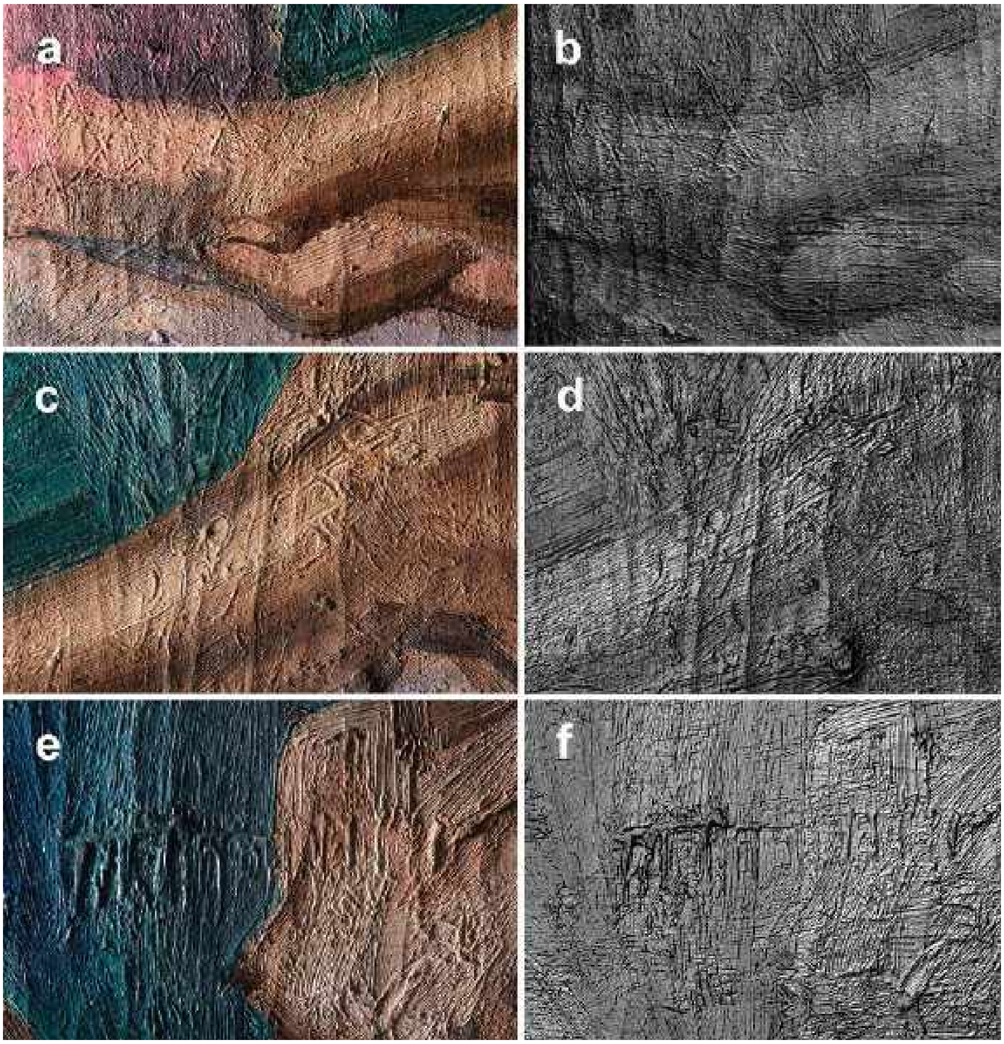

Fig. 7 Details of *Nude*: **a**, **c**, **e** photographed in raking light; **b**, **d**, **f** photographed employing RTI technique. Both imaging techniques reveal texture details corresponding to the earlier painted composition

of ultramarine with an admixture of viridian (the particles are large and rounded, with a rough surface, and appear warm grey with Chelsea filter). These findings correspond to the purple colour in the IRFC image of the area. The blue paint was brightened with the addition of zinc and barium whites based on the SEM–EDS co-location of Ba and S. The microscopic observation of the paint cross-section reveals that the blue paint was laid directly on the ground layer, thus suggesting that it may relate to the previous paint scheme (Fig. 15). Liu Kang, while creating the present painting, decided to retain this fragment of the previous work; therefore it was included in the study.

Based on the SEM–EDS and PLM analysis of the paint from the violet fabric in *Nude*, it is possible to conclude that the mixture contains ultramarine with yellow iron oxide-containing pigment and organic red. Iron oxide pigment was identified with PLM by anisotropic yellow and brown particles with high refractive index. Organic red can be distinguished from the other reds with PLM by its unique low refractive index; however, a full identification of the organic red pigment is needed. The presence of Zn and the analogous location of Ba to that of S may indicate the use of zinc white—identified with PLM and barium white extender—which could be assigned to an organic red [16].

In the same painting, the dark-blue shadows of the folds of the green background were painted mainly with a mixture of ultramarine, viridian, yellow iron oxide, zinc and barium whites.

Fig. 8 The XRR image of *Nude* remains inconclusive; however, it suggests that the unveiled composition was painted in the horizontal orientation and that there might be shrubs or other greenery on the left side of the painting, where the scratching marks were noticed

Green paints

The green shrubs painted above the fence in *Zuo La Lu* are imaged in IRFC partially violet and purple, suggesting a complex paint mixture (Fig. 11). The MA-XRF recorded strong Cr- and Ba-signals, which could suggest the presence of Cr-containing green and/or yellow pigments (Fig. 4). The SEM–EDS and PLM identified a mixture of viridian and ultramarine (both appear purple in the IRFC), Prussian blue (responsible for partial violet imaging in the IRFC), lead white and cadmium yellow. Cadmium yellow was characterised by strong Cd- and S-signals, recorded with SEM–EDS (Fig. 16) and PLM observation (yellow, anisotropic particles with high refractive index turn green in crossed polarized filters). The intensity of SEM–EDS peaks of Zn and Ba may suggest a presence of zinc and barium whites or lithopone but they also can be attributed to the light cadmium yellow commonly extended with barium white and called cadmopone [17]. Paint cross-section microphotography (Fig. 17) shows another layer beneath the top green that consists of clusters of not properly mixed yellow and green paints. The SEM–EDS analysis of the yellow (Fig. 18) and green (Fig. 19) clusters and elemental distribution maps (Fig. 20) of the entire sample indicate a strong Pb-, Ca- and Cr-signals, suggesting a presence of Cr-containing yellow and green pigments with possible extenders. Hermann Kühn and Mary Curran mention that chrome yellow may have extenders such as barium white, gypsum or kaolin [18], while calcium chromate was also used as an admixture [18]. Although pigments identified beneath the top layer of green paint provided some information about the paint mixture, it is unclear whether this layer is part of the current composition build-up or belongs to the underlying painting.

In *Nude*, the green curtain behind the model was visualised with MA-XRF distribution maps of Cr, Ba, Sr, S and Zn (Fig. 9), while IRFC imaged the area in purple (Fig. 14). Although both results indicated a probable use of Cr-containing green and yellow pigments, a turquoise hue of the green paint suggested that blue could have been added as well. This observation was further confirmed by the identification of viridian and ultramarine with SEM–EDS and PLM (Fig. 21). The artist probably modified a green colour by adding strontium yellow (distinct large needles are visible in PLM) and brightened it with zinc and barium whites; however, strong Ba-, Zn- and Cr-signals would also account for the presence of other Cr-containing yellow pigments, which were not detected with PLM but cannot be excluded [18].

Four fragments of green paint along the bottom, top, left and right edges of *Nude* are part of the hidden painting (Fig. 6). Liu Kang did not intend to cover the earlier artwork while painting *Nude*, therefore the green paint fragments are included in this study. The MA-XRF elemental distribution maps (Fig. 9) showed that these green paint fragments consist of several elements that could be made up of Cr-containing green and yellow pigments identified by SEM–EDS and PLM as viridian, strontium and chrome yellow (the particles between crossed polarized filters appear as tiny rods with high refractive index). The source of other elements like, Al, S, Ca and Ba, is difficult to pinpoint as their presence may be due to a number of materials, such as extenders for chrome yellow [18]; although these additions were not identified with PLM, they cannot be excluded. Admixtures of ultramarine and Prussian blue were also identified with SEM–EDS and PLM. The green paint sample from the right edge contains a very high concentration of Cr, which was assigned to viridian with SEM–EDS and PLM. Thus, the elemental analyses are consistent with the IRFC image (Fig. 14), indicating that viridian and ultramarine are responsible for the purple appearance, and the admixture of Prussian blue contributes to the violet appearance. All fragments of green paint were brightened with zinc white, identified with SEM–EDS and PLM.

Yellow and brown paints

In *Zuo La Lu*, different hues of yellow paint appear on the house wall, windows and road while brown was used for the roof and fence tiles. In *Nude*, yellow and brown were used for the flesh tones rendering and outlining the model's body. These parts of the paintings are imaged with different hues of yellow-green in the IRFC (Figs. 11, 14) and are well visualised with the MA-XRF Fe distribution maps (Fig. 4, 9), suggesting the use of ferrous

Fig. 9 Visible light image and MA-XRF maps of *Nude* showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. The distribution map of Ca indicates areas of later conservation infills. The distribution map of Pb corresponds mainly to the underlying composition and its impastos recorded with RTI and XRR, except for the Pb-signal from the model's face, which links directly with the final composition

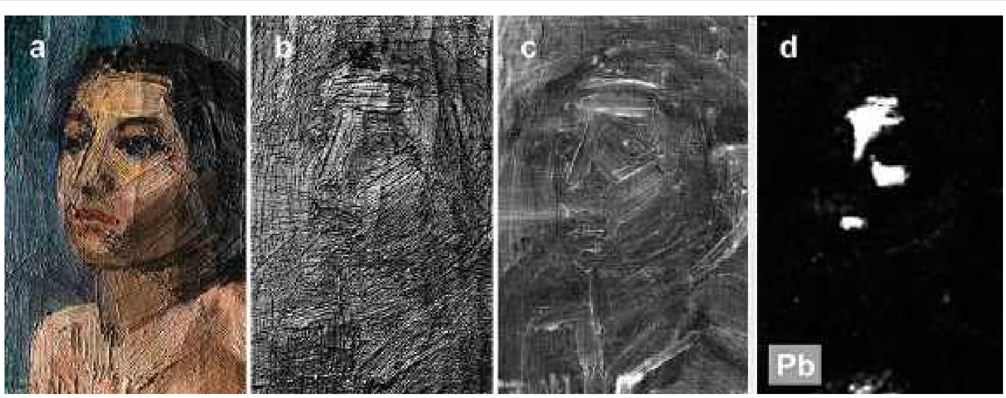

Fig. 10 Close-up of the model's face imaged by means of: **a** raking light photography; **b** RTI; **c** XRR; **d** MA-XRF Pb-distribution map. The Pb-signal from model's face does not correlate with a thick brushwork recoded with raking light photography, RTI and XRR

Fig. 11 Infrared false-colour image of *Zuo La Lu*

pigment(s). The SEM–EDS and PLM identified them as yellow and brown iron oxides. In addition, traces of As were detected with SEM–EDS in the areas with a higher concentration of Fe, indicating a natural origin of iron oxide pigments [19]. The sources of Pb, Ca and Ba are difficult to determine as these elements co-exist naturally with iron oxides [20], but together with Cr, which is also present in the paint samples, they can make up chrome yellow, confirmed in PLM and other Cr-containing yellow pigment(s) not identified with PLM. However, it is known that ochres had been enhanced during the manufacturing process by a small addition of chrome yellow, [18, 20], which can also have its own extenders, such as barium white, gypsum and kaolin, and may be present in the paint samples [18]. In *Zuo La Lu*, an addition of strontium yellow is suspected in the yellow and brown paints, based on the SEM–EDS Sr-signal, while the presence of Ca and P in the brown paint may indicate the admixture of bone black. In *Nude*, the model's flesh tone was mainly achieved by mixing yellow iron oxide with zinc white. Traces of Pb, Cr and Sr may suggest low concentration of chrome yellow and contamination with of strontium yellow. Interestingly, the MA-XRF scan (Fig. 9) reveals a strong signal from Pb and S, present in the forehead, right cheek and chin, suggesting the use of a Pb-containing paint at an earlier painting stage, and covered later by a thick application of a Zn-containing paint.

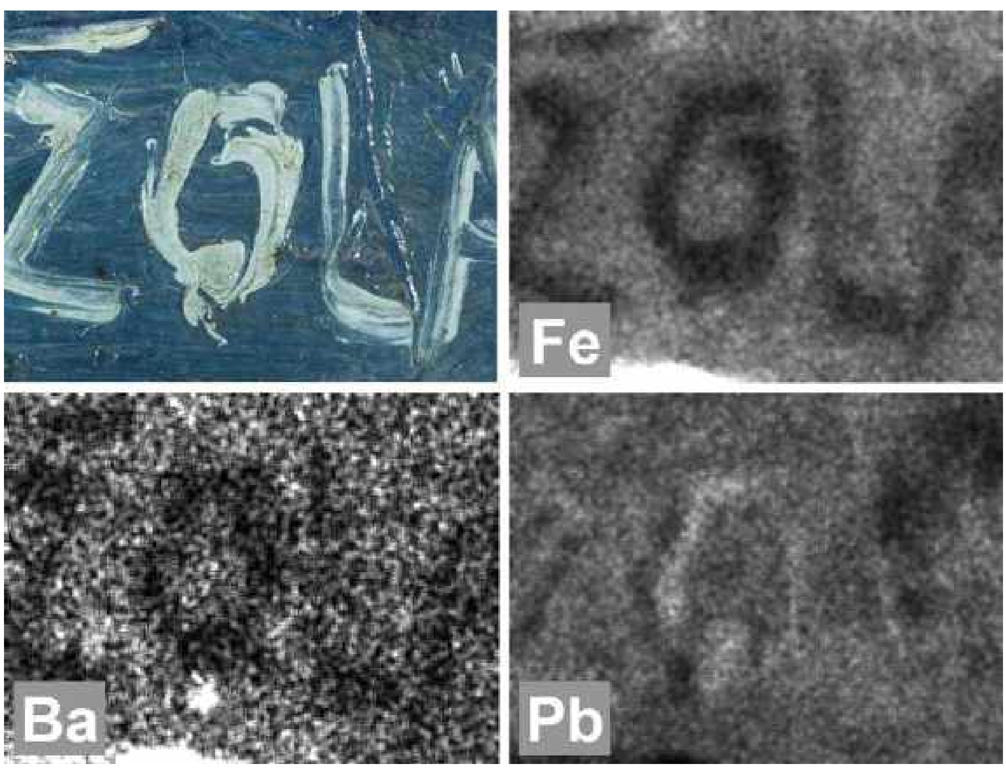

Fig. 12 Close-up of the detail of the blue street sign from *Zuo La Lu* and MA-XRF maps. The distribution of the three main elements, Fe, Ba, Pb, is shown. Fe-signal relates to the Prussian blue later identified with SEM–EDS and PLM. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity

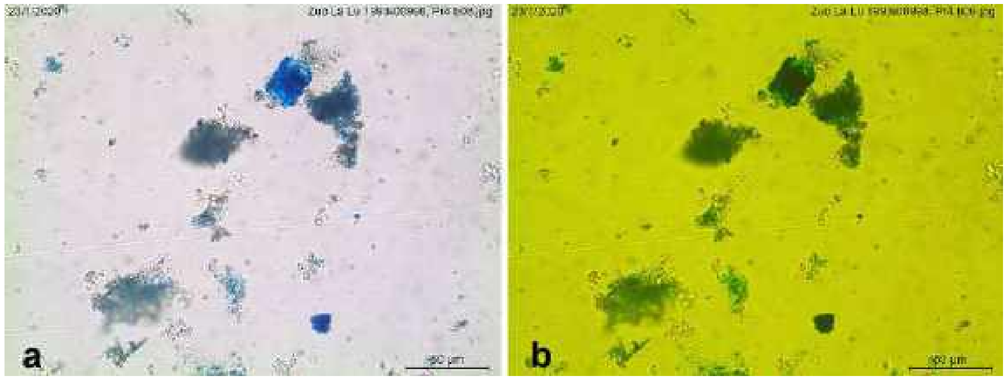

Fig. 13 Prussian blue particles from sample 4 taken from blue street sign from *Zuo La Lu* photographed in transmitted polarized (**a**) and with Chelsea filter (**b**)

Fig. 14 Infrared false-colour image of *Nude*

Fig. 15 Cross-section of sample 9 from *Nude*. The image shows that the blue paint was laid directly on the ground layer, thus suggesting that it may relate to the previous paint scheme

Red and pink paints

Red paint from the roof of the smaller house in *Zuo La Lu* probably contains a red iron oxide pigment (anisotropic and uniform red particles between polarized filters with high refractive index) with the admixture of chrome yellow. Other Cr-containing yellow pigment(s), although not identified with PLM, cannot be excluded. In *Nude*, red paint was used for the definition of the model's lips. Based on SEM–EDS and PLM, it is probably composed of red iron oxide, organic red, an admixture of strontium yellow and zinc white. Strong MA-XRF and SEM–EDS signals of Ba and S may suggest the presence of barium white extender for organic red.

Based on the MA-XRF, SEM–EDS and PLM analysis of the pink curtain, I deduce that the area consists mainly of several elements that could be assigned to strontium yellow, yellow iron oxide, zinc and barium whites and chrome yellow. The PLM allowed the identification of an organic red, which would be consistent with the yellow colour in the IRFC image. Although other red pigments are also imaged yellow in the IRFC, none of them was detected with the instrumental methods; nonetheless, further analyses are required to identify the red pigment.

Black paints

The black paint from the tree branches in *Zuo La Lu* is characterised by the strong Fe-signal recorded by MA-XRF and SEM–EDS. The detection of Fe is usually related to both the presence of iron oxide pigments and Prussian blue, which was further identified with PLM. A presence of a small admixture of bone black is possible, based on the SEM–EDS detection of Ca- and P-signals in the paint sample and PLM observation (anisotropic grey and black particles). The additional presence of Pb, Ba and S can suggest the use of lead and barium whites.

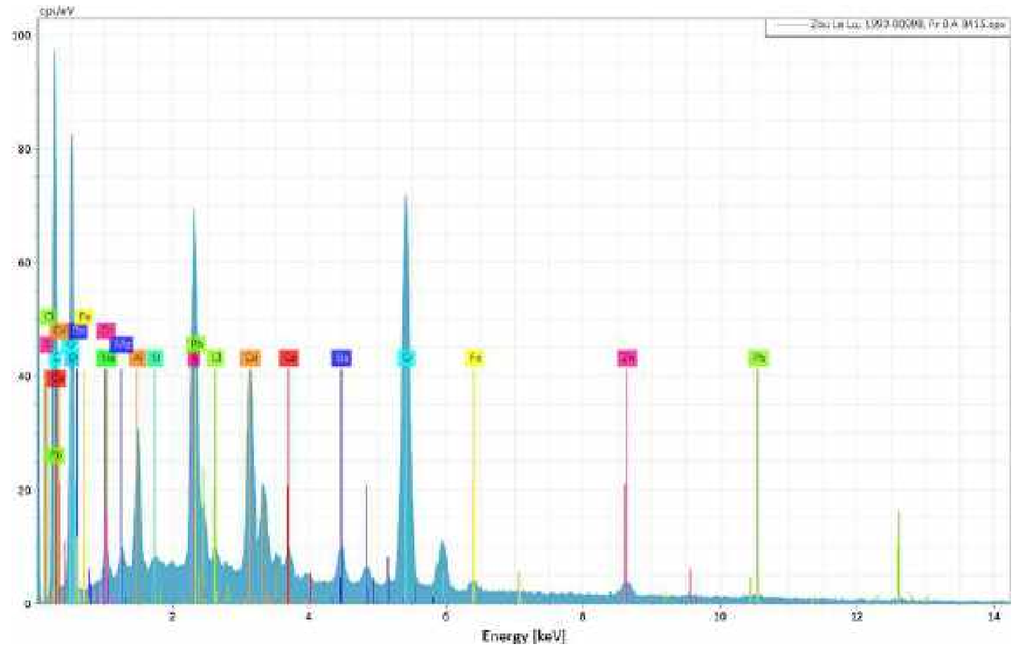

Fig. 16 SEM–EDS quantitative elemental analysis of the top green layer in sample 8 from *Zuo La Lu*. The spectra indicates elements that were assigned to viridian, ultramarine, Prussian blue, lead white and cadmium yellow. Cadmium yellow is characterised by strong Cd- and S-signals. The findings were correlated with PLM observations

The model's black hair in *Nude* is imaged black but with a warm, reddish hue in the IRFC, suggesting that the black colour was obtained by mixing several pigments. This information was found relevant with the SEM–EDS results where elements characteristic for bone black, ultramarine and viridian were detected and identified later with PLM. The yellow iron oxide-containing pigment with a possible addition of zinc and barium whites were found in the mixture as well.

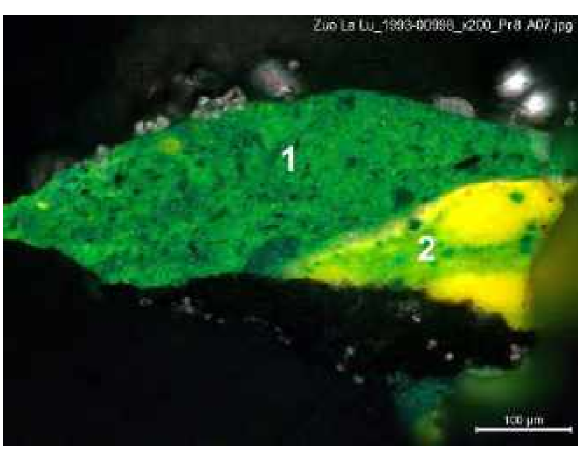

Fig. 17 Cross-section of sample 8 from *Zuo La Lu*. Layer 2 is characterised by clusters of green and yellow paint

White paints

In both paintings, Liu Kang did not apply a pure white paint; however, white appears in mixtures with other pigments already identified. It is quite clear that lead white is predominant in *Zuo La Lu* and appears in mixtures with zinc and barium whites. In *Nude*, the artist preferentially used zinc and barium whites; lead white appears only on the model's face and was clearly visualised with MA-XRF scanning.

Conclusions

The analytical investigations carried out in this study proved to be complementary and gave insights into the pigments used by Liu Kang in the paintings representing his two early and distinct artistic phases—Paris and Shanghai. The MA-XRF scanning provided an opportunity to visualise the distribution of elements indicative of pigments; however, it didn't allow the pigments associated with the underlying paintings to be fully characterised. Although the IRFC imaging did not provide conclusive results, it proved to be a useful tool for the tentative identification of the pigments and the selection of potential sampling areas for the SEM–EDS and

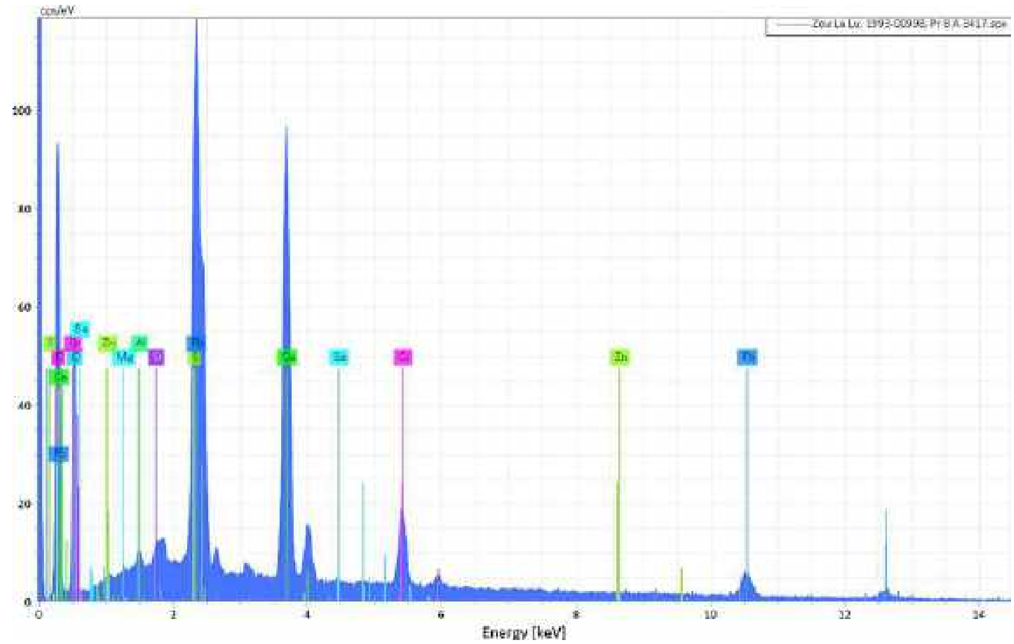

Fig. 18 SEM–EDS quantitative elemental analysis of yellow cluster in sample 8, layer 2 from *Zuo La Lu*. Cr-containing pigment with possible extenders can be attributed to the yellow paint

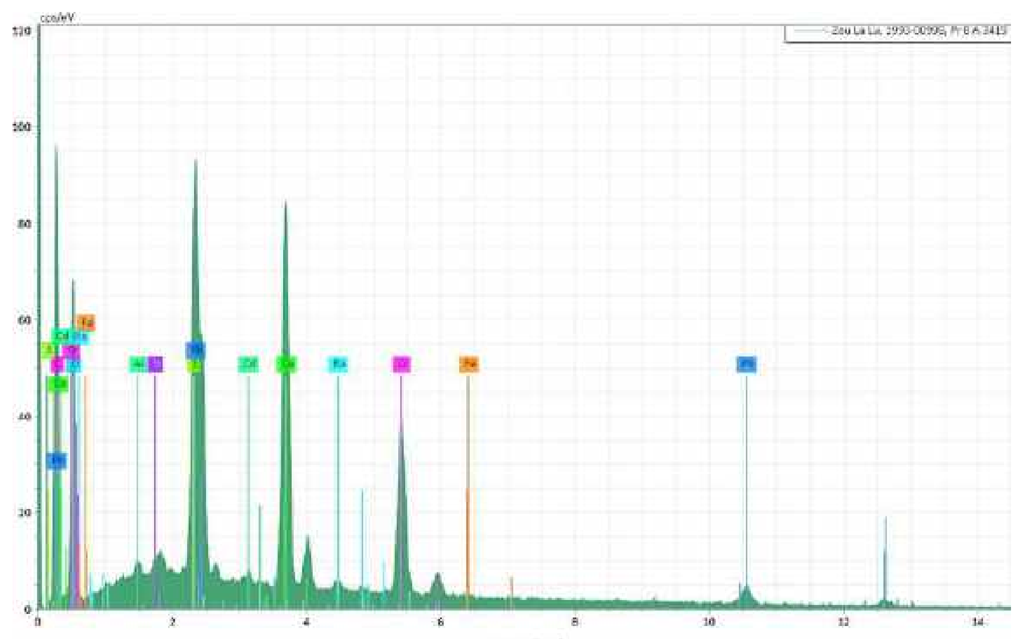

Fig. 19 SEM–EDS quantitative elemental analysis of green cluster in sample 8, layer 2 from *Zuo La Lu*. The green paint probably contains Cr-based green and yellow pigments with possible extenders. The weak Cd-signal indicates a trace amount of cadmium yellow

PLM [8]. The provided results show that the majority of pigments used in both paintings are similar and include Prussian blue, ultramarine, viridian, strontium yellow, chrome yellow, cadmium yellow, iron oxides (yellow, brown and red), lead, zinc and barium whites. The analytical methods also suggest the use of bone black and

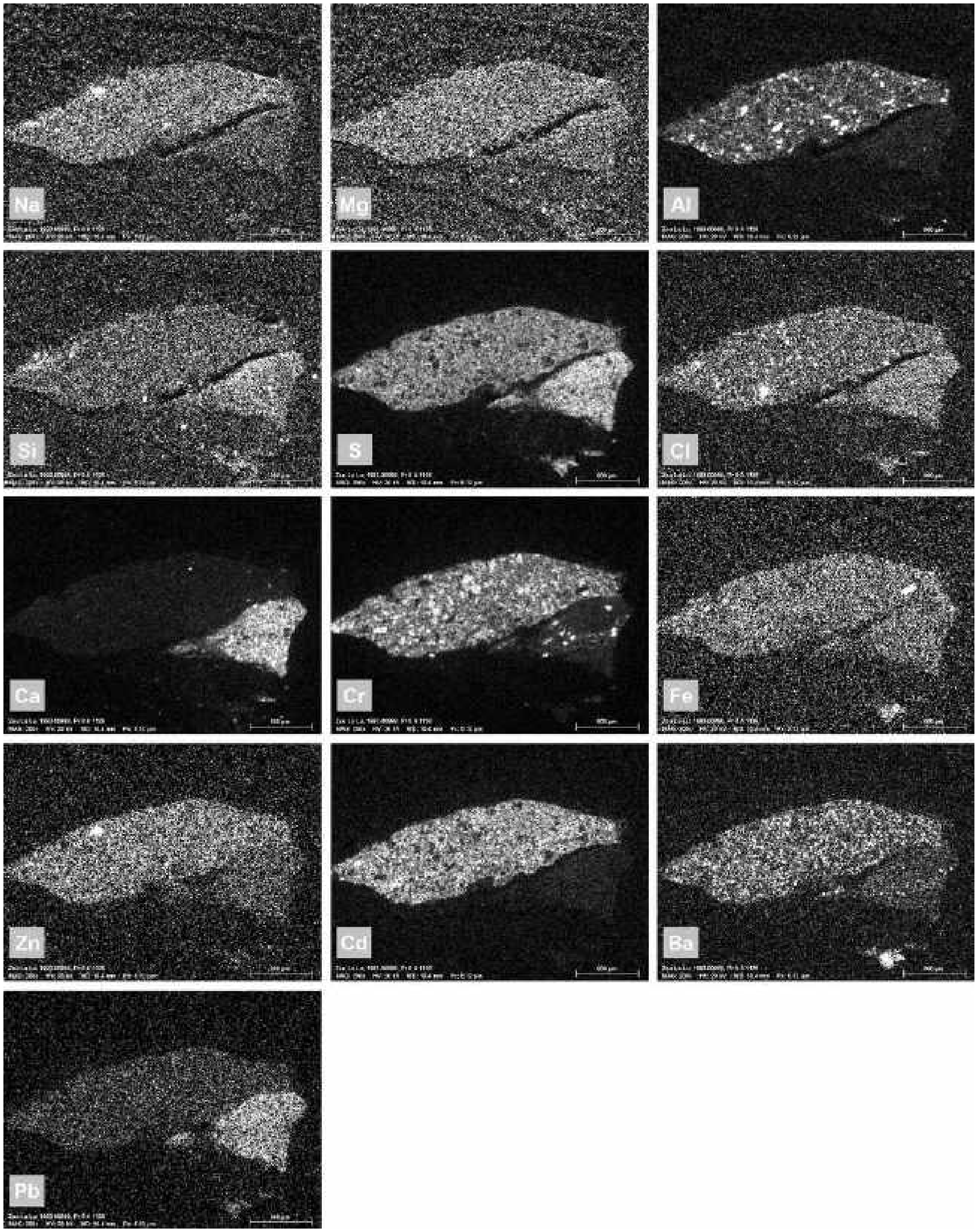

Fig. 20 SEM–EDS maps showing the distribution of the detected elements in sample 8 from *Zuo La Lu*. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. Cadmium, which was assigned to cadmium yellow, is confined only to the upper layer while the second layer is characterised mainly by Ca, Pb and Cr

organic red. Particularly interesting is the predominance of lead white in *Zuo La Lu* while zinc white was extensively used in *Nude*. A comparison of the ground layers also indicates the presence of a lead white admixture in *Zuo La Lu* while its absence in *Nude* may point to a characteristic difference between the two artistic phases, possibly determined by the availability of materials.

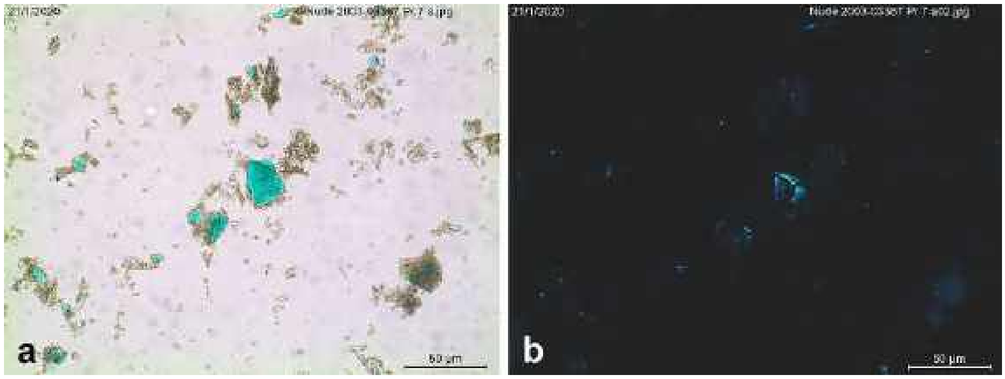

Fig. 21 Viridian particles from sample 7 taken from green curtain behind the model from *Nude*, photographed in transmitted polarized (**a**) and between crossed polars (**b**)

The combination of RTI, XRR and MA-XRF permitted the visualisation of the hidden canal house behind *Zuo La Lu* and allowed the detection of a discarded composition, probably an outdoor view, which was later overpainted with the final image of *Nude*. The details of the compositions remain unknown; however, different analytical techniques permitted the preliminary identification of some pigments used in the creation of the hidden paintings.

The interpretation of the collected data highlighted some points that require further research. These aspects include the clarification of whether, other than chrome and strontium yellow, Cr-containing yellows were used; and of the characterisation of the organic red pigment from *Nude*. The fragmentary presence of the Pb-containing pigment on the model's face is particularly interesting and requires further analysis to fully identify the pigment composition in this area. The revelation of the two hidden paintings creates an opportunity for further analysis to determine the composition details and the materials used. Extending the research over a broader group of paintings could determine whether the composition of the ground layers and the usage of lead white actually underwent an important transition after 1933. The identification of the canvas supports and paint binding media used for these works was beyond the scope of this study and will be addressed in the next phase of the research.

The study contributes to the knowledge on Liu Kang's painting materials and habits. The results of this study may be interesting for conservators and art historians investigating the painting materials and techniques of this artist and other artists active during the same period.

Abbreviations

UVF: Ultraviolet fluorescence; UVR: Reflected ultraviolet; NIR: Near-infrared; IRFC: Infrared false-colour; RTI: Reflectance transformation imaging; XRR: X-ray radiography; MA-XRF: Macro X-ray fluorescence; SEM–EDS: Scanning electron microscope with energy dispersive spectroscopy; OM: Optical microscopy; PLM: Polarized light microscopy.

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Authors' contributions

DL carried out the examination of the paintings, using technical photography, sampling, SEM–EDS and PLM analysis; provided the interpretation of the datasets; and wrote the manuscript. The author 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 author upon request.

Competing interests

Author declares that he has no competing interests.

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RESEARCH ARTICLE

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

Damian Lizun[1*], Teresa Kurkiewicz[2] and Bogusław Szczupak[3]

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

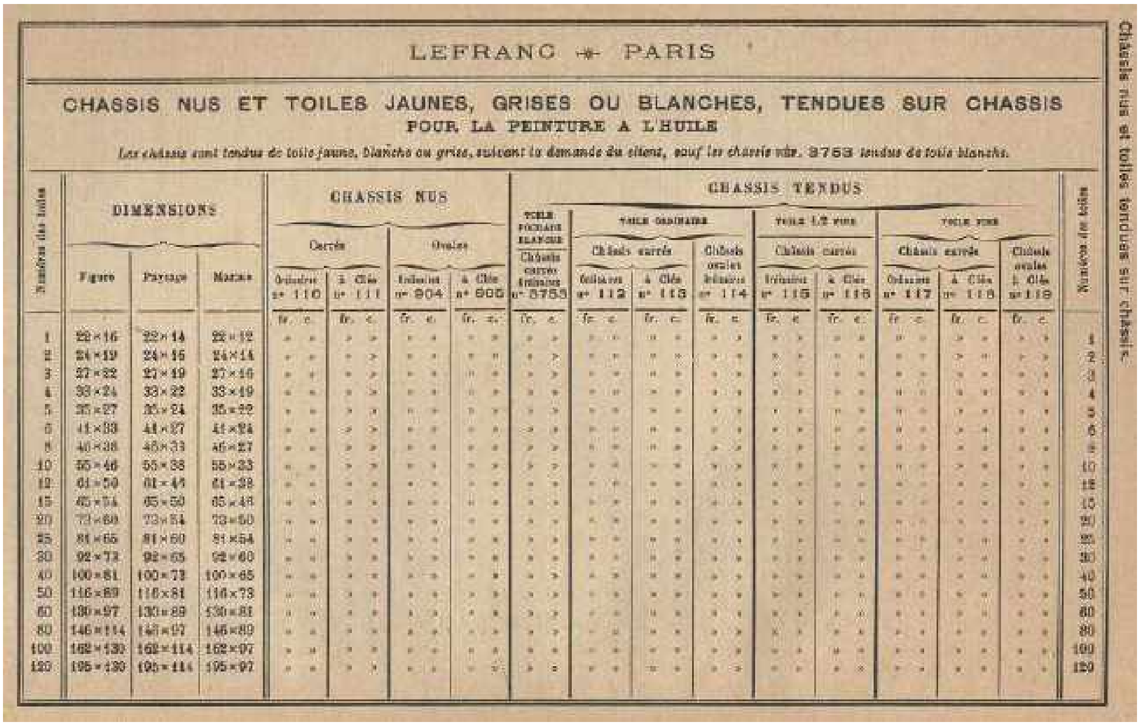
A total of 104 micro samples of fibres were collected from the threads of weft and warp for the microscopic examination. The samples were first boiled in water to remove contaminants and then mounted on microscope slides with a drop of water under the cover glass. In addition, 45 micro-samples of the 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 nos. 3753 tendus de toile blanche.

Numéros des toiles	DIMENSIONS Figure	Paysage	Marine	CHASSIS NUS Carrés Ordinaire n° 110	Carrés à Clés n° 111	Ovales Ordinaire n° 904	Ovales à Clés n° 905	CHASSIS TENDUS Toile pochade blanche Châssis carrés ordinaires n° 3753	Toile ordinaire Châssis carrés Ordinaires n° 112	Toile ordinaire Châssis carrés à Clés n° 113	Toile ordinaire Châssis ovales Ordinaires n° 114	Toile 1/2 fine Châssis carrés Ordinaires n° 115	Toile 1/2 fine Châssis carrés à Clés n° 116	Toile fine Châssis carrés Ordinaires n° 117	Toile fine Châssis carrés à Clés n° 118	Toile fine Châssis ovales à Clés n° 119	Numéros des toiles
				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

Châssis nus et toiles tendues sur châssis.

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

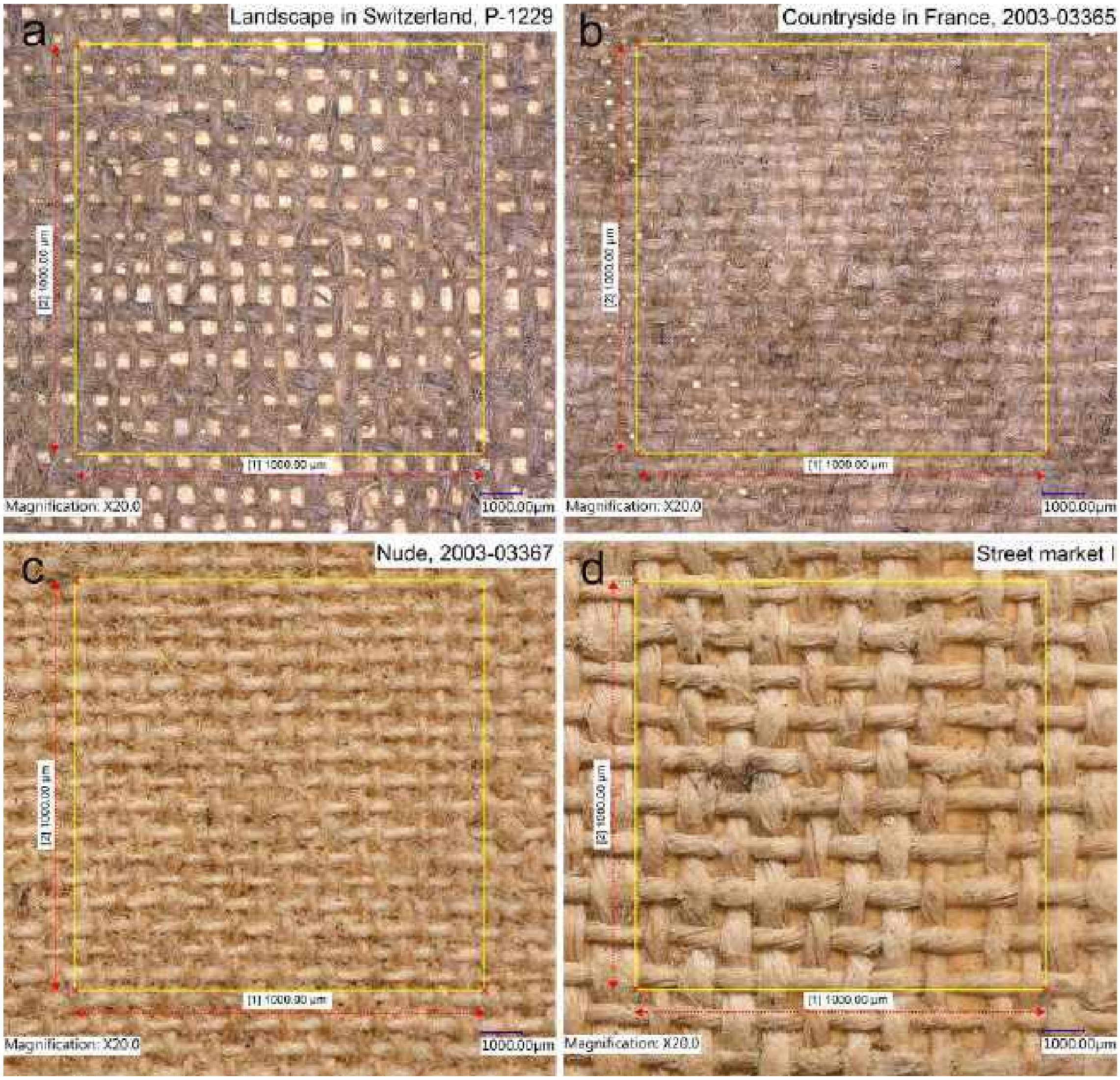


Fig. 5 Photomicrographs of different types of canvases identified in the Paris and Shanghai paintings; from Paris: **a** canvas type 1; **b** canvas type 2; from Shanghai: **c** canvas type 1; **d** canvas type 2

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 ($\pm$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,

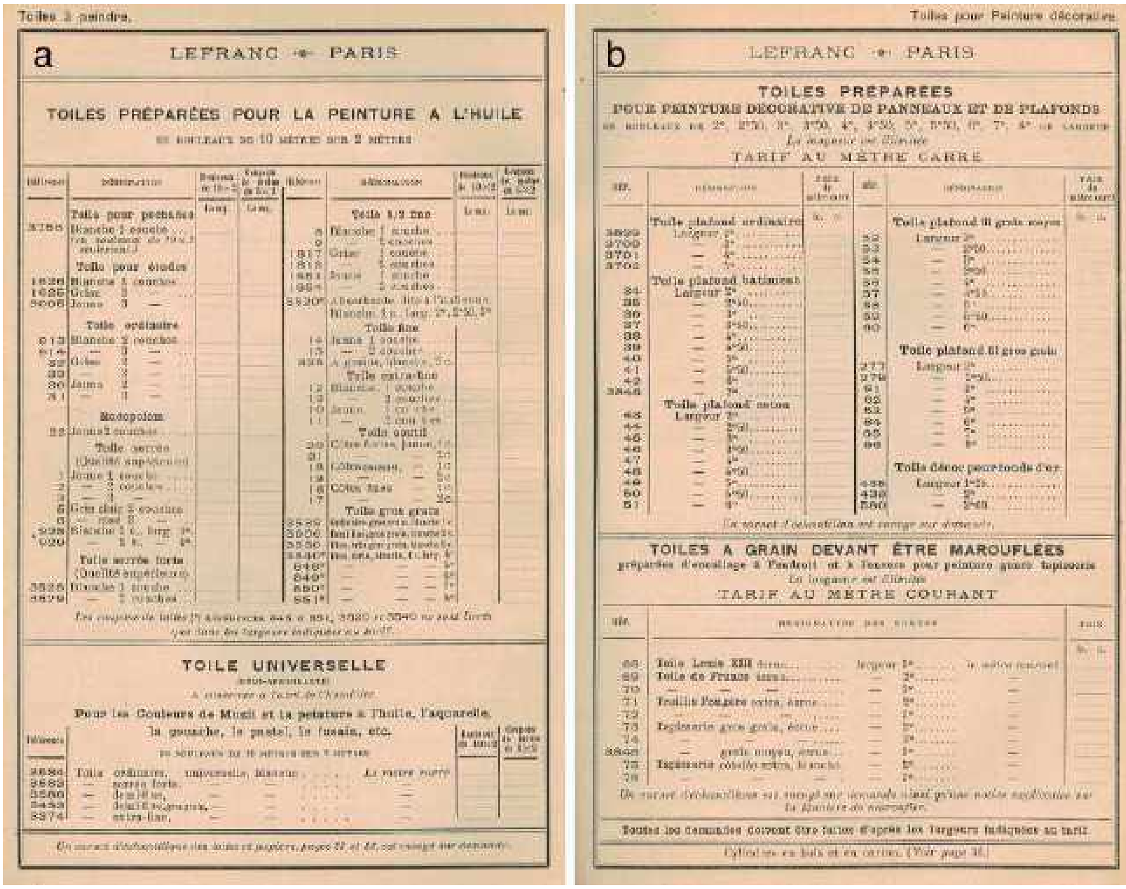


Fig. 6 List of commercially prepared (**a**) and raw canvases (**b**) available from Lefranc in 1930

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*

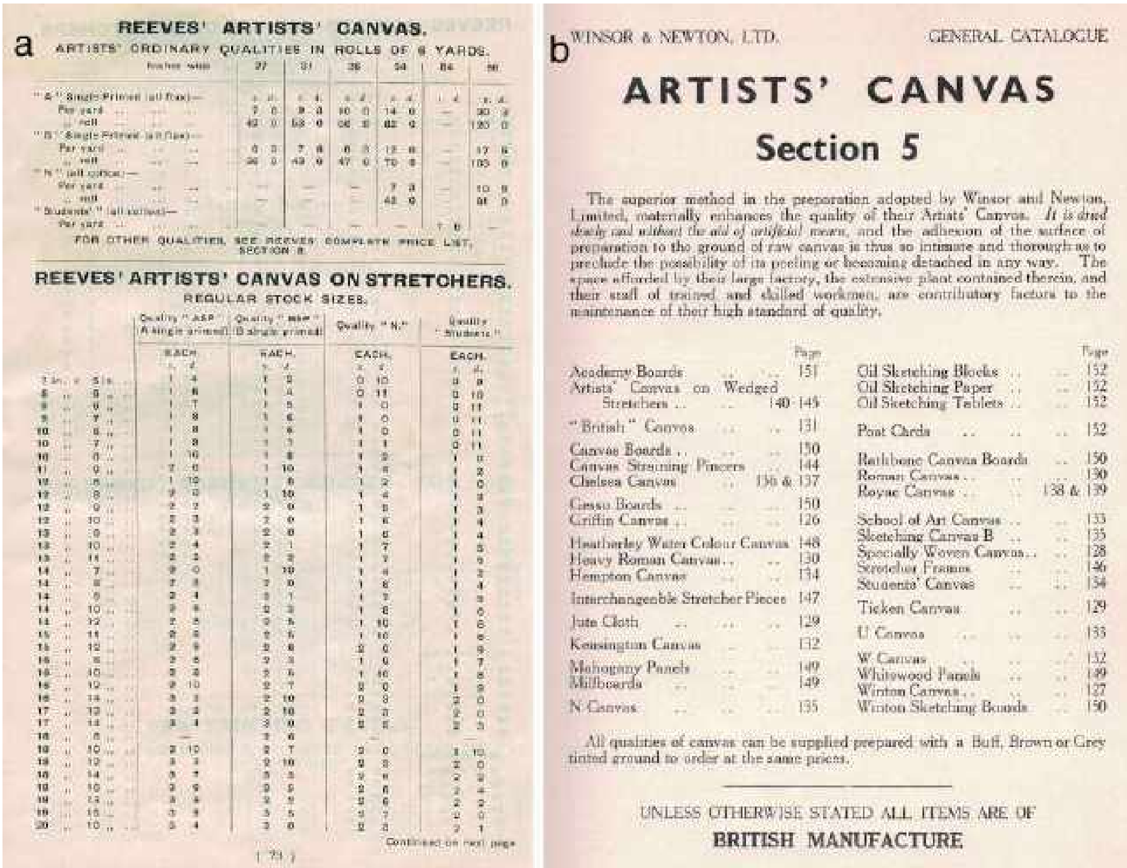


Fig. 8 List of commercially prepared canvases available from: **a** R&S in 1926; **d** W&N in 1934

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

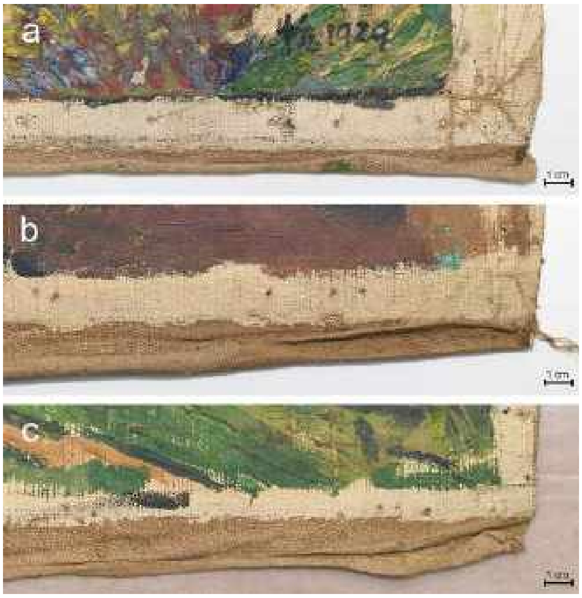


Fig. 9 Close-ups of the partial ground coverage found on the tacking margins of: **a** *St Gingolph, Lac Leman, Switzerland*, 1929, oil on canvas, 45.5 × 37.5 cm; **b** *Portrait of a man with his hat, Belgium*, 1930, oil on canvas, 55 × 45 cm; **c** *French countryside*, 1930, oil on canvas, 46 × 54.5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

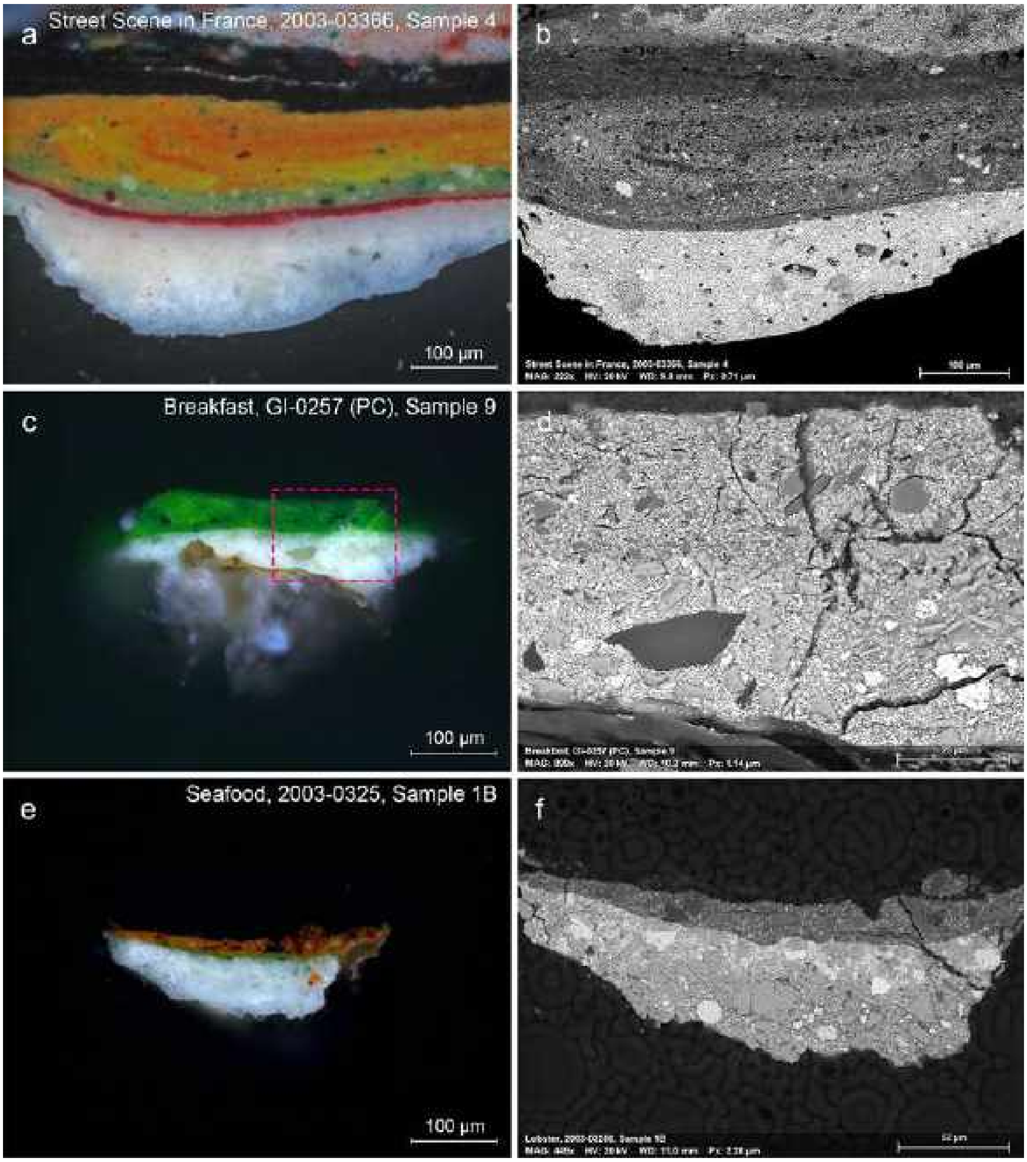


Fig. 10 Microscopy and corresponding backscattered electron (BSE) images of cross-sections with the ground layer extracted from the Paris paintings. The images show five types of identified grounds: **a**, **b** ground of type 1 with clumps of lead white (white) and fine particles of chalk; **c**, **d** 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

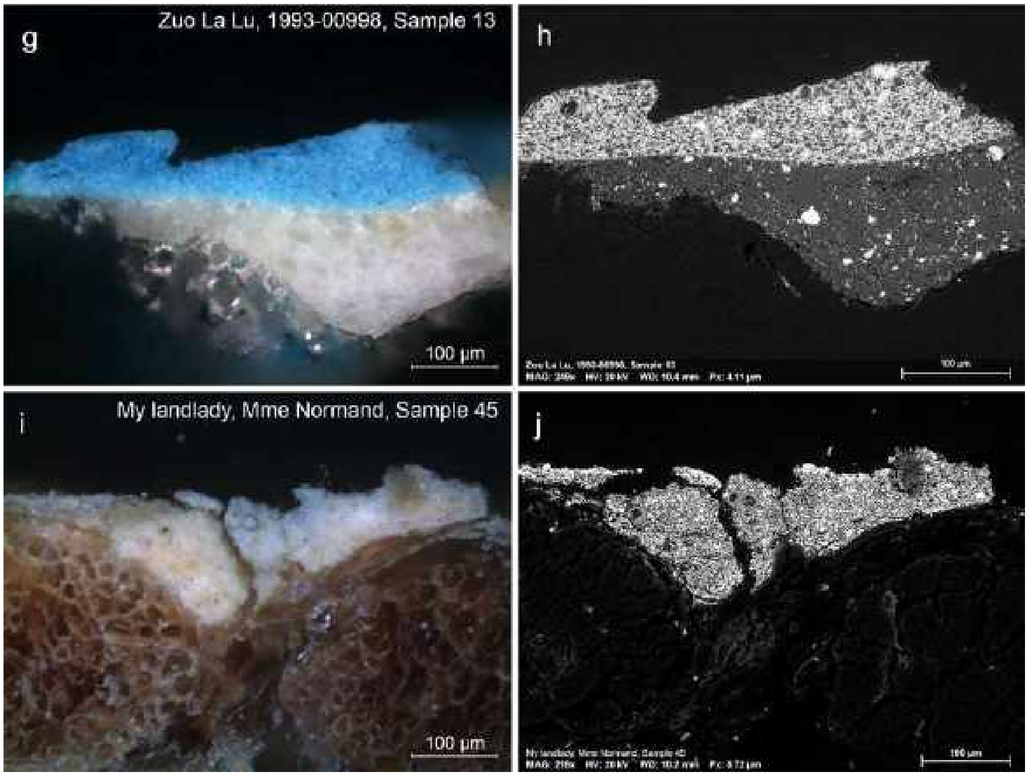


Fig. 10 continued

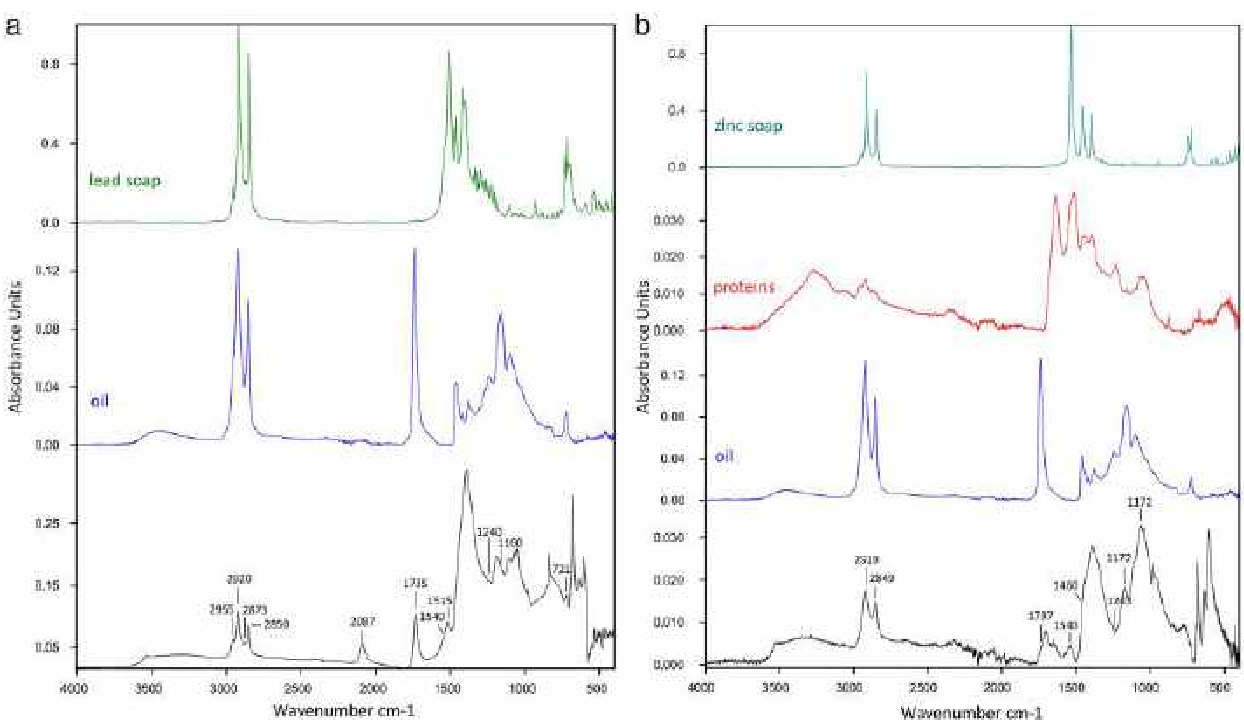


Fig. 11 ATR-FTIR spectra of grounds and reference samples of binders and metal soaps: **a** ground of type 1 from *Landscape in Switzerland*, with labelled marker peaks of oil and lead soap, peak 2087 indicates Prussian blue originating from the paint layer; **b** ground of type 2 from *Breakfast* with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

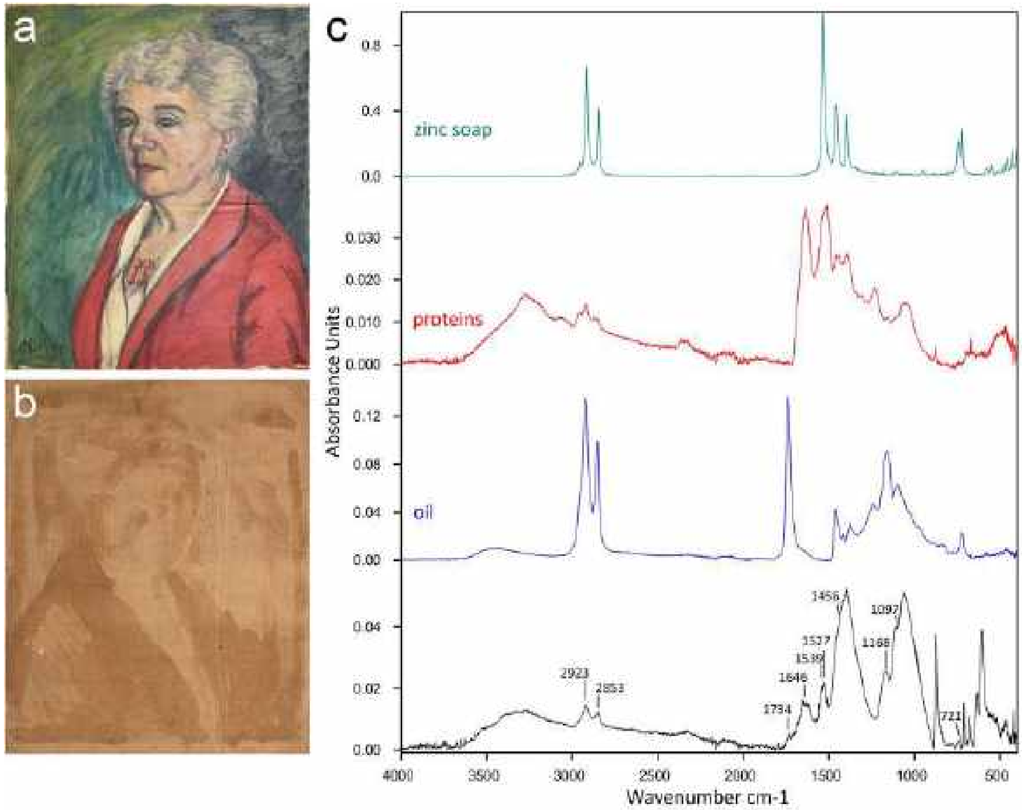


Fig. 12 Liu Kang, *My landlady, Madame Normand*, 1932, oil on canvas, 54 × 45 cm. Images of the painting photographed in normal light: **a** front; **b** reverse side. Liu Kang Family Collection. Images courtesy of Liu family. **c** ATR-FTIR spectra of a ground and reference samples, identifying proteins,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

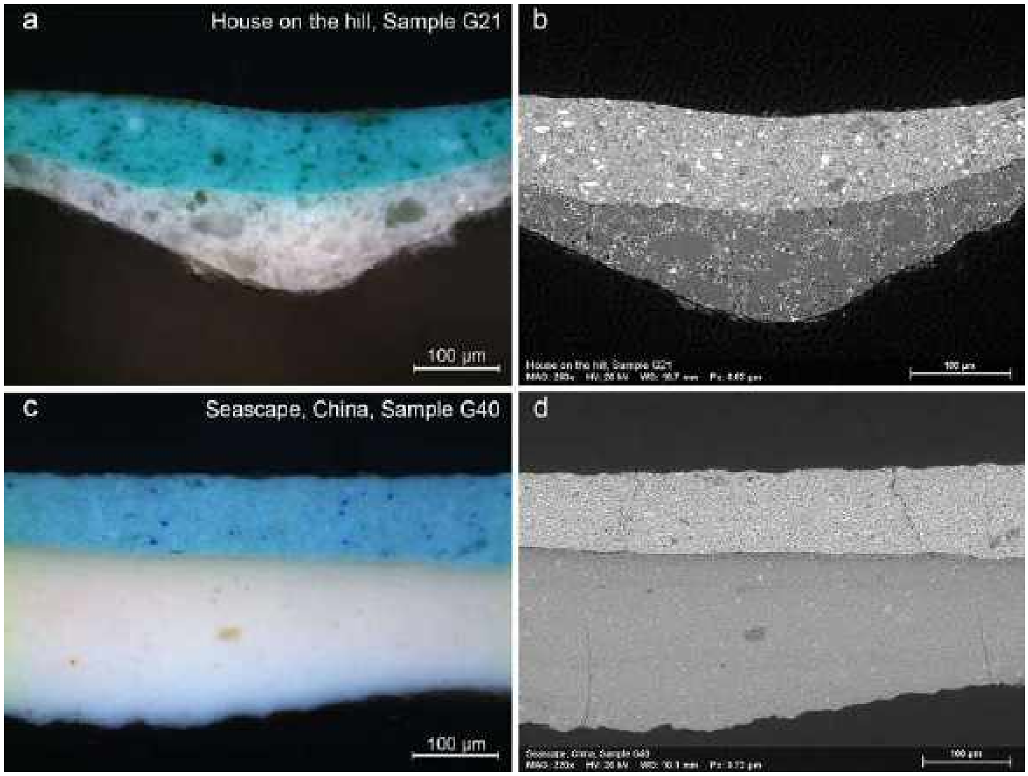


Fig. 13 Microscopy and relevant backscattered electron images (BSE) of cross-sections with ground extracted from the Shanghai paintings. The images show different types of identified grounds: **a**, **b** ground type 1 with large particles of chalk (grey); **c**, **d** ground type 2 with homogenous structure

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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Article

Exploring Liu Kang's Paris Practice (1929–1932): Insight into Painting Materials and Technique

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Abstract: This paper presents the results of an extensive study of 14 paintings by the pioneering Singapore artist Liu Kang (1911–2004). The paintings are from the National Gallery Singapore and Liu family collections. The aim of the study is to elucidate the painting technique and materials from the artist's early oeuvre, Paris, spanning the period from 1929 to 1932. The artworks were studied with a wide array of non- and micro-invasive analytical techniques, supplemented with the historical information derived from the Liu family archives and contemporary colourmen catalogues. The results showed that the artist was able to create compositions with a limited colour palette and had a preferential use of commercially available ultramarine, viridian, chrome yellow, iron oxides, organic reds, lead white, and bone black bound in oil that was highlighted. This study identified other minor pigments that appeared as hue modifications or were used sporadically, such as cobalt blue, Prussian blue, emerald green, cadmium yellow, cobalt yellow, and zinc white. With regard to the painting technique, the artist explored different styles and demonstrated a continuous development of his brushwork and was undoubtedly influenced by Modernists' artworks. This comprehensive technical study of Liu Kang's paintings from the Paris phase may assist art historians and conservators in the evaluation of the artist's early career and aid conservation diagnostics and treatment of his artworks. Furthermore, the identified painting materials can be compared with those used by other artists active in Paris during the same period.

Keywords: Liu Kang; SEM-EDS; MA-XRF; FTIR; IRFC; X-RAY; RTI; hidden paintings; pigments

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1. Introduction

Liu Kang (1911–2004) was one of the most influential figures in the early development of modern art in Singapore. He was born in Yongchun, Fujian province, China. After graduating from Xinhua Arts Academy in Shanghai in 1928, he moved to Paris, where he stayed from February 1929 to April 1932. In the early decades of the 20th century, there was a growing enthusiasm in China towards the study of Western culture. Western art appealed to Chinese educational modernisers because of its realism and supposed association with science and progress [1]. Hence, the Chinese government encouraged graduates as well as established artists to further their art education in France and to promote modernisation ideas in a rapidly transforming China upon their return [2]. Liu Kang's stay in Paris had a significant influence on his career. He attended the Académie de la Grande Chaumière in Montparnasse and studied Impressionist, Post-Impressionist, and Fauvist styles [3]. In an essay from 1970, Liu Kang made a reference to his Paris phase: "We visited fine art museums and studied the masterpieces of past generations of artists, toured famous art galleries to admire recent works by contemporary artists, and gained much from this initiation" [4].

Although his Paris paintings may seem to show a chaotic mixture of different styles at first glance, a close examination reveals a variety of influences and the search for an individual technique. Liu Kang was attracted to Post-Impressionist and Fauvist styles for their expressive use of colour and form to depict a subjective view of the world [5,6]. It is worth noting that his artistic explorations of the Western painting styles achieved some success—his works were accepted by Salon d'Automne in 1930 and 1931. The variety of styles adopted by the artist in Paris invites the question of whether he actively explored different painting materials. Hence, this study aims to characterise Liu Kang's painting technique and the pigments he used during the period under review. This study expands the scope of the earlier preliminary investigation of two of Liu Kang's paintings [7,8] and the overview of his painting supports from Paris phase [9]. The collected data contribute to the knowledge of Liu Kang's painting materials. It may be useful to art historians exploring Liu Kang's workmanship and conservators planning conservation treatments of his paintings.

2. Materials and Methods

2.1. Materials

2.1.1. Investigated Paintings

The discussion focuses on seven paintings from the National Gallery Singapore (NGS) and six paintings from the Liu Kang Family Collection (Figures 1 and 2). The inclusion of the paintings from the Liu collection ensured that the overall research base represents a range of the artist's genres and painting technique during the period from 1929 to 1932. It needs to be noted that the Paris phase also includes artworks he painted during a trip to Saint Gingolph on the French–Swiss border between 8 August and 20 September 1929 [10]. The painting supports of the investigated artworks are not in the scope of this research as a comprehensive study of the supports was carried out earlier [9].

2.1.2. Samples

A total of 59 samples of the paint layer were collected only from the NGS paintings (Figure 1). There was no intention of carrying out any invasive sampling procedures on the paintings from the Liu collection.

2.2. Methods

The range of the applied analytical methods differed between the NGS and Liu collections, mainly due to the Liu family's wish to conduct only non-invasive in situ examination of their paintings. Thus, only visible light (VIS) photography of the characteristic features of the paint layers was conducted on paintings from the Liu collection to provide further insights into the artist's painting technique. The NGS paintings were studied first by means of non-invasive imaging techniques, comprising VIS, ultraviolet fluorescence (UVF), reflected ultraviolet (UVR), and near-infrared (NIR) photography. The aim of these non-invasive techniques was to conduct a preliminary characterisation of the pigments by recording their optical features under different wavelengths of the electromagnetic spectrum. An investigation of the paint textures was conducted with reflectance transformation imaging (RTI). To verify the presence of underlying paint layers, NIR and X-ray radiography (XRR) were carried out. The obtained results guided a sampling of the paint layers from the areas with prior loss, for characterising the paint mixtures in detail. Thus, the samples were analysed using optical microscopy (OM), polarised light microscopy (PLM), and field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS). A handheld portable X-ray fluorescence (XRF) was used to analyse some areas of the *Countryside in France* where sampling was not safe. A macro X-ray fluorescence (MA-XRF) scanner was engaged to perform the elemental mapping of *Landscape in Switzerland* and to support interpretation of data collected from the painting. The initial indication of the organic components of the paint samples was given by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR). The results are summarised in Appendix A, Table A1.

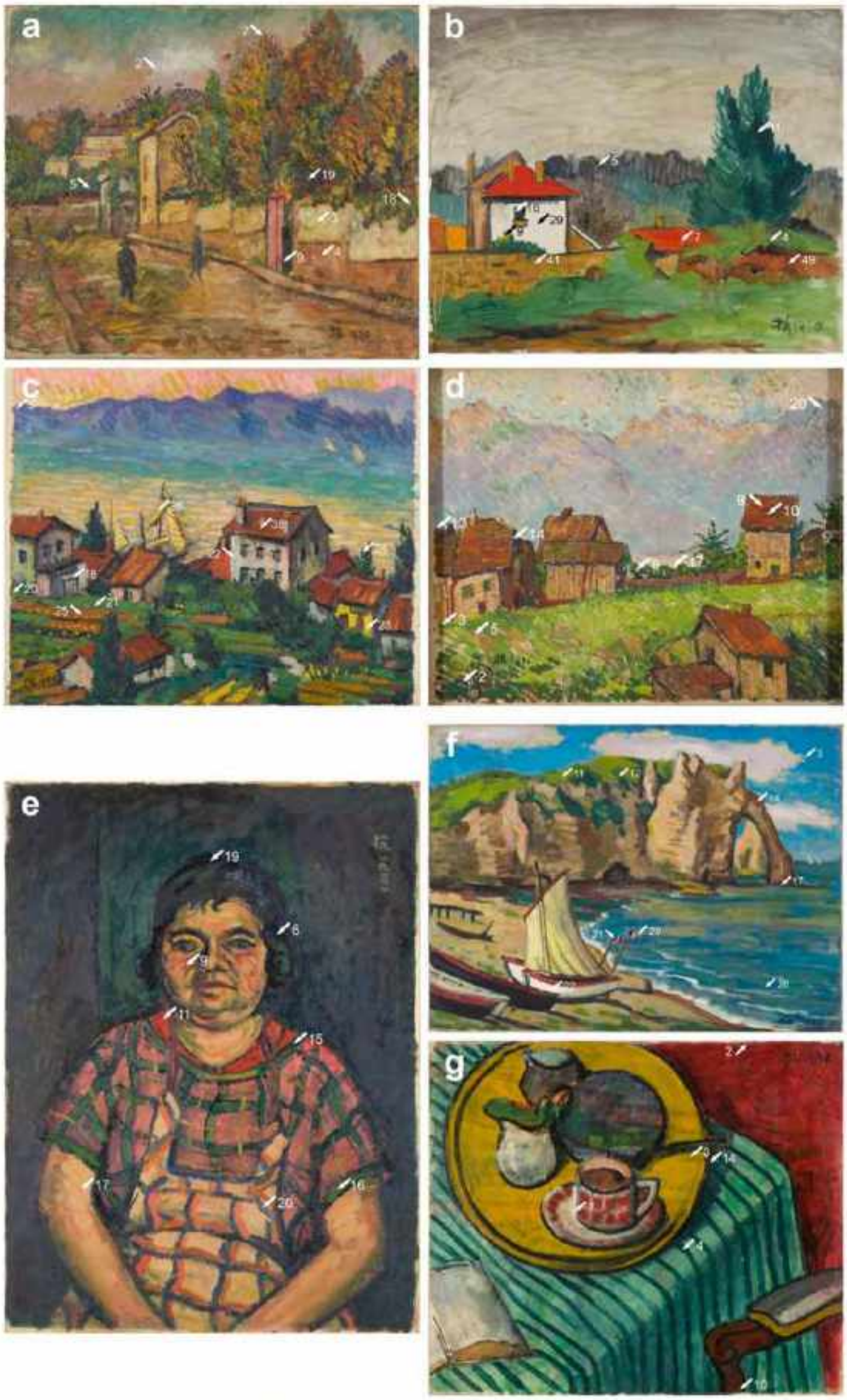

Figure 1. Paintings by Liu Kang from the collection of National Gallery Singapore: (**a**) *Autumn colours*, 1930, oil on canvas, 38.3 × 45.3 cm; (**b**) *Countryside in France*, 1930, oil on canvas, 46 × 54.7 cm, gift of the artist's family; (**c**) *Landscape in Switzerland*, 1930, oil on canvas, 45.6 × 55.7 cm, gift of C Y Hwang; (**d**) *Village scene*, 1931, oil on canvas, 46 × 55 cm, gift of the artist's family; (**e**) *French lady*, 1931, oil on canvas, 60.7 × 45.8 cm; (**f**) *Boat near the cliff*, 1931, oil on canvas, 53.7 × 72.4 cm, gift of the artist's family; and (**g**) *Breakfast*, 1932, oil on canvas, 46 × 54 cm. Images courtesy of National Heritage Board. White arrows indicate sampling areas.

Figure 2. Paintings by Liu Kang from the Liu Kang Family Collection: (**a**) *St Gingolph, Lac Leman, Switzerland*, 1929, oil on canvas, 45.5 × 37.5 cm; (**b**) *Landscape*, 1930, oil on canvas, 46 × 38 cm; (**c**) *Still life with books, Paris*, 1931, oil on canvas, 45 × 38 cm; (**d**) *Portrait of a man with his pipe, Paris*, 1931, oil on canvas, 45 × 38 cm; (**e**) *Self-portrait*, 1931, oil on canvas, 55 × 46 cm; and (**f**) *My landlady, Madame Normand*, 1932, oil on canvas, 54 × 45 cm. Images courtesy of Liu family.

2.2.1. Technical Photography

High-resolution technical images were acquired according to the workflow proposed by Cosentino [11–13]. A Nikon D90 DSLR modified camera with a sensitivity of between about 360 and 1100 nm was used. The camera's white balance preset for VIS photography was created with the X-Rite White Balance Target. The American Institute of Conservation Photo Documentation target was used to additionally finetune the white balance and determine optimum exposure for the VIS imaging. The photographs were shot RAW and further processed by Adobe Photoshop CC according to the standards described by the American Institute of Conservation [14].

VIS and UVF photography at 365 nm were taken with X-Nite CC1 and B + W 415 filters mounted together. NIR photography at 1000 nm, with an additional aim of false-colour infrared imaging (IRFC), was taken with Heliopan RG1000. UVR photography was achieved with Andrea "U" MK II filter.

A pair of 500 W halogen lamps were used for the VIS and NIR illumination system. The light source for UVF and UVR imaging consisted of two lamps equipped with eight 40 W 365 nm UV fluorescence tubes.

2.2.2. RTI

RTI was carried out according to the workflow proposed by the Cultural Heritage Imaging [15]. The images were processed using Adobe Photoshop CC, followed by RT-IBuilder and RTIViewer software, as proposed by the Cultural Heritage Imaging [16,17].

2.2.3. XRR

The paintings from the NGS collection were digitally XRR using a Siemens Ysio Max digital XRR system with a detector size of 350 × 430 mm and a resolution of over 7 million pixels. The X-ray tube operated at 40 kV and 0.5–2 mAs. The images were processed with iQ-LITE imaging software and then exported to Adobe Photoshop CC for final alignment and merging.

2.2.4. XRF

XRF measurements were performed using Thermo Scientific™ Niton™ XL3t 970 spectrometer with a GOLDD+ detector and an Ag anode X-ray tube with a 6–50 kV voltage and up to 0.2 mA current. A mining mode with four elemental ranges and a measurement duration of 50 s each (total acquisition time of 200 s) was used to better differentiate the light elements from the heavy ones. The spectra were collected from a 3 mm diameter spot size. The acquired spectra were collected and processed using Thermo Scientific™ Niton Data Transfer (NDT™) 8.4.3 software.

2.2.5. MA-XRF

The elemental mapping of *Landscape in Switzerland* was conducted with the M6 Jet-stream from Bruker Nano GmbH. The instrument's measuring head is equipped with a Rh-target microfocus X-ray tube (30 W, maximum voltage of 50 kV, maximum current of 0.6 mA), and a 30 mm^2 active area XFlash Silicon Drift Detector (energy resolution of $<$145 eV for Mn-Kα). The measuring head is mounted on an X-Y-Z motorised stage with a maximum travel range of 800 × 600 × 90 mm. The instrument offers an adjustable spot size from 100 μm to approximately 500 μm [18]. The paintings' elemental distribution maps were acquired with a dwell time of 10 ms/pixel, a pixel size of 300 μm, and an anode current of 599 μA. The data were collected and analysed with the Bruker's M6 software.

2.2.6. FE-SEM-EDS

The paint samples' cross-sections were mounted on carbon tapes and examined with a Hitachi SU5000 FE-SEM coupled with Bruker XFlash® 6/60 EDS. The SEM, backscattered electron mode (BSE) was operated with 60 Pa chamber pressure, accelerating voltage of

20 kV, 50–60 intensity spot and a working distance of 10 mm. The acquisition of data and processing were performed using the Bruker ESPIRIT 2.0 software.

2.2.7. ATR-FTIR

ATR-FTIR analyses were performed using a Bruker Hyperion 3000 FTIR microscope equipped with a mid-band MCT detector, coupled to a Vertex 80 FTIR spectrometer. For each sample, 64 scans were recorded in the spectral range of 4000–600 cm^{-1} and resolution of 4 cm^{-1}. The spectra were interpreted with Bruker Opus 7.5 software.

2.2.8. OM and PLM

The samples' structure was studied in reflected VIS and UV light on a Leica DMRX polarised microscope at magnifications of ×50, ×100, ×200, and ×400 coupled with a Leica DFC295 digital camera. PLM was carried out in transmitted VIS light at magnifications of ×100, ×200, and ×400 using the methodology developed by Peter and Ann Mactaggart [19].

2.2.9. Preparation of Samples

The samples selected for the cross-sections were embedded in a fast-curing acrylic resin, ClaroCit from Struers (Cleveland, OH, USA), and fine polished. The PLM pigment dispersions were prepared with a Meltmount nD = 1.662 mounting medium from Cargille (Cedar Grove, NJ, USA).

2.3. Archival Sources

The technical examination of paintings was supplemented with materials from the Liu family archives to elucidate the artist's painting practice. These materials include Liu Kang's photographs, watercolours artwork, and a Lefranc artists' colourmen price list of oil colours from October 1928. The latter may reflect the artist's interest in Lefranc colours as he had brought the price list home [8]. However, firm conclusions about any links between the Lefranc colours and materials used by Liu Kang should not be made due to weak evidence at the current stage of the research. From observing the advertisement sections of Le Salon's 1930 and 1932 exhibition catalogues [20,21] and Salon des indépendants 1930 [22], it is deducible that Liu Kang might have had access to a great range of painting materials from other local manufacturers and retailers [9]. He also might have had an opportunity to purchase the overseas brands from retailers, such as Lechertier Barbe LTD, Paris American Art Co., and S. C. & P. Harding (Paris) LTD (Figure 3). The advertisements of these retailers listed a selection of local brands such as Lefranc, Bourgeois Ainé, as well as imported materials from Rowney, Winsor & Newton (W&N), Talens, and Schmincke. While it remains uncertain what brand of colours the artist used, some references are made to the contemporary colourmen catalogues, such as the W&N catalogue from 1928, Lefranc catalogues from 1928 to 1931, and Bourgeois Ainé catalogue from 1929 to provide insights into the availability of certain pigments that are found in the paintings under investigation.

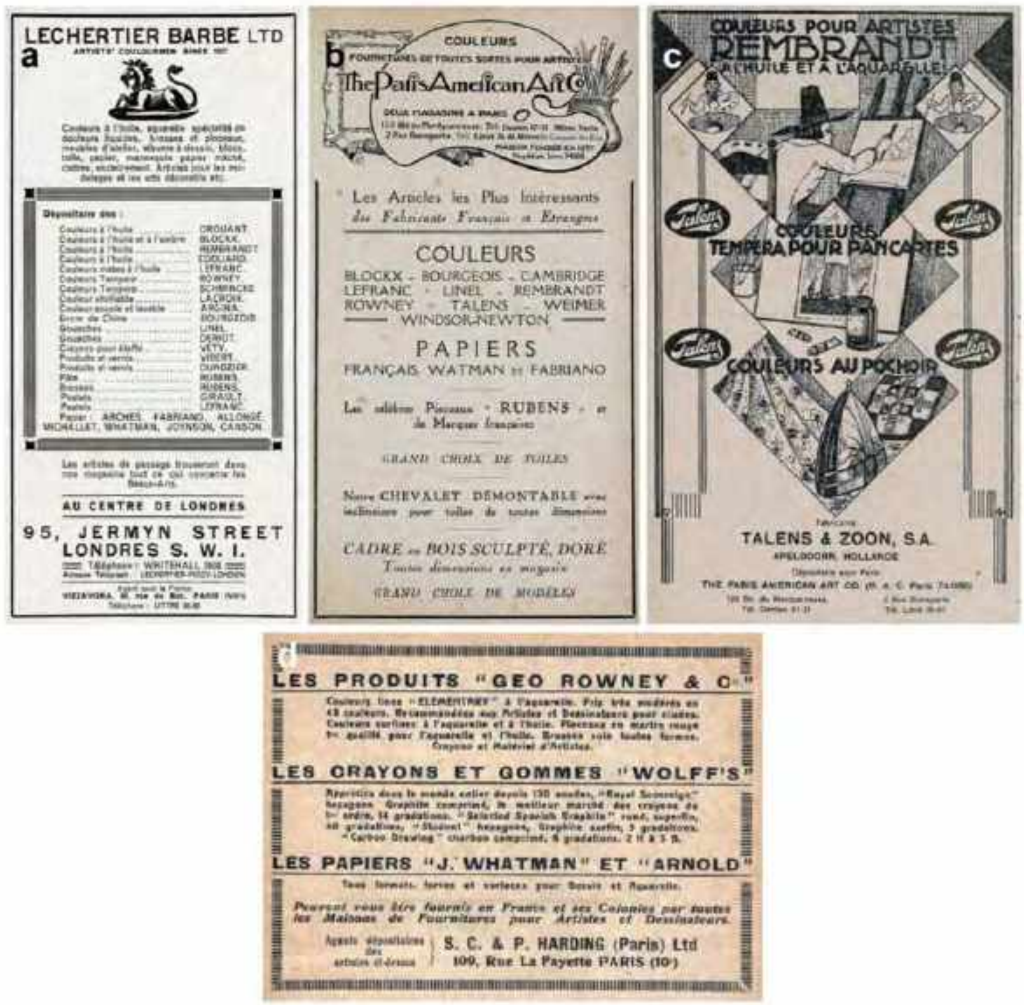

Figure 3. Advertisements by official retailers of local and overseas art materials, available in Paris in 1930 and 1932: (**a**) Lechertier Barbe LTD; (**b**) Paris American Art Co.; (**c**) Talens and Zoon, S.A. advertisement indicating Paris American Art Co. as its Paris representative; and (**d**) S. C. & P. Harding (Paris) LTD.

3. Results and Discussion

3.1. Pigments

3.1.1. Blue

Blue painted areas of the examined paintings are very often imaged purple in an IRFC, suggesting a use of ultramarine and/or co-containing blue. The analyses confirmed that the different blue hues primarily involve ultramarine (sulphur-containing sodium aluminium silicate), observed with PLM by particles with low refractive index that appear red with Chelsea filter and by SEM-EDS detection of Na, Al, Si, and S. Admixtures of viridian (hydrated chromium oxide) were confirmed by the detection of Cr and coincident PLM observation of large and rough particles with high refractive index. The presence of ultramarine and viridian is compliant with the purple appearance of the paint mixture in IRFC. Admixtures of cobalt blue (cobalt aluminium oxide) were confirmed with SEM-EDS by the concomitant presence of Co and Al as well with PLM (particles with a high refractive index that appear red with Chelsea filter) in *Boat near the cliff* (sample 26) and *French lady* (sample 20). Very dark blue in *Countryside in France* (sample 5) was probably made by mixing ultramarine with carbon black. It is worth noting that no Prussian blue (hydrated iron hexacyanoferrate) was found in the investigated blue mixtures, despite its discovery in the earlier study [7]. Prussian blue is known for its high tinting strength, which may be easy for artists to handle. It also produces dark greenish-blue shades that Liu Kang probably did not find suitable for painting sky or water. He might also be aware of the Prussian blue's tendency to fade or change in colour over time [23,24].

In almost all examined blue paint samples, except those from *Landscape in Switzerland* and *Boat near the cliff*, a high concentration of Pb seems to point to the consistent use of lead white (lead carbonate) for achieving lighter tints. Meanwhile, the presence of Ba, S, and Zn elements could be related to lithopone (a mixture of barium sulfate and zinc sulfide) and/or zinc white (zinc oxide) and barium white (barium sulfate), a common extender for lead white [25] as well as for viridian [26].

3.1.2. Green

The acquired PLM and SEM-EDS data revealed that viridian was Liu Kang's consistent choice for green. However, it is very often present in combination with other pigments. For instance, positive identification of emerald green was possible in sample 18 from *Autumn colours* with SEM-EDS detection of Cu and As elements and with FTIR by absorption bands at 1555, 1451, 816, 762, 690, and 635 cm^{-1} (Appendix A, Figure A1) [27]. However, based only on the concomitant presence of Cu and As, elements in other green paint mixtures, emerald green (copper acetoarsenite), and/or Scheele's green (copper arsenite) were considered.

According to Bourgeois Ainé and Lefranc's catalogues of oil paints, *Vert Veronese* (emerald green), *vert de Scheele* (Scheele's green), and its variant, *vert minérale*, were available during that time in Paris (Appendix A, Figures A3 and A4). Emerald green was also offered by W&N (Appendix A, Figure A2). Although it is known that some grades of emerald green were commercially adulterated with chromium pigments [28,29], MA-XRF distribution maps of Cr and Cu elements from *Landscape in Switzerland* showed only a partial co-location of Cu and Cr in the green areas (Figure 4). Hence, it could be said that the Cu–As-based green was not modified by the manufacturer but deliberately mixed with viridian where it suited the artist.

The analyses of the light and warm green hues of the investigated paintings confirmed a consistent use of chrome yellow (lead chromate) as an admixture of viridian. This can be exemplified by sample 3 from *Village scene* (Figure 5a). In this sample, besides viridian, chrome yellow was detected with PLM by anisotropic, rod-shaped particles with a high refractive index. The SEM-EDS analyses of the green and yellow clusters of not properly mixed paint indicated a varied intensity of Pb-, Ca-, and Cr-peaks contributing to viridian and chrome yellow, probably extended with chalk (calcium carbonate) or calcium chromate [30]. The presence of viridian in the examined paint is in agreement with the purple imaging of the sampling area (Figure 5b,c).

The co-location of Cr- and Cd-signals recorded with MA-XRF of *Landscape in Switzerland* (Figure 4) suggested an addition of cadmium yellow (cadmium sulfide) to viridian. This observation was corroborated with red UV fluorescence of the yellow particles [11], SEM-EDS detection of strong Cd- and S-signals, and PLM observation of sample 21 from *Landscape in Switzerland* (yellow, anisotropic particles with a high refractive index turn green in crossed polarised filters) (Figure 6). However, the presence of S, Ba, and Zn in the investigated mixture may suggest that, instead of pure cadmium yellow with lithopone and/or zinc and barium whites, zinc-modified light cadmium yellow or cadmopone (co-precipitated cadmium sulfide and barium sulfate) was used [31]. A high concentration of Pb in most of the examined light-green samples may suggest concurrent admixtures of chrome yellow and/or lead white to viridian. A combination of viridian and lead white to obtain a light-green tone was detected in *Breakfast* (sample 4). Meanwhile, strong Zn-signals recorded in the light-green brushstrokes of *Landscape in Switzerland* (sample 20) and *Boat near the cliff* (sample 11) suggest an admixture of lithopone and/or barium white and zinc white.

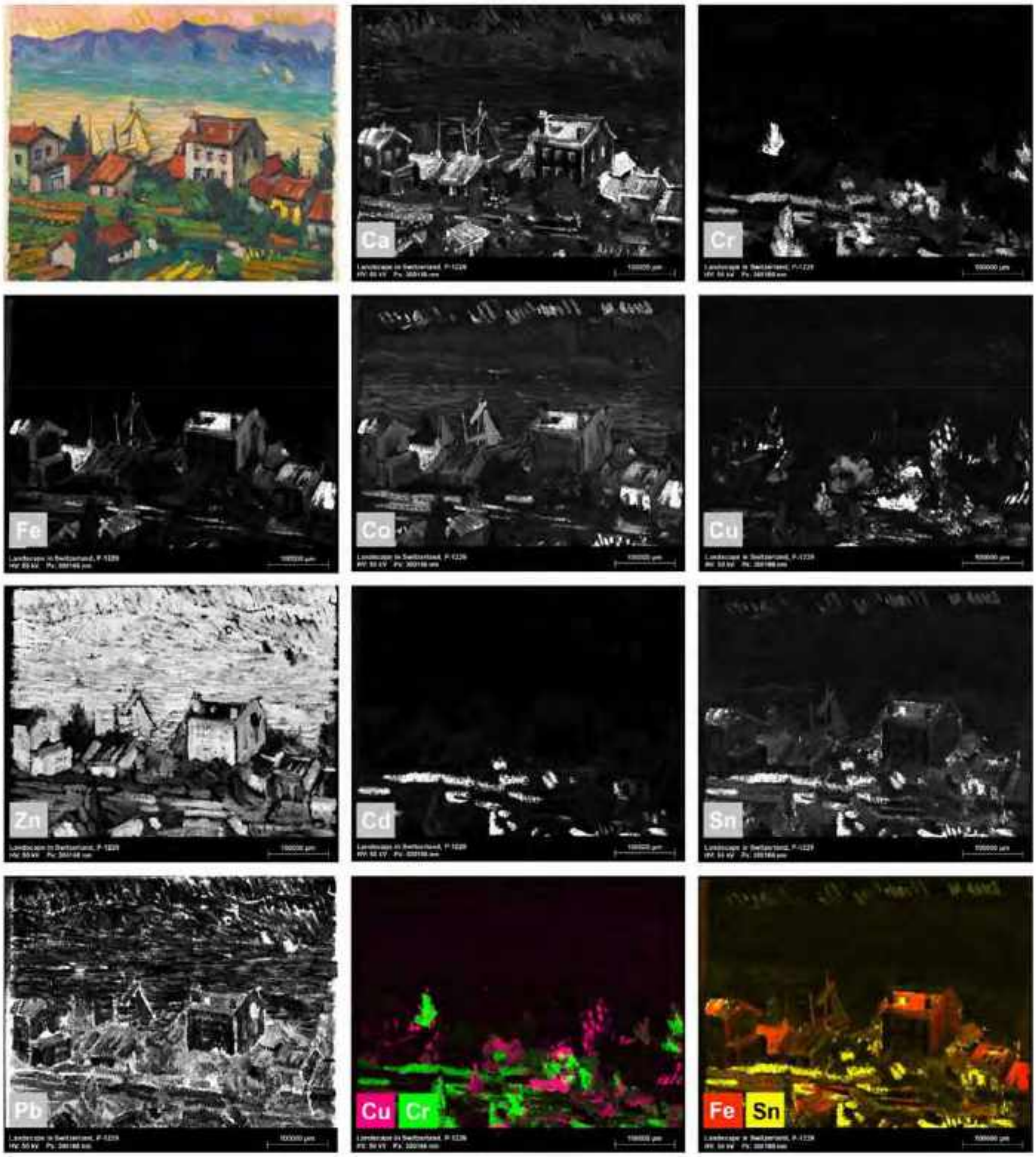

Figure 4. Visible light image and MA-XRF maps of *Landscape in Switzerland*, showing the distribution of the major elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. The colour maps combine distribution of Cu- and Cr-based pigments and Fe- and Sn-based pigments.

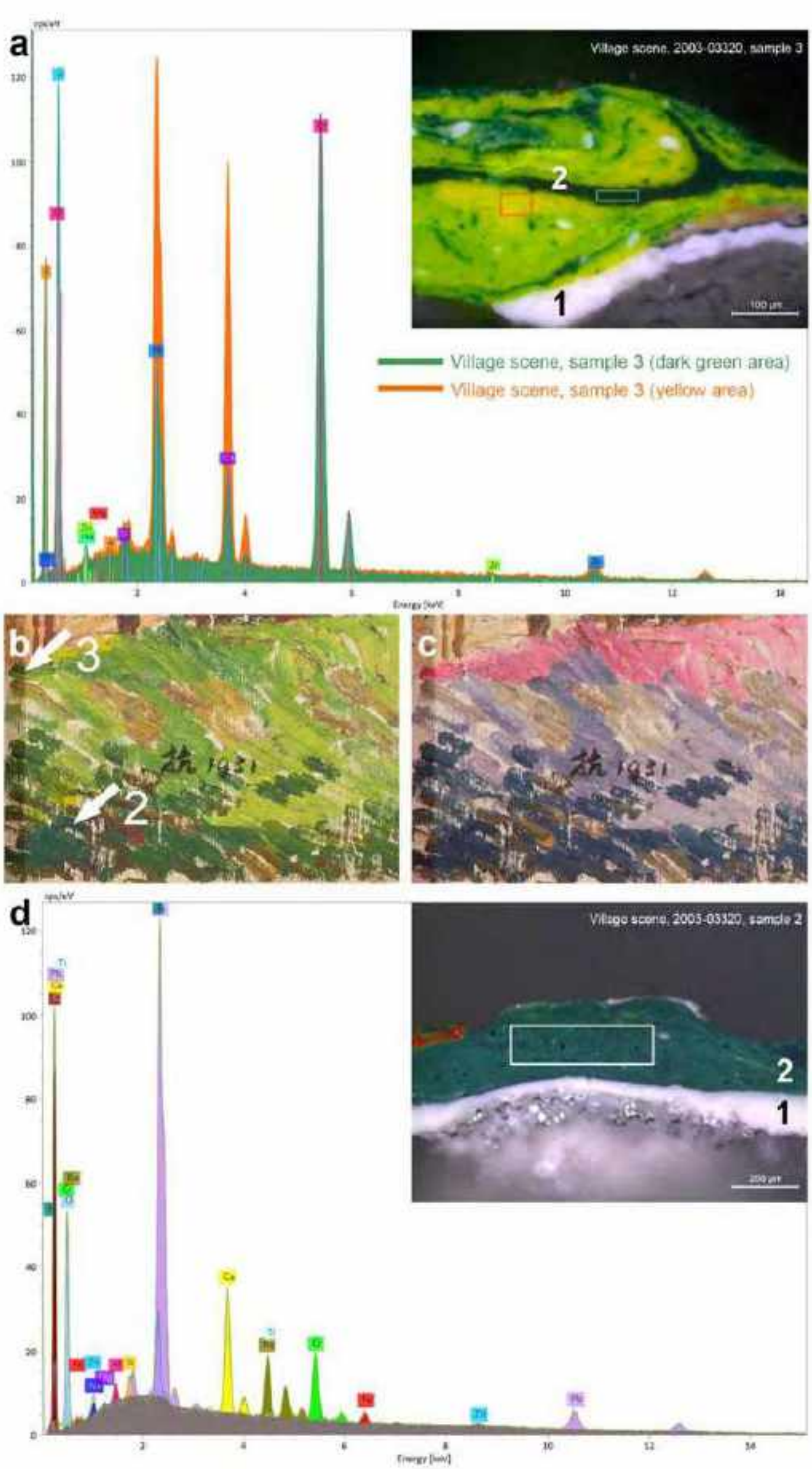

Figure 5. SEM-EDS spectra of: (**a**) green and yellow areas in sample 3 extracted from *Village scene* and inset microscopy image of the cross-section with marked areas of analyses; (**d**) dark-green paint from sample 2 extracted from the same painting and inset microscopy image of the cross-section with the marked area of analysis. The detail of the painting shows the sampling spots (**b**) and infrared false-colour image of the same areas, revealing the distribution of viridian (purple) and the mixture of Prussian blue with viridian and lead white (tints of violet) (**c**).

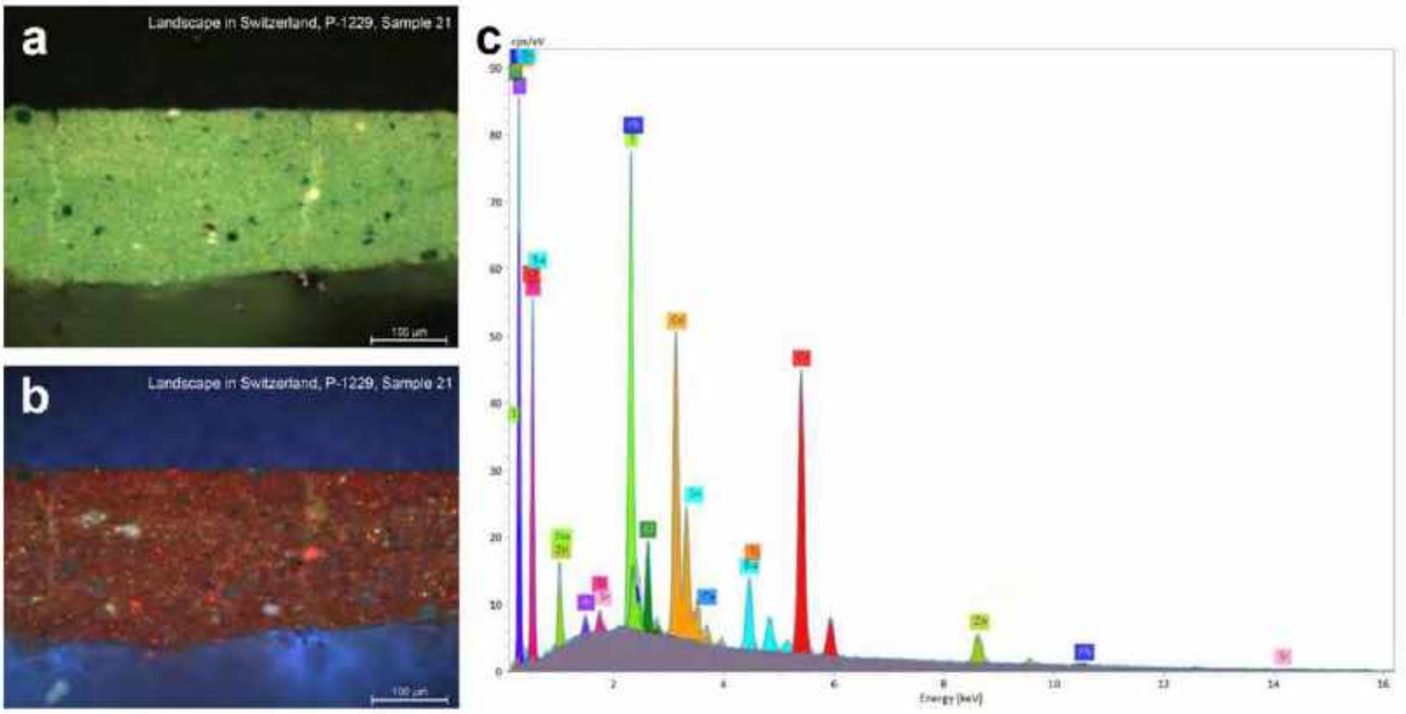

Figure 6. Microscopy images of the cross-section of sample 21, extracted from *Landscape in Switzerland*, photographed in: (**a**) VIS; (**b**) UV. The corresponding SEM-EDS spectra of the green paint are seen in (**c**). Red fluorescence of yellow particles and a strong Cd-signal suggested the presence of cadmium yellow.

Based on the SEM-EDS and PLM analyses, dark green was very often achieved by mixing viridian with Prussian blue in combination with lead white and/or chrome yellow. This can be exemplified by sample 2 in *Village scene* (Figure 5d). The SEM-EDS analysis of the dark-green paint revealed that it is rich in lead, chromium, and iron, which can be assigned to lead white, viridian, and Prussian blue. The latter was observed with PLM by dark-blue isotropic particles with a low refractive index that appear dark green with a Chelsea filter. This pigment mixture is consistent with the IRFC imaging, as the dark-violet colour is determined by the purple representation of viridian, combined with a dark-blue representation of Prussian blue (Figure 5b,c). A similar pigment mixture was identified with PLM and SEM-EDS in dark-green paint from *Countryside in France* (sample 11). However, FTIR did not depict any peaks attributable to viridian due to overlapping bands of other compounds; the most intensive peaks of this pigment fell in the range of 500–400 cm^{-1}, behind the spectral range of the measurement. Although the artist did not employ Prussian blue in the blue painted areas, he preferred it for his hue modification of the green colours. Interestingly, in *French lady* (sample 15), in addition to Prussian blue, a cobalt blue was added to the green paint to produce the desired hue.

The green colour, obtained by mixing blue and yellow, was found in *Landscape in Switzerland* (sample 20). The green sampling area appears blue in the IRFC, suggesting the presence of Prussian blue. The SEM-EDS detection of Pb, Cr, and Fe elements, combined with PLM and FTIR analyses, confirmed chrome yellow by absorption peaks at 1061, 967, 826, and 626 cm^{-1} and Prussian blue by absorption peak at 2086 cm^{-1}. The paint mixture also contains yellow iron oxide observed with PLM (anisotropic yellow particles with a high refractive index). However, its FTIR confirmation was inconclusive due to overlapping bands of chrome yellow. Moreover, there is a possibility that the artist used a commercial chrome green composed of Prussian blue and chrome yellow [26,32]. Such composite paint was available from Bourgeois Ainé in three different hues and from Lefranc in five hues under the name of *vert anglais* (Appendix A, Figures A3 and A4). It was also listed by

W&N as chrome green, available in three hues, and as cinnabar green, available in five hues (Appendix A, Figure A2).

3.1.3. Yellow

The analyses of the samples of yellow paints revealed the use of four different yellow pigments, but it is evident that chrome yellow was a prevailing pigment. It was identified as a principal component of sample 9 from *Countryside in France* and sample 8 from *Village scene*. It appears as an ingredient found together with yellow iron oxide in *Autumn colours* (sample 3) and *Breakfast* (sample 3). Nevertheless, it is difficult to ascertain if chrome yellow and iron oxide were deliberately mixed by the artist on the palette or commercially prepared. It is known that the ochres were tinted during the manufacturing process with the addition of chrome yellow [30,33], which also has its own extenders, such as barium white, gypsum, kaolin, and calcium chromate [30].

Analyses of the yellow paint mixture from *Landscape in Switzerland* (sample 23) allowed features consistent with cadmium yellow or its variants—light cadmium yellow or cadmopone—to be detected. As visualised by the MA-XRF Cd-distribution map, a usage of this pigment for painting yellow areas was very limited; however, it occurs extensively as an admixture in light-green passages (Figure 4).

The SEM-EDS detection of Co and K in the samples of yellow paint from *Landscape in Switzerland* (samples 23, 36) allowed their attribution to cobalt yellow (potassium cobaltinitrite), later confirmed with PLM by observation of isotropic, yellow, and dendritic particles with a high refractive index (Figure 7). The use of cobalt yellow by Liu Kang seems to be unusual as the pigment is known for its undesirable low hiding power in oil medium. Therefore, its main application was usually a watercolour technique [34,35]. Cobalt yellow was available from Bourgeois Ainé and Lefranc only as a dry pigment and in watercolour and gouache paints. However, it appears in W&N catalogues of oil paints (Appendix A, Figure A2).

Figure 7. Cobalt yellow particles from sample 23, extracted from *Landscape in Switzerland*, photographed in plane-polarised light.

3.1.4. Brown

Brown passages were painted using predominantly brown and yellow iron oxides. Lighter tints were produced with a small addition of lead white and/or Cr-containing yellow(s). Darker-brown brushstrokes in *Boat near the cliff* (sample 14) contain Ca and P elements that can be assigned to bone black admixture, confirmed with PLM (anisotropic black and grey particles). In addition, the co-location of Fe and Mn recorded with SEM-EDS suggests the presence of umber. The SEM-EDS and PLM of the dark-brown colour from the armrest of the chair in *Breakfast* (sample 10) suggested a mixture of red iron oxide with Prussian blue and organic red pigment (unique low refractive index). FTIR completed this outcome by detecting of some absorption bands indicative of organic red at 1656, 1623, 1545, 1451, and 1270 cm^{-1}. However, more peaks typical for organic red fall in the range from 1200 to 1000 cm^{-1} and were interfered by the presence of red iron oxide. In addition, the paint mixture contains a good deal of starch grains with an extinction cross, which were visible in cross-polarised light (Figure 8a–d). However, FTIR measurements detected only one peak at 3270 cm^{-1} that is related to starch, while further identification was hampered by the intensive peak of red iron oxide at 1005 cm^{-1} and overlapping characteristic bands of starch at 1014 and 995 cm^{-1}. Starch was frequently added to the organic reds during the manufacturing process to improve its handling properties and to obtain a lighter tint [36,37]. The PLM and FTIR analyses of the paint sample correlate with the occurrence of Sn, detected with SEM-EDS, suggesting the presence of a tin-containing substrate for the organic red, which was usually cochineal lake or brazilwood lake pigment (Figure 8e) [38,39]. A composition containing alizarin crimson and brazilwood on starch and tin substrates was reported in the earlier study of Liu Kang's painting [8]. Lefranc listed a tin-containing organic red *laque anglaise* composed of *carmin* and *oxyde d'etain* (tin oxide); it was one of the most expensive, priced at 22 francs for a No. 6 tube and 9.50 francs for tube No. 2, whereas blanc d'argent (lead white) was at 3.75 francs for a tube No. 6. (Appendix A, Figure A4). *Laque anglaise* from Bourgeois Ainé had a comparable price (Appendix A, Figure A3).

3.1.5. Red

The analytical results showed that Liu Kang employed three types of organic red pigments in most of the examined paintings. They were used as primary reds or in combination with other pigments added to modify hue. An Sn-containing organic red on starch substrate was confirmed with SEM-EDS, PLM, and FTIR in *Village scene* (sample 9) and *Landscape in Switzerland* (sample 35, layer 1) and resembled the aforementioned mixture from *Breakfast* (sample 10).

The FTIR of sample 9 from the *Village scene* showed low intensity peaks at 1562 and 1545 cm^{-1}, which are indicative of organic red; however, an in-depth molecular characterisation was not possible due to overlapping signals of other compounds present in the investigated sample. A similar issue concerns the identification of starch. Although starch was well observed with PLM, only two FTIR peaks, at 3280 and 1649 cm^{-1}, were considered conclusive. Additionally, detection of Fe and co-location of Pb-, Cr-, and Ca-signals, suggested that an organic red was used in a combination with red iron oxide (absorption peaks at 1026, 1007, 935, 911, 798, 777, and 753 cm^{-1}), chrome yellow (absorption peaks at 1031, 844, 834, and 624 cm^{-1}), chalk (absorption peaks at 1410, 870, and 712 cm^{-1}), and probably lead white (1410 and 677 cm^{-1}) (Figure 9).

The sample 35 from *Landscape in Switzerland* contains two distinguishable layers. Based on the PLM, SEM-EDS, and FTIR, the top red is composed mainly of red iron oxide with an admixture of Sn-containing organic red, detected by absorption peaks at 1620, 1563, 1555, 1529, 1471, 1290, 1265, 1246, and 588 cm^{-1}, and chalk. This top layer was applied over dry paint predominantly consisting of the organic red, detected by peaks at 1621, 1562, 1552, 1531, 1310, 1265, 1247, and 604 cm^{-1}. In addition, a presence of starch was confirmed with PLM observation and FTIR by absorption peaks at 3294, 1639, 1370, 1341, 1247, 1204, 1150, 1077, 1016, 931, 861, 759, and 704 cm^{-1}, while Sn-based substrate was confirmed with the SEM-EDS. Moreover, the analysed paint contains some admixtures of lead white and probably Cr-containing yellow(s) (Figure 10). The MA-XRF map of Sn distribution in *Landscape in Switzerland* shows that some passages were initially painted with a heavy use of Sn-containing organic red (Figure 4) and finally covered with different colours as visualised on the cross-section of sample 25 (Figure 11).

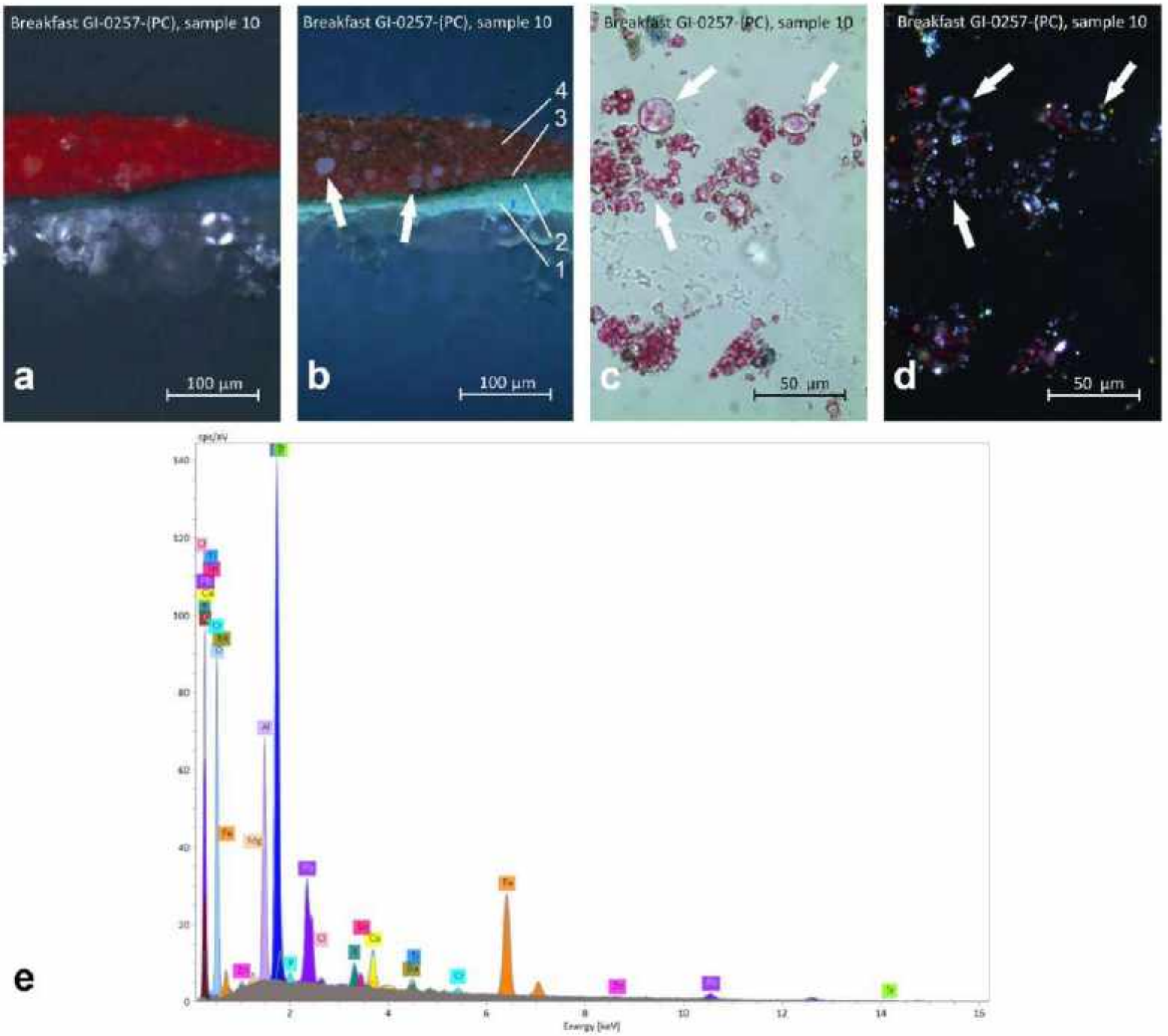

Figure 8. Microscopy images of the cross-section of sample 10, extracted from *Breakfast*, photographed in: (**a**) VIS; (**b**) UV. Circular, blue-fluorescing particles of the starch substrate are visible in layer 4 and marked with arrows (**b**). The PLM pigment dispersion from layer 4 is photographed in: (**c**) plane-polarised light; (**d**) cross-polarised light. The clumps of starch particles are marked with arrows. The corresponding SEM-EDS spectra of the red paint from layer 4 (**e**) shows a strong Sn-signal, suggesting the presence of tin substrate.

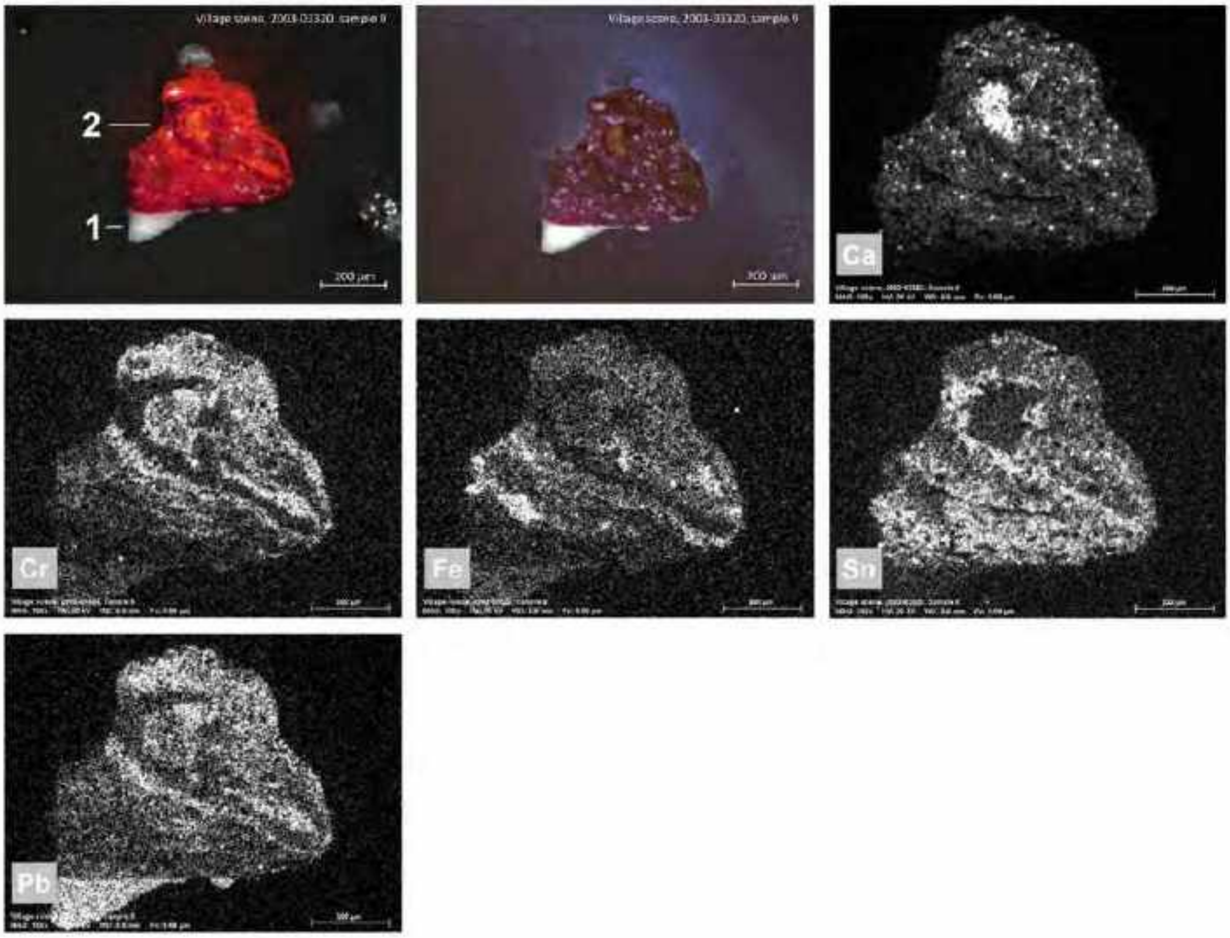

Figure 9. Microscopy image of the cross-section of sample 9 extracted from *Village scene*, photographed in VIS and UV, followed by SEM-EDS maps showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. A high intensity of Sn can be assigned to the tin substrate of organic red while the co-location of Ca-, Cr-, and Pb-signals in the centre of layer 2 suggests the presence of chrome yellow.

Another organic red was detected in *Boat near the cliff* (sample 29). PLM allowed the observation of red particles with a low refractive index, which is characteristic of organic reds. An intense orange fluorescence in UV light (Figure 12b) suggests natural madder [38]; however, the SEM-EDS detection of bromine, based on Br $L\alpha_1$ and Br $K\alpha_1$ signals (Figure 12c), indicates that the red may be a compound related to eosin red—commercially known as geranium lake—which is also characterised by the orange UV fluorescence [40–42]. A comparison of the FTIR spectra of the investigated red with the reference sample of eosin Y revealed some degree of matching. Typical FTIR features consistent with the organic red were identified by absorption bands at 3335, 1561, 1455, 1345, 1221, 1174, 981, 877, 802, 766, 717, 667, and 634 cm^{-1}. However, the overlapping bands at 1455, 1174, 981, 802, 717, and 634 are also attributable to lithopone and/or barium white, oil, and acrylic resin, the latter of which is considered to be a varnish and applied during the conservation treatments in 2006 (Figure 13) [43]. Other elements present in the sample, such as Pb, Ba, Al, and S, were difficult to interpret. They can be assigned to lead white admixture and barium white extender. However, it is known that eosin was used to produce lake pigments (such as geranium lake), usually precipitated on an Al- or Pb-containing substrate [32,44–47]. Thus, Ba and S could be assigned to barium white, which is a common extender of lake pigments. Nevertheless, a presence of lithopone is suggested based on the FTIR detection of characteristic peaks at 1174, 1116, 1077, 981, 634, and 607 cm^{-1}.

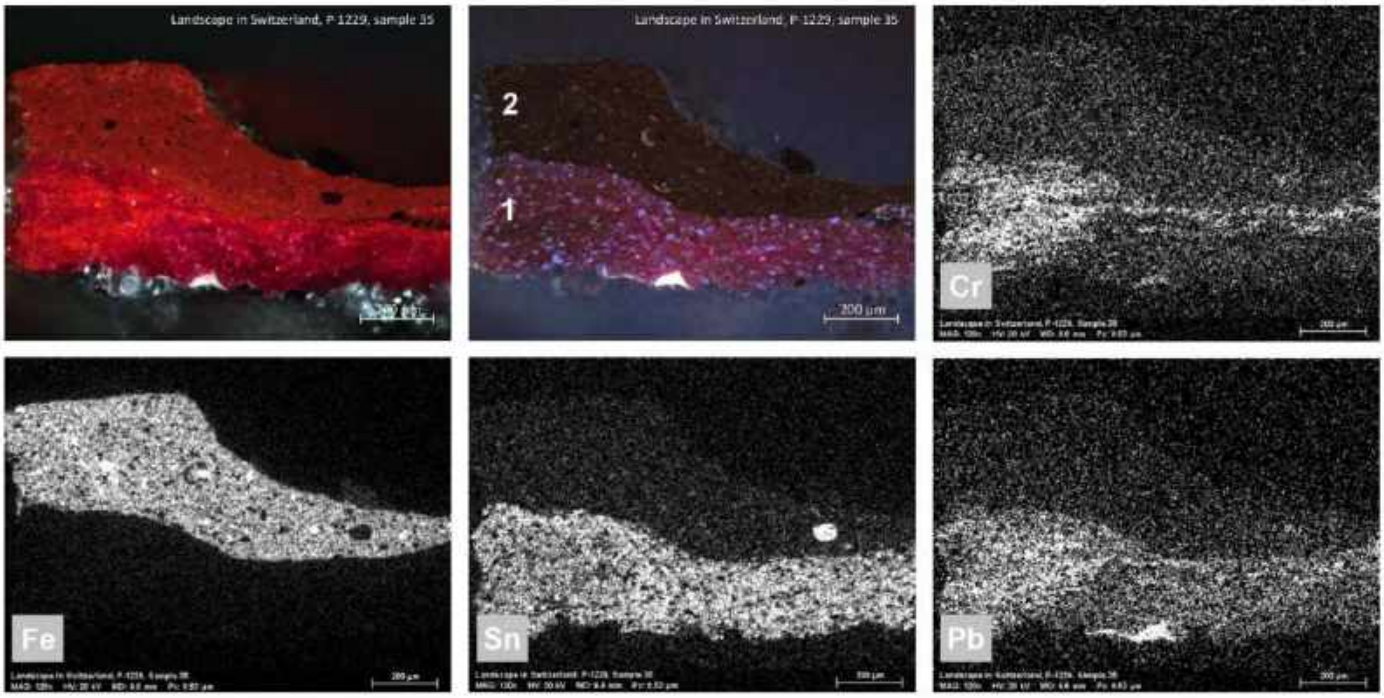

Figure 10. Microscopy image of the cross-section of sample 35 extracted from *Landscape in Switzerland*, photographed in VIS and UV, followed by SEM-EDS maps showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. The high intensity of Sn in layer 1 can be assigned to the tin substrate of organic red, which is probably mixed with chrome yellow based on the co-location of Cr- and Pb-signals. Layer 2 reveals strong Fe- and weak Sn-signals, suggesting a mixture of iron oxide with organic red with tin substrate.

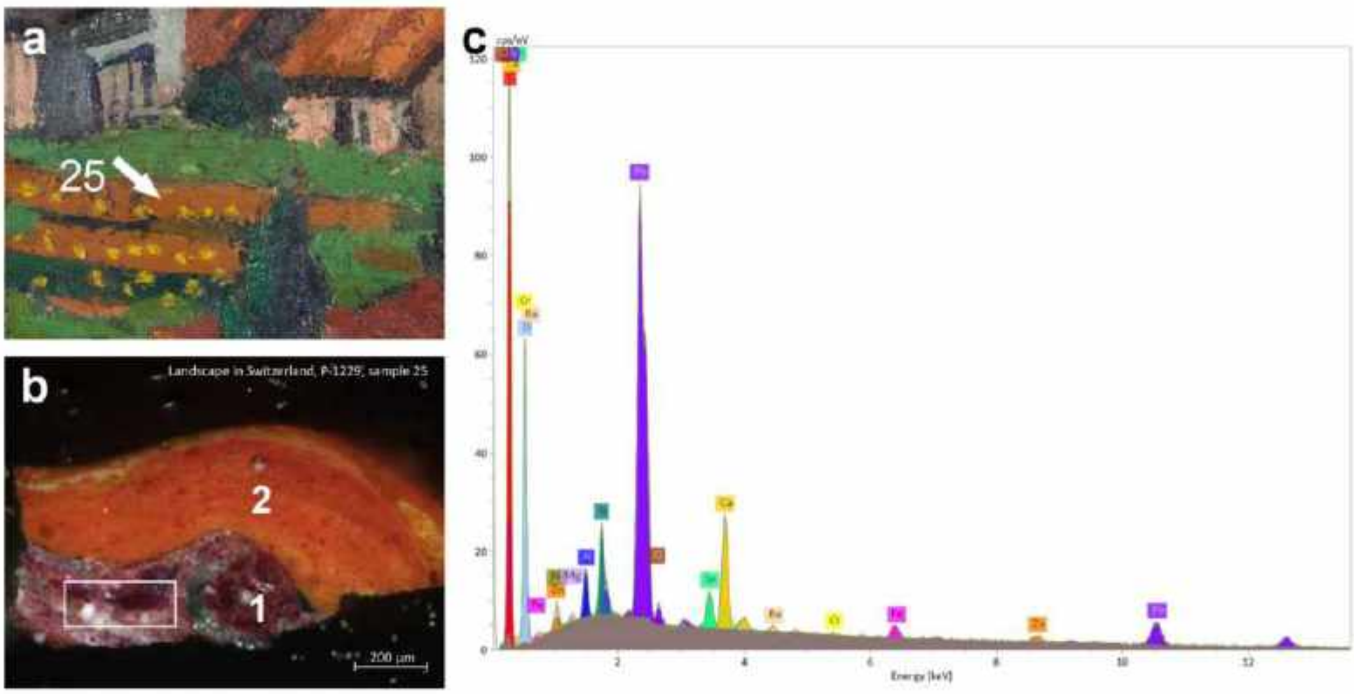

Figure 11. (**a**) Detail of *Landscape in Switzerland*, showing the sampling spot; (**b**) microscopy image of the cross-section of sample 25 with the marked area of SEM-EDS elemental analyses; (**c**) corresponding SEM-EDS spectra of the analysed area from layer 1, indicating a strong Sn-signal from the tin substrate of organic red.

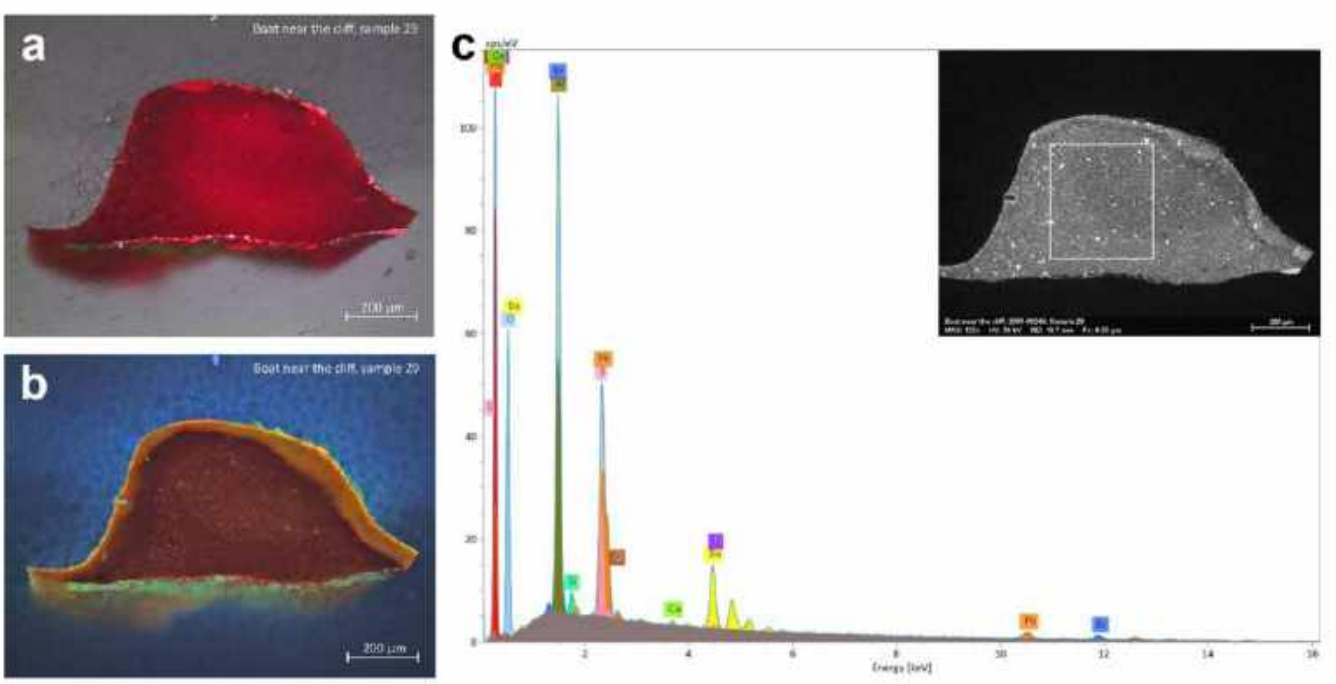

Figure 12. Microscopy image of the cross-section of sample 29 extracted from *Boat near the cliff* photographed in: (**a**) VIS; (**b**) UV. SEM-EDS spectra of the sample and inset backscattered electron (BSE) image with marked area of analyses (**c**). The spectra shows Br peaks which could be indicative of geranium lake, as well as Pb, Ba, Al, and S, which can be assigned to lead white and barium white extender and/or Pb- or Al-based substrate.

Lefranc marketed the *laque geranium* (geranium lake) with information that it is aniline-based pigment (Appendix A, Figure A4), although recent research identified eosin in its sample from 1926 [48]. Bourgeois Ainé listed *laque géranium* and *rouge géranium* (geranium red) without a chemical description, while geranium lake from W&N was derived from coal tar, according to their catalogue (Appendix A, Figures A2 and A3). Although the investigated red paint from *Boat near the cliff* exhibits features intrinsic to geranium lake, more analyses are needed to better elucidate its composition.

The organic red was also observed with PLM in the sample extracted from *Countryside in France* (sample 7). The sample does not fluoresce in UV, and the SEM-EDS detection of Al might be indicative of Al-containing substrate for the organic red detected with FTIR by peaks at 1617, 1576, 1559, 1506, 1499, 1447, 1417, 1397, 1343, 1303, 1276, and 1256 cm^{-1} [49]. However, the insufficient suit of FTIR peaks or low intensity of peaks did not allow a conclusive attribution.

In *Autumn colours* (sample 7) and *French lady* (sample 9), red paints are composed mainly of red iron oxide, modified with minor admixtures.

3.1.6. White

UVR photography is a powerful tool for a preliminary differentiation of lead white painted areas from zinc white and titanium white (titanium dioxide). Thus, lead white was observed in almost all paintings, based on its unique ability to reflect UV (Figure 14a,b). Additional SEM-EDS analyses showed that lead white occurs with a calcium carbonate, which was probably added by the manufacturer as an extender. It is worth noting that the examined white from the *Countryside in France* (sample 29) is a ground layer intentionally exposed by the artist during the painting process. It is composed predominantly of lead white with admixtures of barium, zinc, and titanium whites [9], suggesting it is of a different grade from the lead white identified in the artist's white paints [28]. Likewise, the white ground skilfully exposed by the artist in *Boat near the cliff* for describing foamy water is composed of mixture of lead and zinc whites [9]. White brushstrokes that turn dark grey and black in the UVR of *Landscape in Switzerland* and *Boat near the cliff* suggested a use of UV-absorbent titanium white or zinc white (Figure 14c,d). The latter was confirmed by the yellow-green UV fluorescence and SEM-EDS measurements of the white paint cross-sections from both paintings. Additionally, the MA-XRF of *Landscape in Switzerland* visualised a strong Zn-signal, which correlates with the white painted areas, while the Pb distribution map suggests chrome yellow and admixtures of lead white (Figure 4). The SEM-EDS detection of Ba and S in the sample 22 of *Landscape in Switzerland* suggests a common admixture of lithopone and/or barium white [50]. A minor and trace presence of Ti identified only in the colour mixtures may suggest a commercial admixture of titanium white.

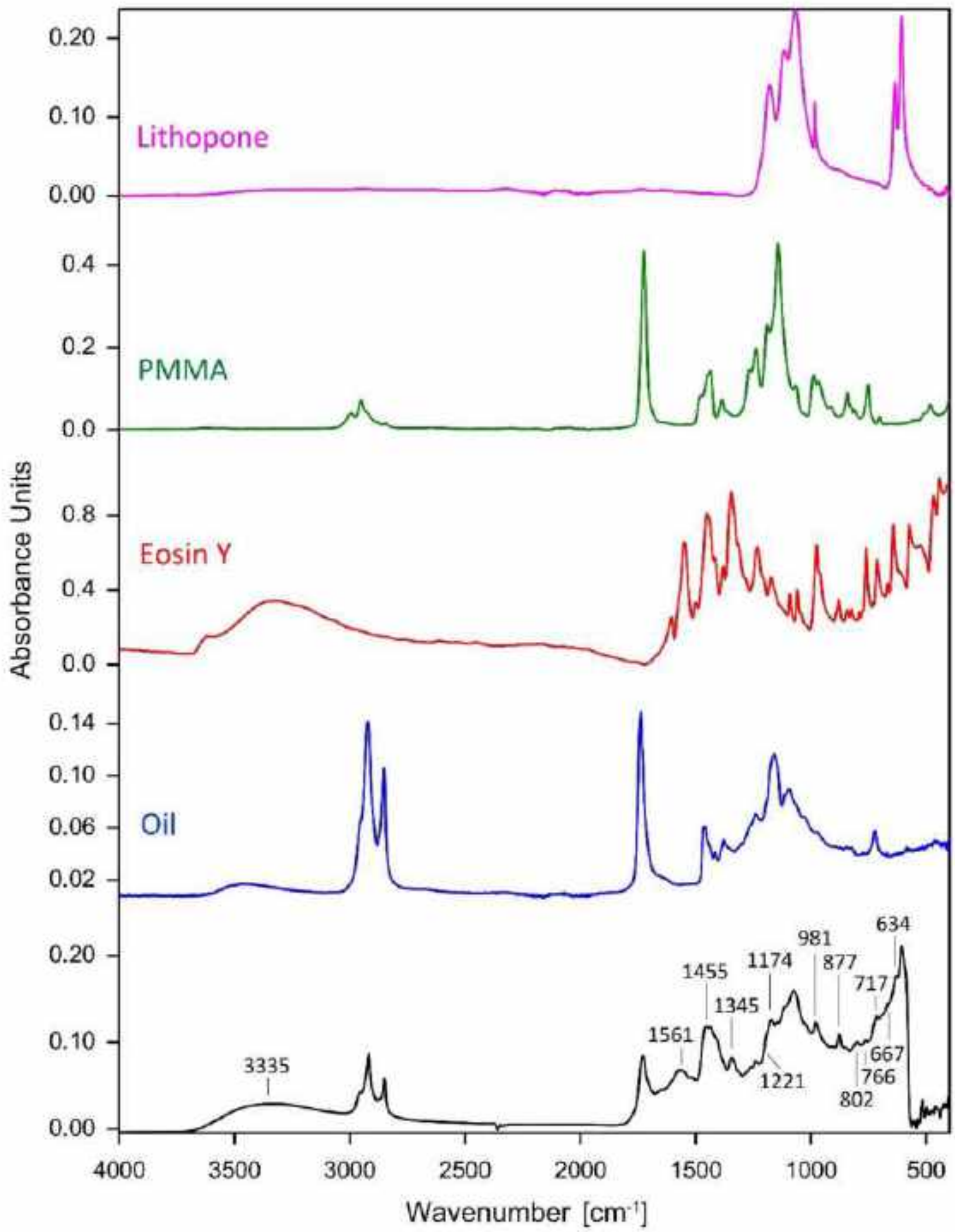

Figure 13. ATR-FTIR spectra of red paint from sample 29, taken from the *Boat near the cliff*, with labelled marker peaks of organic red and spectra of reference samples, identifying oil, eosin Y, acrylic resin, and lithopone.

Figure 14. VIS and corresponding UVR detail images of (**a**,**b**) *Countryside in France*; (**c**,**d**) *Boat near the cliff*. The UVR images indicate that white house in *Countryside in France* and foamed water in *Boat near the cliff* (marked with red arrows) show a strong UV reflectance attributable to lead white. White brushstrokes on the boat and clouds in *Boat near the cliff* appear dark grey and black in UVR (marked with yellow arrows), suggesting a use of UV absorbent zinc white, later confirmed with SEM-EDS.

3.1.7. Black

The IRFC photography determined that the black paints were very often mixtures of black with other pigments. The SEM-EDS and PLM analyses revealed that bone black is prevalent only in black brushstrokes of *Autumn colours* (sample 9). The intense black found in other paintings resulted entirely from mixing carbon blacks with ultramarine, Prussian blue, cobalt blue, and viridian. In *Village scene* (sample 13, 14) and *Landscape in Switzerland* (sample 18), it is evident that the role of the black pigment is taken by ultramarine.

3.2. Binding Media and Other Identified Compounds

The FTIR spectra from all the examined paint samples depicted characteristic bands at around 2925, 2850, 1730, 1460, 1160, and 720 cm^{-1}, confirming a consistent use of drying oil. Furthermore, the presence of zinc soap was confirmed by an absorption peak at 1539 cm^{-1} in *Countryside in France* (sample 7) and *Landscape in Switzerland* (sample 20), while lead soap was found in French lady (sample 16) by an absorption peak at 1514 cm^{-1}. The formation of metal soaps can be explained by the probable reaction of free fatty acids from the oil binder with metals present in the lead- and zinc-containing pigments [51,52]. The detection of the acrylic resin in three of the investigated samples may correspond to the varnish applied during the conservation treatments [43,53,54].

3.3. Painting Process

It is noteworthy that the VIS and NIR photography of the paintings did not detect the presence of the preparatory underdrawings. However, Liu Kang probably studied the subject matter by small-scale sketching prior to painting the composition on the canvas. For instance, a watercolour sketch of *Breakfast* from the Liu collection reveals an early idea of the composition for the canvas painting *Breakfast*, which was executed in the same year (Figure 15). Technical evidence from the *Countryside in France*, *Village scene*, *Breakfast*, and *Self-portrait* indicated that the artist approached the canvas with a clear concept of the general composition, which was established with rough brushstrokes usually of a black paint (Figure 1b,d,g and Figure 2e).

Figure 15. (**a**) Liu Kang, *Breakfast*, 1932, watercolour, 23 × 29 cm. Liu Kang Family Collection. Image courtesy of Liu family. (**b**) Liu Kang, *Breakfast*, 1932, oil on canvas, 46 × 54 cm.

The next step of the painting process involved a gradual colouring in of the outlines of the forms, providing the base for further work, as seen in *Countryside in France* and *Landscape* (Figures 1b and 2b). This method, known as *ébauche* (coloured sketch), was a common practice among Impressionists [55]. Analyses of the brushstrokes revealed that the middle-ground buildings of *Countryside in France* and the foreground house and a tree of *Landscape* were painted first. Then, the artist continued building the colouristic structure around these main subjects. The sky in *Countryside in France* was probably sketched at the end, after the background greenery was completed. Both sketches were conducted in local, vivid colours. A minimal suggestion of light effects observed in the sky of *Countryside in France* was achieved by the increased transparency of the colour, allowing the white ground to show through. The rapid development of the composition during the initial painting phase was facilitated by a few factors observed in *Countryside in France*. The small size of the painting support (number 10) reduced the time required to cover the surface with colours. The use of the absorbent or semi-absorbent ground with the ability to draw the oil from the paint accelerated the drying of the paint layer [9,56]. A thin application of colours mixed with lead white promoted the rapid drying of the paint layer. The presence of the signatures and dates indicates that the artist envisaged the coloured sketches as a completed exercise.

The further painting process can be observed in *My landlady, Madame Normand* (Figure 2f). Here, the artist intensified the colours of the main subject and built-up details with thicker paint. The advanced light effects were achieved by the increased opacity of different tints of white paint. Although the green background is sketchy and transparent, the artist's signature and date on the painting indicate that he considered the artwork as completed.

Liu Kang's variety of methods of handling the paint show constant self-development. In *Autumn colours*, his application of the paint using a small brush in short, vigorous, and descriptive paint touches reflects his attention to detail (Figures 1a and 16a). A daring adoption of parallel brushstrokes in *St Gingolph, Lac Leman, Switzerland* is reminiscent of van Gogh's style (Figures 2a and 16b). The structure of the paint layer with attractive touches is achieved by contrasting juxtaposition of greens with reds and yellows with blues. However, another painting, *Landscape in Switzerland*, shows some modification to this painting method. While the background depicting lake, mountains, and sky was conducted with directional touches, the foreground buildings and fields are depicted by coloured patches (Figures 1c and 16c,d).

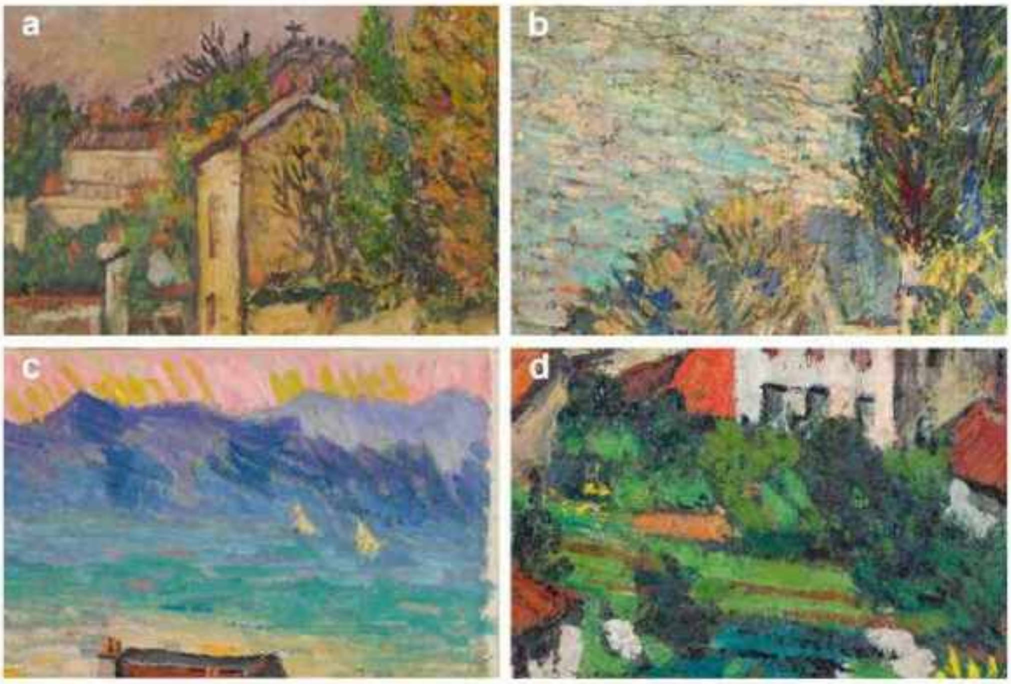

Figure 16. Details showing different types of brushwork in: (**a**) *Autumn colours*; (**b**) *St Gingolph, Lac Leman, Switzerland*; and (**c**,**d**) upper and bottom parts of *Landscape in Switzerland*.

The analyses of the paint structure of *Landscape in Switzerland* revealed the hardened brushwork beneath the upper layers, suggesting that the painting, including the signature and date, was executed in a wet-on-dry technique, as illustrated by the microscopic images (Figures 10 and 11b). Hence, two distinct painting sessions can be identified, where the second session, according to the artist's date and signature, could have been in 1930, at least six months after Liu Kang's trip to Switzerland. A combination of wet-on-wet and wet-on-dry paint applications was detected in other examined paintings, suggesting that the artist did not attempt to complete the work at one sitting and sometimes worked further on the composition after the initial painting was dry. This tendency could be a result of Liu Kang working on several paintings during one session as documented in the photograph from 1929 taken in Saint-Gingolph, Switzerland. Interestingly, one of the paintings seen in the photograph appears to be unfinished; hence, it can be hypothesised that the artist tended to apply finishing touches later (Figure 17).

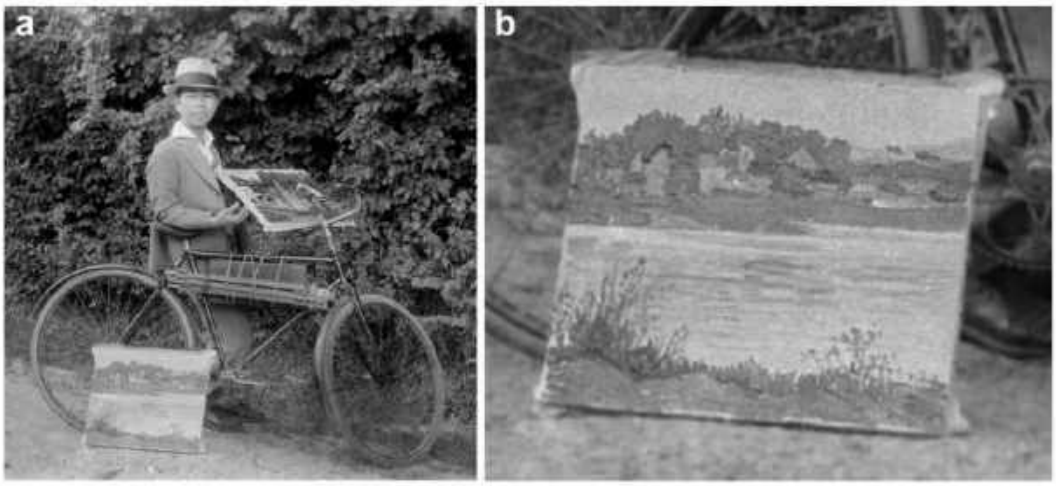

Figure 17. Archival photograph of Liu Kang during a painting session in Saint-Gingolph, Switzerland, in 1929: (**a**) Detail of the photograph showing a painting, probably unfinished; (**b**) Liu Kang Family Collection. Images courtesy of Liu family.

A good example of a painting executed rapidly in a single sitting is *Village scene*. In this artwork, there are significantly few details while the general artistic expression is achieved by directional and highly textured brushwork combined with solid colours (Figures 1d, 5b and 18c,d). Meanwhile, *Boat near the cliff* is characterised by a synthesis of colours and forms achieved by the broad and flat application of the paint (Figure 1f). Although the painting appears to be spontaneously and rapidly executed, the analyses proved a wet-on-dry execution, suggesting that later modifications were conducted over previous partially hardened touches.

Figure 18. Details showing the incorporation of the colour of ground in the painting process in: (**a**) *Boat near the cliff*; (**b**) *Still life with books, Paris*; and (**c**) *Village scene*. Initial compositional lines are exposed in: (**c**,**d**) *Village scene*.

During the painting process, Liu Kang experimented with incorporating the white colour of the ground layer with other paint colours reflecting inspiration from Modernists' techniques [9,57]. A good example is *Countryside in France*, in which the colour of the exposed ground was utilised for depicting the main building (Figure 14a). In contrast, the ground in *Landscape* remains exposed between the patches of applied paint, giving the artist a chance to make adjustments of colour and form (Figure 2b). In *Boat near the cliff*, the ground was used as a highlight and colour in its own right to describe foamy water (Figure 18a). However, *Still life with books*, *Paris*, and *Village scene* exhibit a new experiment with a white ground. Liu Kang enhanced the brilliance of the painted scenes by exposing bright accents of the white ground through the spaces between directional brushstrokes (Figures 5b and 18b,c). This painting method seems to support the notion that the artist sometimes skipped the colour sketching and confidently applied the colours after establishing the general composition with dark outlines. Moreover, to moderate the monotony of a methodical brushwork, the artist creatively produced effects of the broken flow of the paint, by dragging a loaded brush across the textured ground layer (Figures 5b and 18a–c) [9].

An interesting example of the artist's inventive way of utilising the colour and texture of the painting support is *Self-portrait* (Figure 19). As it was executed on the reverse side of an earlier composition, the brownish canvas made it particularly well suited for providing colouristic unity among the mixed yellows and browns. Moreover, the colour and texture of an un-primed canvas were skilfully exposed to give an impression of the back side of a depicted painting.

Figure 19. Detail of *Self-portrait*, showing the incorporation of the colour and texture of the painting support in depicting the reverse side of the painting in his artwork. The inset detail shows the structure of the canvas.

Another feature common in the examined paintings is the presence of a strong contour. The lines accompany the painting process from the sketching until the final stage, and they play a crucial role in the aesthetic of the paintings giving greater definition to the forms of the subjects. In *Village scene,* some of the initial compositional lines describing the highest distant hilltops as well as the shapes of the houses are still visible through the paint layer (Figure 18c,d). In the final stage, the artist usually reinforced the outlines of the subjects with a dark paint composed mainly of bone black with ultramarine and/or Prussian blue, as identified in *Village scene* (sample 13, 14), *Landscape in Switzerland* (sample 18), and *Breakfast* (sample 14).

3.4. Reusing Earlier Paintings

The evidence collected from five examined paintings revealed that Liu Kang had a practice of reusing earlier, unwanted compositions or utilising their reverse sides. For example, a visual inspection of the painted edges of the *St Gingolph*, *Lac Leman*, *Switzerland* revealed the presence of colours to be unrelated to the final image. The raking light and RTI examination of *Autumn colours* pointed out the surface brushstrokes that skip over the more complex texture of the underlying paint scheme. Subsequent transmitted NIR photography conducted with a camera facing the back of the painting revealed a presence of a still life composition that had been created in the vertical orientation. Further XRR analysis confirmed that the underlying painting depicts plants in flowerpots (Figure 20).

A visual examination of *Breakfast* provided some indications of another composition underneath. For instance, a different paint scheme was observed in the areas that were not completely covered by the current painting. Moreover, the final paint layer is characterised by several dark paint strokes that do not correspond to the present composition. They are visible on the green table top and red background, probably due to decreasing hiding power of thinly applied upper paint layer (Figure 21) [58]. This feature is similar to the reported case study of *Seafood* by Liu Kang, in which his hidden self-portrait was discovered beneath [8]. The NIR photography of *Breakfast* rotated 180° revealed a view that could be interpreted as a riverbank with trees.

Besides the aforementioned examples of paintings over discarded compositions, Liu Kang also utilised the reverse sides of earlier paintings. *Self-portrait* and *Portrait of a man with his pipe*, *Paris* are examples of artworks created directly on un-primed canvases. The artist's practice of reusing unsatisfactory compositions or utilising their reverse sides could have been motivated by a temporary shortage of materials or by financial constraints.

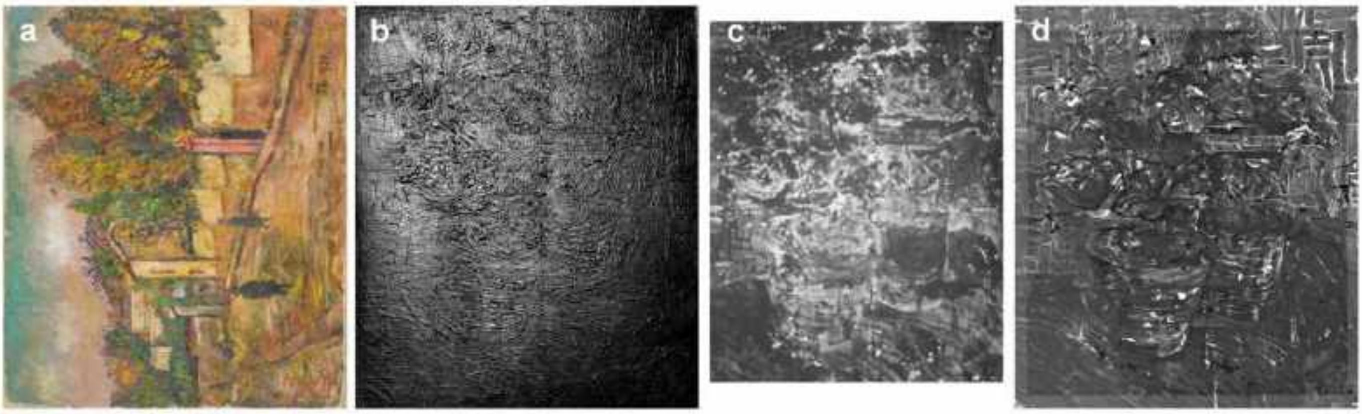

Figure 20. Images of *Autumn colours* rotated at 90° anticlockwise and photographed in: (**a**) VIS; (**b**) RTI; and (**c**) transmitted NIR executed with camera facing the back of the painting, then cropped to remove the strainer bars, inverted horizontally, and reproduced with the same relative scale; (**d**) XRR. The images revealed paint features of hidden still life painting with plants in the flowerpots.

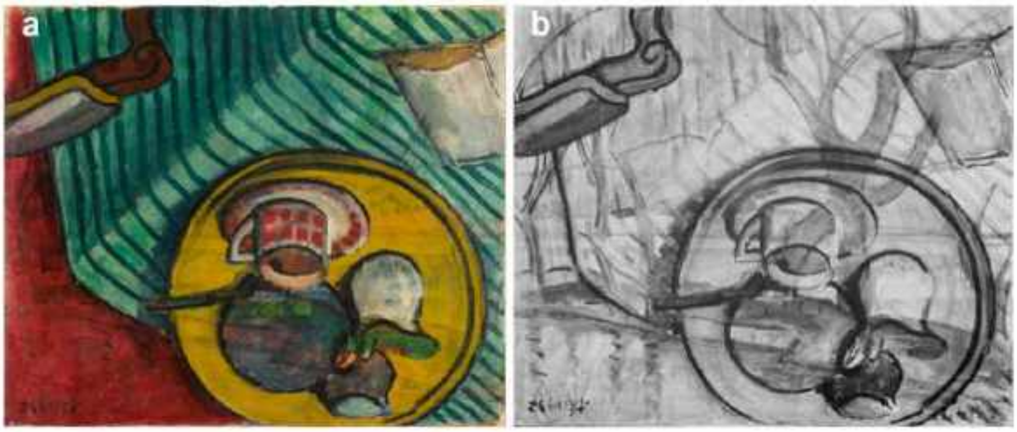

Figure 21. VIS (**a**) and NIR (**b**) images of *Breakfast* rotated at 180°. NIR reveals the hidden view of a riverbank with trees.

4. Conclusions

The study of Liu Kang's paintings from the Paris phase provides information about the artist's choice of pigments and advances our knowledge of his working practice. Selecting artworks from both the NGS and Liu family collections enabled the tracking of the development of the artist's painting technique during the said period. In addition, the artist's family archives provided insights into his painting process. The imaging techniques, such as IRFC and UVR, played a crucial role in the tentative identification of pigments and guiding sampling of the material for further detailed analyses. RTI, XRR, and NIR provided valuable information about artist's painting process by visualising the hidden compositions underlying *Autumn colours* and *Breakfast*. The MA-XRF scanning of *Landscape in Switzerland* highlighted the distribution of elements that are indicative of certain pigments and their role in the evolution of the painting. Additional PLM, SEM-EDS, and FTIR analyses led to the identification of the paint mixtures. The contemporary colourmen catalogues are a precious resource that supplemented the interpretation of certain materials found in the course of paints' analyses.

The interpretation of the collected data unveiled a restricted palette of colours and the preferential use of ultramarine, viridian, chrome yellow, iron oxides, organic reds, lead white, and bone black. These major pigments were accompanied with the artist's admixtures. For instance, cobalt blue was hardly used and was recorded in some blue, green, and black paint mixtures. Prussian blue was used as a tint for green and black colours. Emerald green had a similar role as an admixture of greens. Additions of cadmium yellow and cobalt yellow are interesting as they were found exclusively in *Landscape in Switzerland*. PLM, SEM-EDS, and FTIR were particularly effective with the detection of three types of organic reds. One could be an organic red on tin and starch substrates. The second is probably a compound related to eosin red on Al- or Pb-containing substrate—known as a geranium lake. The third is probably an organic red on an Al-containing substrate. However, more analyses are needed to better characterise the organic red pigments. Although lead white is a predominant white pigment, its role seems to have been reduced in favour of the lithopone and/or barium white and zinc white in *Landscape in Switzerland* and *Boat near the cliff*. Artist also liked to incorporate the white of the ground into the final effect. Carbon black was added to other colours to modify their shade. However, deep blacks usually appear in bold outlines and were achieved by mixing carbon black with ultramarine, Prussian blue, cobalt blue, and viridian.

FTIR analyses additionally confirmed the presence of an oil binder in all investigated paintings from the NGS collection. Moreover, the identification of formation of metal soaps and geranium lake pigment will have some relevance for future conservation diagnostics. This is because metal soaps may contribute to the deterioration process of the paint layers, while geranium lake has a strong fading tendency [59,60].

Studies of the artist's technique revealed that he adopted coloured sketching; however, he was also able to skip this stage and effectively create compositions with rapid and decisive brushstrokes. It can be speculated that he had conducted small-scale compositional studies in different techniques prior to painting on the canvas. The subsequent progression of painting process can be characterised by constant and generally successful experimentation with brushwork. Ultimately, Liu Kang's paintings from the Paris phase are defined by continual exploration and learning of different Modernist painting styles. This very mature artistic approach benefitted him upon his return to China, when he felt a strong need to develop his own painting style.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Overview of the materials identified in the paint samples extracted from the investigated paintings from the NGS collection.

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * and XRF ** Detected Elements	PLM, SEM-EDS, XRF Assignment	FTIR Identification
Autumn colours, GI-0255 (PC)	1930	Blue	19	**C**, **O**, **Pb**, Cr, Ca, Si, Al, Na, Ba, S, As, (Sr, Fe, Cu, Zn)	Lead white, lithopone and/or barium white and zinc white, chalk, viridian, ultramarine, emerald green or Sheele's green, Prussian blue	
		Green	5	**C**, **O**, **Pb**, Ba, Sr, S, As, Cr, Cu, (Si, Ca, Al, Fe, Na)	Lead white, barium white, chalk, viridian, emerald green or Sheele's green, Prussian blue	
		Green	18	**C**, **O**, **As**, **Cu**, Ba, Pb, S, Ca, (Ti, Na, Cr, Cl, Si, Fe, Mn)	Emerald green, barium white, lead white, chalk, viridian, umber, possible Cr-containing yellow(s) and titanium white	Emerald green, lithopone and/or barium white, lead white, possible chrome yellow, oil
		Yellow	3	**Pb**, **C**, **O**, Ca, (Cl, Cr, Si, Al, Fe, Ba)	Lead white, chrome yellow, chalk, barium white, yellow iron oxide	
		Brown	4	**Pb**, **C**, **O**, Ca, Fe, Al, Si, (Cr, Ba, Sr, Ti, Na)	Lead white, chalk, yellow iron oxide, barium white, possible Cr-containing yellow(s), and titanium white	
		Red	7	**O**, **C**, **Fe**, Pb, Ca, Ti, Si, Al, Mg, (P, Na, Sr, Cl, Zn, K, Cr, S)	Red iron oxide, lead white, chalk, titanium white, bone black, possible Cr-containing yellow(s)	
		Black	9	**C**, **O**, **Ca**, Pb, P, (Si, Al, Na, Fe, Ba, Mg, Cr, Cl, Zn, As)	Bone black, lead white, lithopone and/or barium white and zinc white	
		White	2	**Pb**, **C**, **O**, Ca, (Al, Cl, Si, Zn)	Lead white, chalk, zinc white	
Countryside in France, 2003-03365	1930	Blue	5	**C**, **Pb**, **O**, Si, Al, Ca, Ba, Na, S, Zn, (Ni, K, Cr, Ti, Sr, Mg)	Lead white, carbon black, ultramarine, lithopone and/or barium white and zinc white, possible titanium white	
		Green	11	**O**, **Pb**, **C**, **Ba**, Cr, Fe, S, Ca, Si, Al, Ti, (Na, K, Zn, Cl)	Lead white, chalk, lithopone and/or barium white and zinc white, viridian, Prussian blue, possible Cr-containing yellow(s), titanium white	Lead white, chalk, lithopone and/or barium white and zinc white, Prussian blue, possible chrome yellow, oil, acrylic resin assigned to the conservation varnish
		Green	4	**Pb**, **C**, **O**, Cr, Ca, Ba, Si, Zn, Al, (S, Fe, Ti, Na)	Lead white, chrome yellow, possible other Cr-containing yellow(s), chalk, viridian, lithopone and/or barium white and zinc white, Prussian blue	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * and XRF ** Detected Elements	PLM, SEM-EDS, XRF Assignment	FTIR Identification
		Yellow	9	**Pb**, **C**, **O**, Cr, (S, Cl, Na, Zn, Al)	Chrome yellow, zinc white	
		Brown	41	*Pb*, *Fe*, *K*, *Si*, *Ca*	Lead white, iron oxide, chalk	
		Brown	49	*Fe*, *Ca*	Iron oxide, chalk	
		Red	7	**C**, **Pb**, **Ba**, **O**, S, Cr, Al, Si, (Zn, Ni, Sr, Ca, P)	Lead white, chrome yellow, lithopone and/or barium white and zinc white, organic red, bone black	Lead white, chrome yellow, lithopone and/or barium white and zinc white, organic red, oil, zinc soap
		Black	16	**O**, **C**, **Pb**, Si, Al, Na, Ba, S, Zn, Ca, (K, Cr, Ti, Sr)	Lead white, ultramarine, carbon black, lithopone and/or barium white and zinc white	
		White	29	**C**, **Pb**, **O**, **Ba**, Ti, Zn, S, Na, (Fe, Si, Al)	Lead white, barium white, zinc white, titanium white	Lead white, barium white, zinc white, oil, proteins
Landscape in Switzerland, P-1229	1930	Blue	5	**Zn**, **C**, **O**, **Na**, Al, Ca, Si, (S, Pb, Sr, Mg)	Zinc white, ultramarine, lead white	
		Green	20	**Pb**, **C**, **O**, **Zn**, Cr, Fe, Na, (Ba, Si, Al, Ca, Cl)	Chrome yellow, yellow iron oxide, Prussian blue, lead white, lithopone and/or barium white and zinc white	Chrome yellow, possible iron oxide, Prussian blue, lead white, lithopone and/or barium white and zinc white, oil, zinc soap, acrylic resin assigned to the conservation varnish
		Green	21	**C**, **O**, **Cd**, **Cr**, S, Ba, Zn, Cl, (Na, Pb, Al, Si, Sn, Ti, Ca, Sr)	Cadmium yellow, lithopone and/or barium white and zinc white, viridian, chalk, lead white, chrome yellow, possible titanium white	
		Green	24	**C**, **O**, **Pb**, Ba, Zn, Cr, Al, Cl, Na, S, Fe, (Cu, Mg, Si, Ti, Ca, As, Sr, P)	Chrome yellow, viridian, Prussian blue, lithopone and/or barium white and zinc white, emerald green or Sheele's green, possible titanium white	
		Yellow	23	**Pb**, **O**, **Zn**, C, K, Na, Ba, Co, Cd, (Mg, Ca, Fe, Si, S, Al, Cr, Cl)	Chrome yellow, possible other Cr-containing yellow(s), lithopone and/or barium white and zinc white, cobalt yellow, cadmium yellow, yellow iron oxide	
		Yellow	36	**Zn**, **C**, **O**, Pb, Na, Ca, Fe, K, Ba, Co, (Si, As, S, Mg, Al, Cr, Cl)	Lithopone and/or barium white and zinc white, lead white, chrome yellow, possible other Cr-containing yellow(s), yellow iron oxide, cobalt yellow	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * and XRF ** Detected Elements	PLM, SEM-EDS, XRF Assignment	FTIR Identification
		Brown	25, layer 2	**O**, **Zn**, **C**, Ba, Na, Pb, Fe, Ca, S, Al, Si, K, (Ti, Co, Mg, As, Sr, Cu)	Lithopone and/or barium white and zinc white, lead white, yellow iron oxide, cobalt yellow, possible emerald green or Sheele's green and titanium white	
		Red	25, layer 1	**C**, **O**, **Pb**, Ca, Sn, Si, Fe, (Al, Ba, Zn, Na, Cl, Cr, Mg)	Lead white, organic red, red iron oxide, starch	
		Red	35, layer 2	**O**, **Fe**, **C**, **Si**, Al, Ca, (K, Sn, Mg, Ti, S, Pb, Zn)	Red iron oxide, organic red, chalk	Red iron oxide, organic red, chalk, oil
		Red	35, layer 1	**C**, **O**, **Pb**, Sn, (Cr, Fe, Ca, Si, Al, Cl)	Lead white, organic red, iron oxide, possible Cr-containing yellow(s)	Lead white, organic red, iron oxide, starch, oil
		Black	18	**C**, **O**, **Zn**, Al, Ca, Ba, S, Na, (Si, Fe, Pb, P, Sr, Mg, Cu, Cl)	Lithopone and/or barium white and zinc white, ultramarine, bone black, Prussian blue	
		White	22	**Zn**, **C**, **O**, **Na**, (S, Ba, Mg, Ca, Al)	Lithopone and/or barium white and zinc white, chalk	
Village scene, 2003-03320	1931	Blue	20	**Pb**, **C**, **O**, **Ca**, (Na, Si, Al, Cr, Cl, Mg, Sr, Zn)	Lead white, ultramarine, viridian, chalk, possible zinc white	
		Green	2	**C**, **Pb**, **O**, Ba, Ca, Cr, S, Fe, (Zn, Al, Na, Si, Ti, Mg)	Lead white, lithopone and/or barium white and zinc white, chalk, viridian, Prussian blue	
		Green	3	**O**, **Cr**, **C**, **Pb**, Ca, (Zn, Na, Si, Mg, Al)	Viridian, lead white, chrome yellow, possible other Cr-containing yellow(s), chalk	
		Yellow	8	**Pb**, **C**, **O**, **Cr**, (Ca, S, Na, Si, Cl, Al)	Chrome yellow, chalk	
		Brown	5	**Pb**, **C**, **O**, Ca, Fe, Si, Al, (Zn, Sr, Mg, Cl, Ba, Cr, P)	Lead white, lithopone and/or barium white and zinc white, yellow iron oxide, bone black, possible Cr-containing yellow(s)	
		Brown	10	**O**, **Fe**, **C**, **Ba**, S, Ca, Si, (Pb, Al, Ti, Sr, Cl)	Yellow iron oxide, barium white, chalk, lead white	
		Red	9	**C**, **O**, **Pb**, Sn, Ca, Cr, Si, Fe, (Al, Zn, Ba, P)	Chrome yellow, possible lead white, organic red, starch, chalk, lithopone and/or barium white and zinc white, red iron oxide, bone black	Chrome yellow, possible lead white, organic red, iron oxide, starch, chalk, oil
		Black	13	**O**, **C**, Ca, Si, Pb, Na, Al, S, P, Zn, (Ba, K, Fe, Sr, Cr, Cl)	Ultramarine, lead white, lithopone and/or barium white and zinc white, Prussian blue, bone black	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * and XRF ** Detected Elements	PLM, SEM-EDS, XRF Assignment	FTIR Identification
		Black	14	**O**, **Pb**, **C**, **Si**, Al, Na, S, Ca, (K, As, Zn, Ba, Fe, Sr, Cl)	Lead white, ultramarine, lithopone and/or barium white and zinc white, red iron oxide, carbon black	
		White	17	**Pb**, **C**, **O**, Ca, (Cl, Al, Mg)	Lead white, chalk	
French lady, 1993-00996	1931	Blue	20	**C**, **O**, **Pb**, Al, Ca, Ba, Si, Co, Na, (S, Cr, Mg, Ti, Sr, K, P, Fe, Zn, Cl)	Lead white, chalk, lithopone and/or barium white and zinc white, cobalt blue, viridian, ultramarine, bone black	
		Green	15	**C**, **O**, **Pb**, **Cr**, Ba, Ca, (As, Si, Al, Na, Cu, Ti, Fe, Co, Cl, S)	Lead white, viridian, chalk, barium white, cobalt blue, Prussian blue, possible emerald green or Sheele's green and titanium white	
		Green	16	**Pb**, **C**, **O**, Ba, Ca, As, Cr, S, Cu, (Fe, Ti, Na, Al, Si, Cl)	Lead white, barium white, chalk, emerald green or Sheele's green, Prussian blue, possible Cr-containing yellow(s) and titanium white	Lead white, lithopone and/or barium white, chalk, possible emerald green or Sheele's green, Prussian blue, chrome yellow, oil, lead soap
		Brown	17	**Pb**, **O**, **C**, Ca, Si, Fe, Al, (Zn, Ba, Cr, Cl, Mg, K, Na, Ti)	Lead white, yellow iron oxide, Cr-containing yellow(s), lithopone and/or barium white and zinc white	
		Red	9	**Pb**, **C**, **O**, Ca, Ba, Fe, Si, (Al, Cl, Cr, Ti, Mg)	Lead white, chalk, Cr-containing yellow(s), barium white, iron oxide	
		Black	19	**O**, **C**, **Fe**, **Ba**, Pb, Al, S, Co, Na, K, Si, As, (Ca, P, Ti, Zn, Mg, Cr, Sr, Cl)	Prussian blue, lithopone and/or barium white and zinc white, lead white, cobalt blue, bone black, viridian, possible titanium white	
		Black	6	**O**, **C**, **Pb**, Si, Al, S, Na, Ca, As, K, Fe, (Sr, Ba, Cl, Mg, Ti, Cr)	Lead white, ultramarine, carbon black, Prussian blue, barium white, viridian, possible titanium white	
Boat near the cliff, 2003-03249	1931	Blue	3	**C**, **Zn**, **O**, **Ba**, Na, S, Cr, (Al, Si, Sr)	Lithopone and/or barium white and zinc white ultramarine, viridian	
		Blue	21	**C**, **O**, Na, Zn, Al, Si, S, Ba, (K, Sr, Cr, Ca, Cl)	Ultramarine, viridian, lithopone and/or barium white and zinc white	
		Blue	26	**C**, **O**, **Ba**, **Zn**, S, Cr, Na, Pb, (Ti, Ca, Al, Si, Co, Mg)	Lithopone and/or barium white and zinc white, lead white, viridian, ultramarine, cobalt blue	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * and XRF ** Detected Elements	PLM, SEM-EDS, XRF Assignment	FTIR Identification
		Green	11	**O**, **C**, **Ba**, **Zn**, Pb, S, Fe, Cr, Ca, Na, Si, (Al, Ti, Mg, P, Cl, K)	Lithopone and/or barium white and zinc white, chalk, chrome yellow, yellow iron oxide, Prussian blue, viridian, bone black, possible titanium white	
		Green	12	**O**, **C**, **Ba**, Ca, Pb, S, Cr, Fe, (Ti, Sr, Si, Al, Na, Zn)	Lithopone and/or barium white and zinc white, viridian, Prussian blue, chrome yellow	
		Yellow	25	**O**, **C**, **Ba**, Ca, Pb, S, Zn, Cr, (Sr, Na, Ti, Mg, Si, Al, Cd, Fe)	Lithopone and/or barium white and zinc white, chrome yellow, cadmium yellow, iron oxide, possible titanium white	
		Brown	14	**C**, **O**, **Zn**, Fe, Na, Al, Ba, (Ca, P, S, Si, Mn, Mg, Cr, Pb, Sr)	Lithopone and/or barium white and zinc white, umber, bone black, chrome yellow, possible other Cr-containing yellow(s)	
		Red	29	**C**, **O**, Pb, Ba, Br, Al, S, (Si, Ti, Cl, Ca)	Br-containing organic red on Pb- or Al-based substrate, barium white, possible titanium white	Lithopone and/or barium white, organic red, oil, acrylic resin assigned to the conservation varnish
		Black	17	**C**, **O**, **Zn**, Pb, Na, Mg, (Si, Al, Fe, S, Ba, Ca, K)	Lithopone and/or barium white and zinc white, lead white, carbon black, Prussian blue	
		White	22	**Zn**, **C**, **O**, Na, (Si, Mg, Pb, Al)	Zinc white, lead white	
Breakfast, GI-0257 (PC)	1932	Green	4	**O**, **Cr**, **C**, Pb, Ba, S, Ca, (Na, Al, Si, Mg, Ti, Sr)	Viridian, lead white, barium white, chalk, possible titanium white	
		Yellow	3	**O**, **C**, **Fe**, Si, Pb, Al, Ca, (K, As, Cr, Sr, P, Ba, Cl, Ti, Zn)	Yellow iron oxide, chrome yellow, lead white, lithopone and/or barium white and zinc white, bone black, possible titanium white	
		Brown	10	**O**, **C**, **Fe**, **Si**, Pb, Al, Sn, Ca, Sr, Ba, K, (Ti, Cr, Mg, Cl, Zn, P)	Red iron oxide, organic red, lead white, chalk, Prussian blue, starch, Cr-containing yellow(s), lithopone and/or barium white and zinc white, bone black, possible titanium white	Red iron oxide, organic red, lead white, chalk, Prussian blue, starch, oil
		Black	14	**O**, **Ca**, **Pb**, **C**, **Cr**, P, Ba, Si, (Fe, Al, Na, Ti, Mg, K, Cl, Sr)	Lead white, bone black, viridian, barium white, Prussian blue, possible titanium white	
		White	7	**Pb**, **C**, **O**, **Ca**, (Cl, Si, Na, Al, Mg)	Lead white, chalk	

* Major elements are given in bold, minor elements in plain type and trace elements in brackets. ** Elements detected with XRF are given in italics.

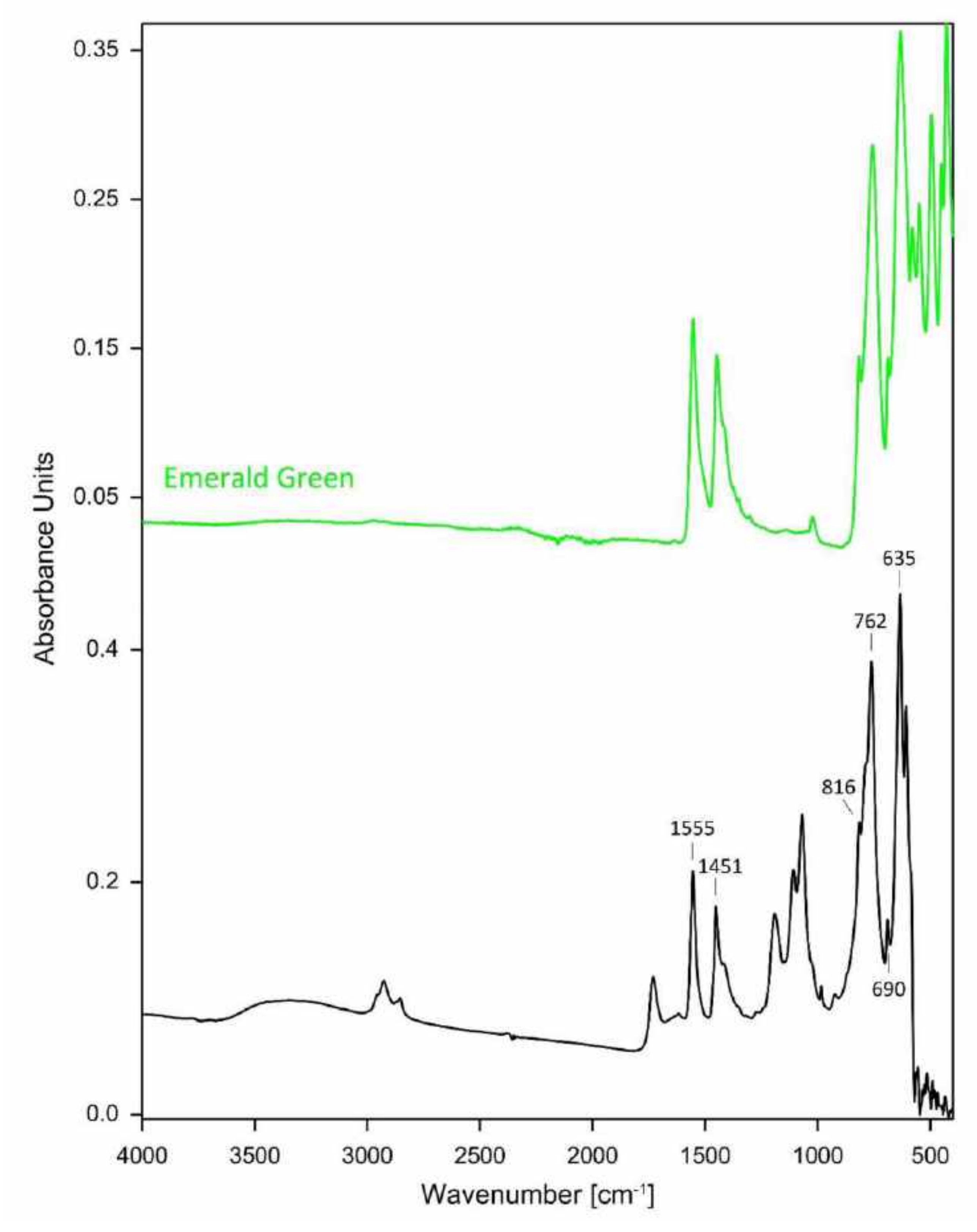
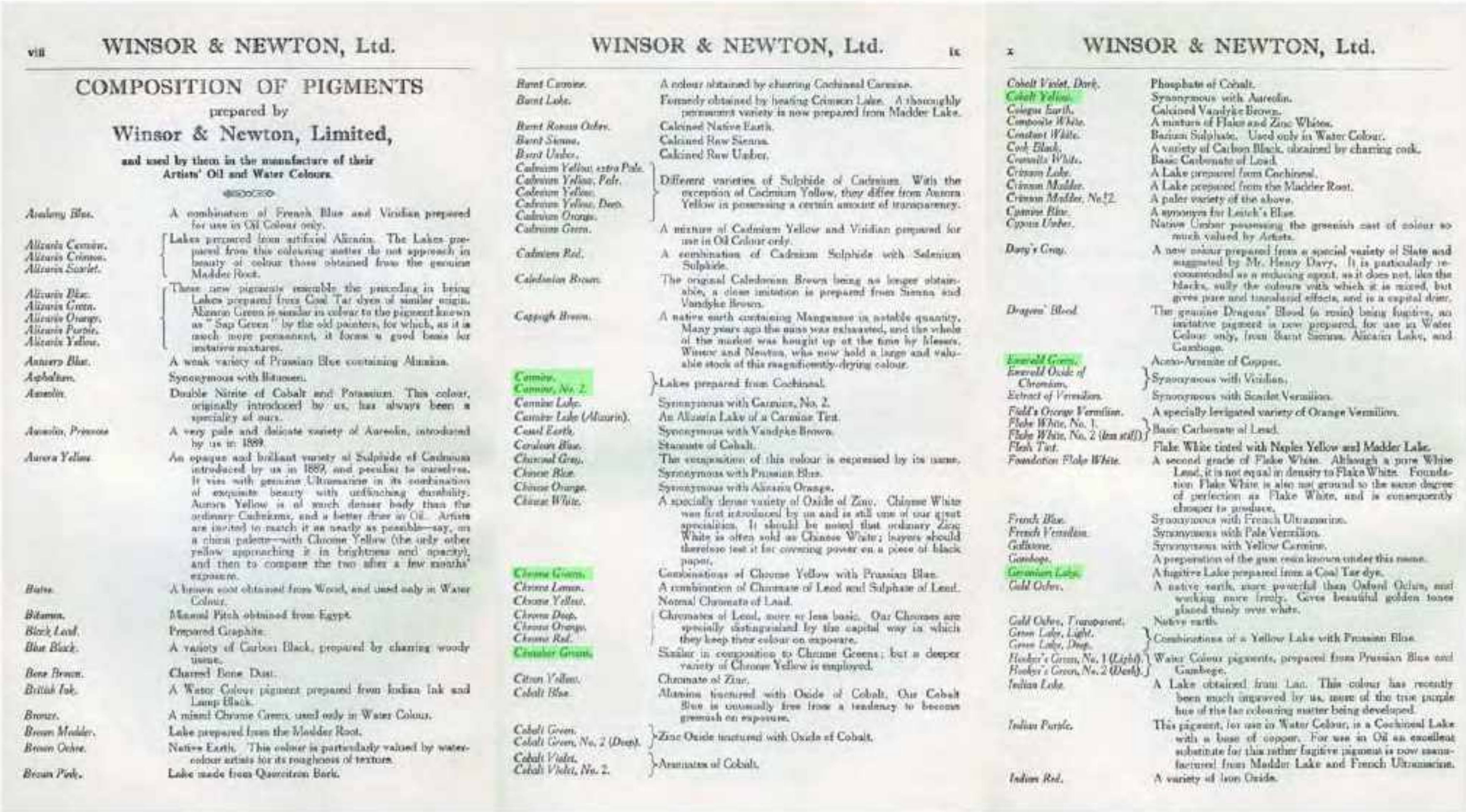


Figure A1. ATR-FTIR spectra of green paint from sample 18, taken from *Autumn colours*, with labelled marker peaks of emerald green and spectra of a reference sample of emerald green.



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COMPOSITION OF PIGMENTS

prepared by

Winsor & Newton, Limited,

and used by them in the manufacture of their Artists' Oil and Water Colours.

Academy Blue.	A combination of French Blue and Viridian prepared for use in Oil Colour only.
Alizarin Carmine. Alizarin Crimson. Alizarin Scarlet.	Lakes prepared from artificial Alizarin. The Lakes prepared from this colouring matter do not approach in beauty of colour those obtained from the genuine Madder Root.
Alizarin Blue. Alizarin Green. Alizarin Orange. Alizarin Purple. Alizarin Yellow.	These new pigments resemble the preceding in being Lakes prepared from Coal Tar dyes of similar origin. Alizarin Green is similar in colour to the pigment known as "Sap Green" by the old painters, for which, as it is much more permanent, it forms a good basis for imitative mixtures.
Antwerp Blue.	A weak variety of Prussian Blue containing Alumina.
Asphaltum.	Synonymous with Bitumen.
Aureolin.	Double Nitrite of Cobalt and Potassium. This colour, originally introduced by us, has always been a speciality of ours.
Aureolin, Primrose	A very pale and delicate variety of Aureolin, introduced by us in 1889.
Aurora Yellow.	An opaque and brilliant variety of Sulphide of Cadmium introduced by us in 1887, and peculiar to ourselves. It vies with genuine Ultramarine in its combination of exquisite beauty with unflinching durability. Aurora Yellow is of much denser body than the ordinary Cadmiums, and a better drier in Oil. Artists are invited to match it as nearly as possible—say, on a china palette—with Chrome Yellow (the only other yellow approaching it in brightness and opacity), and then to compare the two after a few months' exposure.
Bistre.	A brown soot obtained from Wood, and used only in Water Colour.
Bitumen.	Mineral Pitch obtained from Egypt.
Black Lead.	Prepared Graphite.
Blue Black.	A variety of Carbon Black, prepared by charring woody tissue.
Bone Brown.	Charred Bone Dust.
British Ink.	A Water Colour pigment prepared from Indian Ink and Lamp Black.
Bronze.	A mixed Chrome Green, used only in Water Colour.
Brown Madder.	Lake prepared from the Madder Root.
Brown Ochre.	Native Earth. This colour is particularly valued by water-colour artists for its roughness of texture.
Brown Pink.	Lake made from Quercitron Bark.

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Burnt Carmine.	A colour obtained by charring Cochineal Carmine.
Burnt Lake.	Formerly obtained by heating Crimson Lake. A thoroughly permanent variety is now prepared from Madder Lake.
Burnt Roman Ochre.	Calcined Native Earth.
Burnt Sienna.	Calcined Raw Sienna.
Burnt Umber.	Calcined Raw Umber.
Cadmium Yellow, extra Pale. Cadmium Yellow, Pale. Cadmium Yellow. Cadmium Yellow, Deep. Cadmium Orange.	Different varieties of Sulphide of Cadmium. With the exception of Cadmium Yellow, they differ from Aurora Yellow in possessing a certain amount of transparency.
Cadmium Green.	A mixture of Cadmium Yellow and Viridian prepared for use in Oil Colour only.
Cadmium Red.	A combination of Cadmium Sulphide with Selenium Sulphide.
Caledonian Brown.	The original Caledonian Brown being no longer obtainable, a close imitation is prepared from Sienna and Vandyke Brown.
Cappagh Brown.	A native earth containing Manganese in notable quantity. Many years ago the mine was exhausted, and the whole of the market was bought up at the time by Messrs. Winsor and Newton, who now hold a large and valuable stock of this magnificently-drying colour.
Carmine. Carmine, No. 2.	Lakes prepared from Cochineal.
Carmine Lake.	Synonymous with Carmine, No. 2.
Carmine Lake (Alizarin).	An Alizarin Lake of a Carmine Tint.
Cassel Earth.	Synonymous with Vandyke Brown.
Cerulean Blue.	Stannate of Cobalt.
Charcoal Grey.	The composition of this colour is expressed by its name.
Chinese Blue.	Synonymous with Prussian Blue.
Chinese Orange.	Synonymous with Alizarin Orange.
Chinese White.	A specially dense variety of Oxide of Zinc. Chinese White was first introduced by us and is still one of our great specialities. It should be noted that ordinary Zinc White is often sold as Chinese White; buyers should therefore test it for covering power on a piece of black paper.
Chrome Greens.	Combinations of Chrome Yellow with Prussian Blue.
Chrome Lemon.	A combination of Chromate of Lead and Sulphate of Lead.
Chrome Yellow.	Normal Chromate of Lead.
Chrome Deep. Chrome Orange. Chrome Red.	Chromates of Lead, more or less basic. Our Chromes are specially distinguished by the capital way in which they keep their colour on exposure.
Cinnabar Greens.	Similar in composition to Chrome Greens; but a deeper variety of Chrome Yellow is employed.
Citron Yellow.	Chromate of Zinc.
Cobalt Blue.	Alumina tinctured with Oxide of Cobalt. Our Cobalt Blue is unusually free from a tendency to become greenish on exposure.
Cobalt Green. Cobalt Green, No. 2 (Deep).	Zinc Oxide tinctured with Oxide of Cobalt.
Cobalt Violet. Cobalt Violet, No. 2.	Arseniates of Cobalt.

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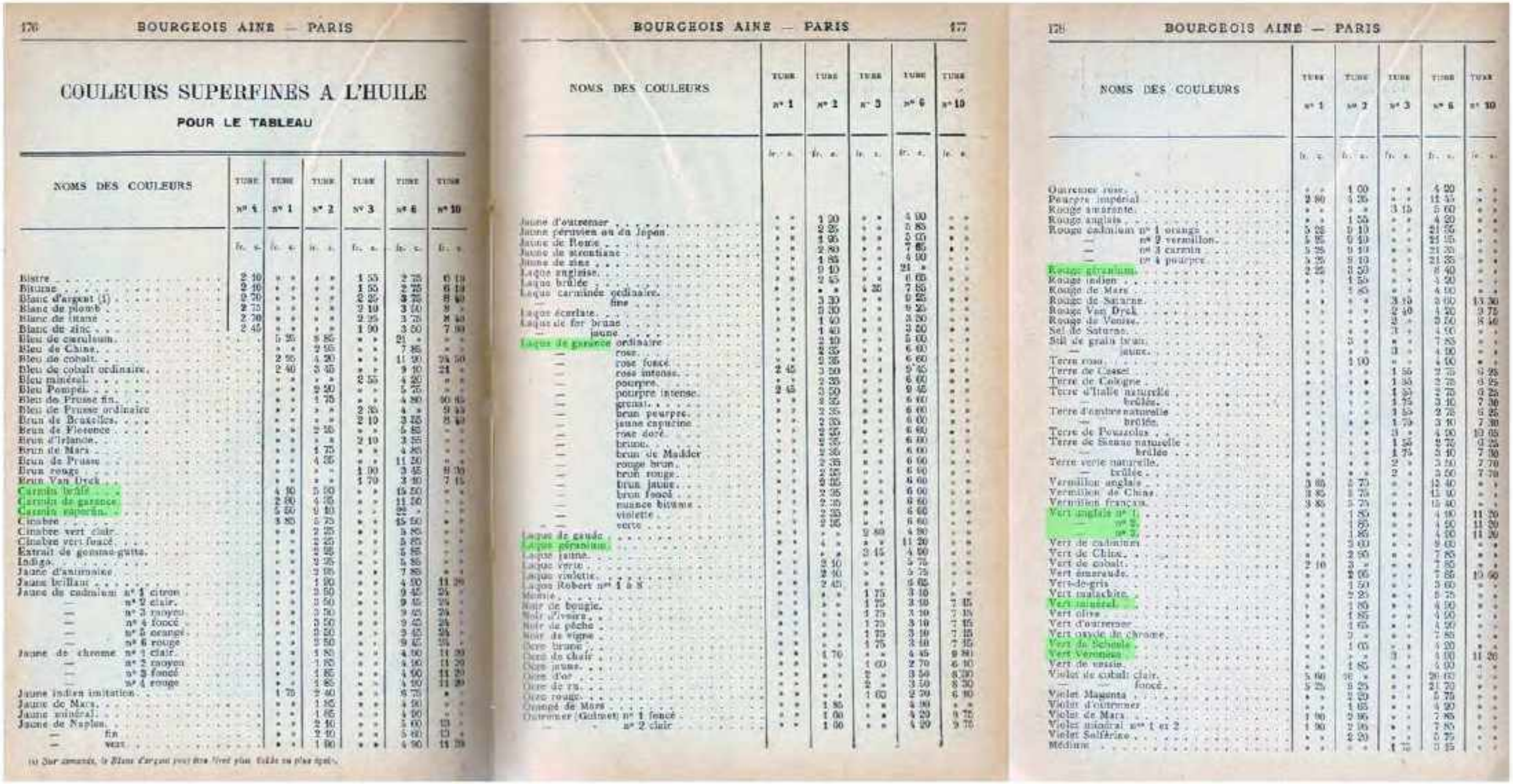
Cobalt Violet, Dark.	Phosphate of Cobalt.
Cobalt Yellow.	Synonymous with Aureolin.
Cologne Earth.	Calcined Vandyke Brown.
Composite White.	A mixture of Flake and Zinc Whites.
Constant White.	Barium Sulphate. Used only in Water Colour.
Cork Black.	A variety of Carbon Black, obtained by charring cork.
Cremnitz White.	Basic Carbonate of Lead.
Crimson Lake.	A Lake prepared from Cochineal.
Crimson Madder.	A Lake prepared from the Madder Root.
Crimson Madder, No. 2.	A paler variety of the above.
Cyanine Blue.	A synonym for Leitch's Blue.
Cyprus Umber.	Native Umber possessing the greenish cast of colour so much valued by Artists.
Davy's Gray.	A new colour prepared from a special variety of Slate and suggested by Mr. Henry Davy. It is particularly recommended as a reducing agent, as it does not, like the blacks, sully the colours with which it is mixed, but gives pure and translucid effects, and is a capital drier.
Dragons' Blood.	The genuine Dragons' Blood (a resin) being fugitive, an imitative pigment is now prepared, for use in Water Colour only, from Burnt Sienna, Alizarin Lake, and Gamboge.
Emerald Green.	Aceto-Arsenite of Copper.
Emerald Oxide of Chromium.	Synonymous with Viridian.
Extract of Vermilion.	Synonymous with Scarlet Vermilion.
Field's Orange Vermilion.	A specially levigated variety of Orange Vermilion.
Flake White, No. 1. Flake White, No. 2 (less stiff).	Basic Carbonate of Lead.
Flesh Tint.	Flake White tinted with Naples Yellow and Madder Lake.
Foundation Flake White.	A second grade of Flake White. Although a pure White Lead, it is not equal in density to Flake White. Foundation Flake White is also not ground to the same degree of perfection as Flake White, and is consequently cheaper to produce.
French Blue.	Synonymous with French Ultramarine.
French Vermilion.	Synonymous with Pale Vermilion.
Gallstone.	Synonymous with Yellow Carmine.
Gamboge.	A preparation of the gum resin known under this name.
Geranium Lake.	A fugitive Lake prepared from a Coal Tar dye.
Gold Ochre.	A native earth, more powerful than Oxford Ochre, and working more freely. Gives beautiful golden tones glazed thinly over white.
Gold Ochre, Transparent.	Native earth.
Green Lake, Light. Green Lake, Deep.	Combinations of a Yellow Lake with Prussian Blue.
Hooker's Green, No. 1 (Light). Hooker's Green, No. 2 (Dark).	Water Colour pigments, prepared from Prussian Blue and Gamboge.
Indian Lake.	A Lake obtained from Lac. This colour has recently been much improved by us, more of the true purple hue of the lac colouring matter being developed.
Indian Purple.	This pigment, for use in Water Colour, is a Cochineal Lake with a base of copper. For use in Oil an excellent substitute for this rather fugitive pigment is now manufactured from Madder Lake and French Ultramarine.
Indian Red.	A variety of Iron Oxide.

Figure A2. Compositions of pigments, listed in the catalogue of W&N from 1928, used for the manufacturing of oil and watercolours. The highlighted details show carmines, varieties of chrome greens, cinnabar green, cobalt yellow, emerald green, and geranium lake.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COULEURS SUPERFINES A L'HUILE

POUR LE TABLEAU

NOMS DES COULEURS

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NOMS DES COULEURS

Figure A3. Oil colours, listed in the catalogue of Bourgeois Ainé from 1929. The highlighted details show carmines, a range of madder lakes, geranium lake, geranium red, varieties of chrome greens, emerald green, Scheele's green, and its variant mineral green.

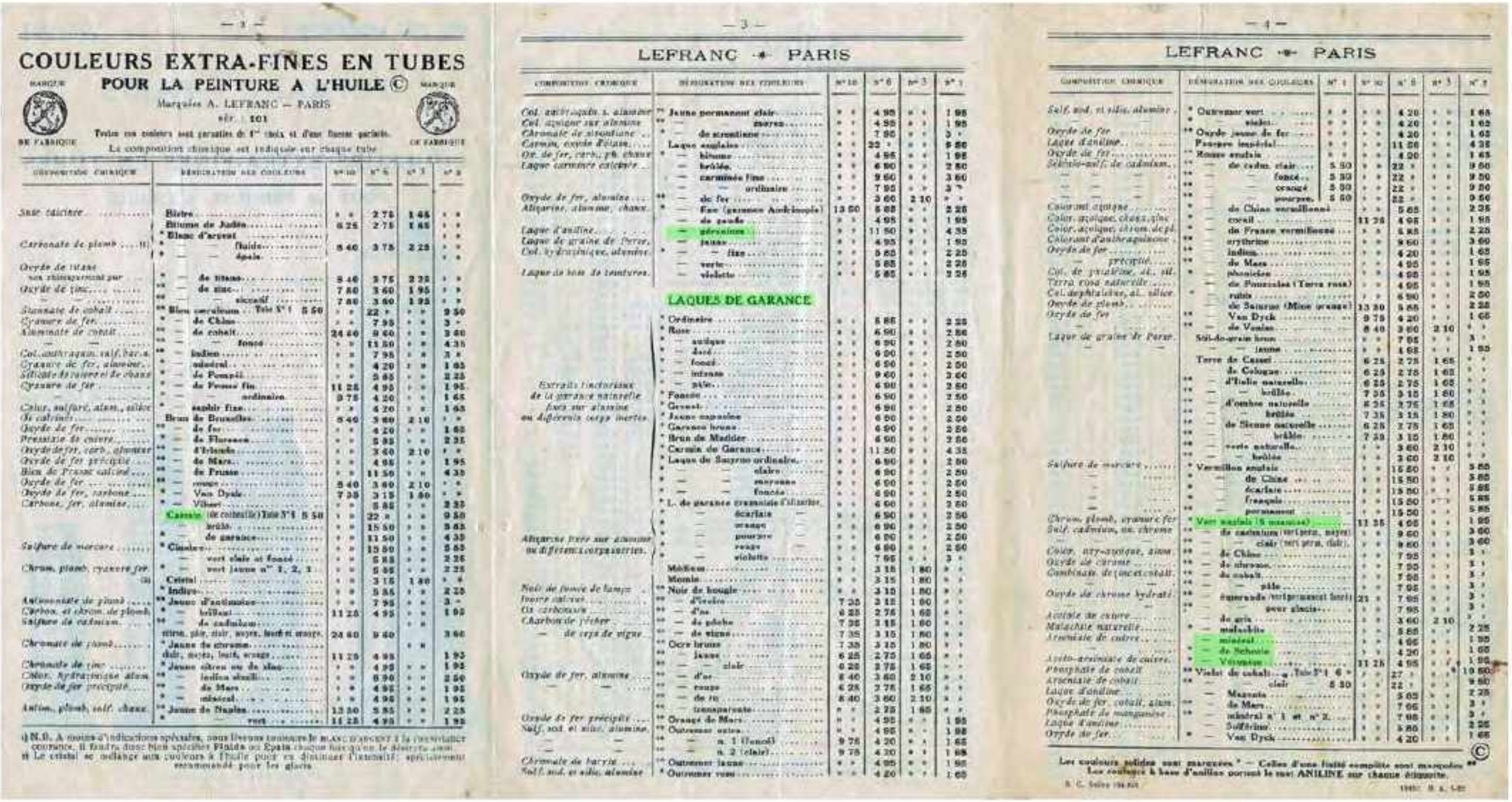

Figure A4. Oil colours, listed in the catalogue of Lefranc from 1931. The highlighted details show carmines, geranium lake, a range of madder lakes, varieties of chrome greens, emerald green, Scheele's green, and its variant mineral green.

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Article

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Article

A Multi-Analytical Investigation of Liu Kang's Colour Palette and Painting Technique from the Shanghai Period (1933–1937)

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Abstract: This study presents the analytical characterisation of Liu Kang's paint mixtures and the painting technique used during the important Shanghai artistic phase (1933−1937). Liu Kang (1911–2004) was a Chinese artist who received an academic art education in Shanghai (1926–1928) and Paris (1929–1932). He settled permanently in Singapore in 1945 and became a leading contributor to the national art scene. This study showcases 12 paintings on canvas from the collections of the National Gallery Singapore and the Liu family. An integrated approach combined non- and micro-invasive analytical methods supplemented with archival sources and enabled characterising the investigated paint mixtures and revealing details of the artist's painting technique. The study has proved the artist's ability to produce a variety of hues by utilising a conventional palette of colours. The predilection for ultramarine, viridian, yellow and red iron-rich earth pigments, umber, yellow chromate pigments, as well as lead white, zinc white or Zn-base compounds like lithopone and barium white was recorded. The study emphasises a minor use of Prussian blue, emerald green, cadmium yellow or its variant and bone black. Although it remains unknown what brands of paints Liu Kang used, the available archival sources give insights into the painting materials available in Shanghai that the artist could have had at his disposal during the period under review. The archival information is based on the Chinese and overseas colourmen advertisements printed in Chinese journals and the respective contemporary colourmen catalogues. The artist's painting technique departs from the experimental approach of his Paris phase. In Shanghai, he focused on synthesising the painting principles of the School of Paris with traditional Chinese calligraphy. The outcomes of this research may support future technical studies of works by other artists contemporary to Liu Kang and who were active in pre-war Shanghai.

Keywords: SEM-EDS; FTIR; IRFC; pigments; Liu Kang; Shanghai Art Academy

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1. Introduction

Liu Kang (1911–2004) was a Chinese emigree to Singapore who began his training in easel painting at the Xinhua Arts Academy in Shanghai (1926−1928). He was admitted to the Académie de la Grande Chaumière in Montparnasse in 1929 [1] and started work at Shanghai Art Academy, the Faculty of Western art in 1933 [2,3]. The outbreak of the Second Sino-Japanese War in 1937 had a profound impact on his prolific artistic activity in Shanghai, resulting in his relocation to Malaya. He eventually settled permanently in Singapore in 1945 and became one of the founders of the modern art movement in the emerging nation-state.

Liu Kang's stay in Shanghai was crucial for formulating his artistic ideas, which accompanied him throughout his professional career. In the late 1920s and early 1930s, Shanghai was the centre of the national art reformation movement, which challenged traditional art practices by introducing artistic ideas from the School of Paris [4–6]. The Shanghai

Art Academy played a pivotal role in these developments and Liu Kang's affiliation with the Academy created many opportunities to develop and professionally contribute to the art reformation movement [4,7]. A teaching position at the Academy meant admission to famous Shanghai artists' circles. Moreover, those affiliated with the Academy enjoyed a local and national reputation through numerous opportunities to present their works to the public through art exhibitions, publications and art societies' activities. In 1933, the Academy hosted a group exhibition of paintings by Liu Kang and fellow artists entitled "Master's art exhibition" [7]. He recalled: "The 30s was the golden age of art in Shanghai, especially of the Academy. There was vision. There was freedom of expression" [8].

As a tutor, Liu Kang promoted outdoor painting as an essential element of fine art education through trips with his students to Suzhou, Hangzhou, Changshu, Qingdao, Wuxi and Nanjing and other scenic locations near Shanghai to study the richness of the natural landscapes (Figure 1) [9]. He recalled: "We left footsteps everywhere in search of ideal subject matter for drawing but would return to our lodging by sunset" [2]. As an artist, he integrated the expression of Chinese identity and a vivid fascination with Post-Impressionism and Fauvism, which he regarded as symbols of universal progress in art. Hence, key modernist visual elements like solid colours, flat surfaces and reduced shading are commonly present in his artworks alongside the local subject matter and expressive lines evoking Chinese calligraphy [4,10].

Figure 1. Archival photograph of Liu Kang during outdoor painting class with students in Shanghai, in 1933. Liu Kang family collection. Images courtesy of Liu family.

The investigation of the artist's paint mixtures and painting technique from the Shanghai phase is of particular interest as, during that time, he consolidated the artistic experience acquired in Paris and expressed new ideas that laid the foundation for his later development. Therefore, the characterisation of his paint mixtures can determine pigment preferences and give insight into Liu Kang's artistic process during this short but important period. The obtained information can aid conservators in treatment of the paint layers and facilitate further investigation into Liu Kang's artistic activity in Shanghai by art historians.

2. Materials and Methods

2.1. Materials

This study showcases 12 paintings created on canvas supports by Liu Kang in Shanghai between 1933 and 1937 from the collections of the National Gallery Singapore (NGS) and the Liu family (Figures 2 and 3). As Liu Kang actively painted outdoors during that period, the predominant genres of his artistic output were landscapes, seascapes and countryside views. This correlation was observed in an earlier technical investigation of the artist's painting supports from the Shanghai phase, indicating that out of 26 examined artworks, 24 were executed outdoors [11]. In-depth analyses of the paint layers were conducted on 42 samples extracted from the NGS paintings. Artworks from the Liu family served as a complementary source of information for a more thorough understanding of the artist's painting technique. The inventory data of the paintings is contained in Table 1.

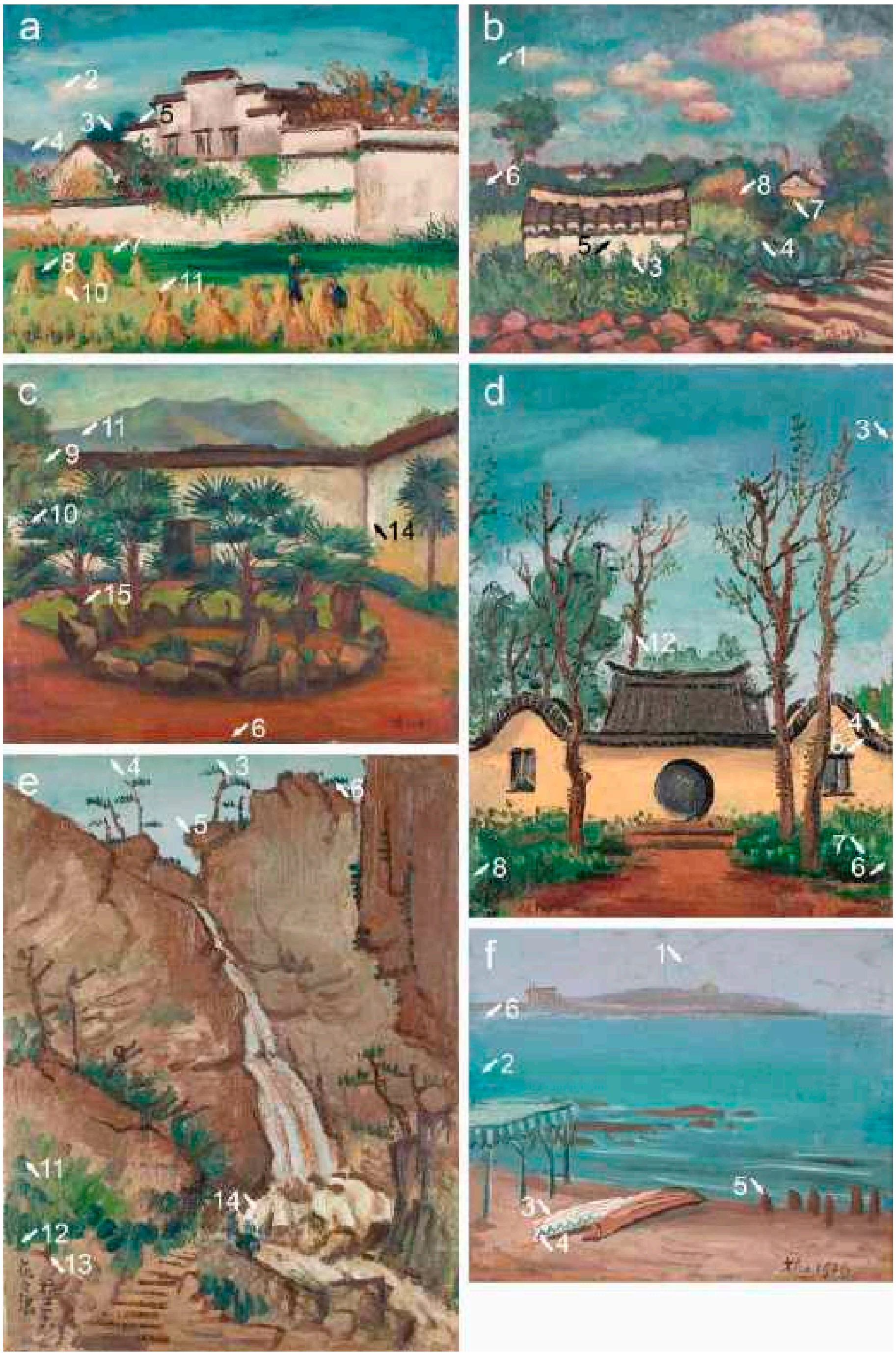

Figure 2. Paintings by Liu Kang from the collection of the National Gallery Singapore. (**a**) *Working at the fields*, 1933, oil on canvas, 49.5 × 64 cm; (**b**) *Countryside in China*, 1933, oil on canvas, 60.5 × 72 cm; (**c**) *Backyard*, 1934, oil on canvas, 59.5 × 72.5 cm; (**d**) *Chinese house*, 1934, oil on canvas, 64.5 × 50.5 cm; (**e**) *Waterfall*, 1936, oil on canvas, 65 × 50 cm; (**f**) *Seaside*, 1936, oil on canvas, 45 × 54 cm. Gifts of the artist's family. Collection of the National Gallery Singapore. Images courtesy of the National Heritage Board, Singapore. Arrows indicate sampling areas.

Figure 3. Paintings by Liu Kang from the Liu family collection. (**a**) *Courtyard, Shanghai*, 1933, oil on canvas, 73 × 60 cm; (**b**) *Countryside landscape*, 1933, oil on canvas, 45 × 54.5 cm; (**c**) *Pagoda*, 1936, oil on canvas, 45 × 55 cm; (**d**) *Rustic landscape*, 1934, oil on canvas, 54 × 46 cm; (**e**) *Seascape*, 1936, oil on canvas, 50 × 64 cm; (**f**) *Seaside near Shanghai*, 1936, oil on canvas, 46 × 55 cm. Liu Kang family collection. Images courtesy of the Liu family.

Table 1. Inventory and technical details of the studied paintings.

Title and Inventory Number	Owner	Date	Dimensions H × W (cm)	Primary Support
Working at the fields, 2003-03258	NGS	1933	49.5 × 64	Primed canvas
Countryside in China, 2003-03299	NGS	1933	60.5 × 72	Primed canvas
Courtyard, Shanghai	Liu family	1933	73 × 60	Primed canvas
Countryside landscape	Liu family	1933	45 × 54.5	Primed canvas
Backyard, 2003-03252	NGS	1934	59.5 × 72.5	Primed canvas
Chinese house, 2003-03328	NGS	1934	64.5 × 50.5	Primed canvas
Rustic landscape	Liu family	1934	54 × 46	Primed canvas
Waterfall, 2003-03247	NGS	1936	65 × 50	Primed canvas
Seaside, 2003-03318	NGS	1936	45 × 54	Primed canvas
Seaside near Shanghai	Liu family	1936	46 × 55	Primed canvas
Pagoda	Liu family	1936	45 × 55	Primed canvas
Seascape	Liu family	1936	50 × 64	Primed canvas

2.2. Methods

The research strategy prioritised the NGS paintings and was based on non-invasive imaging techniques, followed by sampling and detailed analyses of the constituents of the paint mixtures. The imaging techniques comprised visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR), near-infrared (NIR) photography and infrared false-colour (IRFC). The latter was achieved by manipulating VIS and NIR photographs. The imaging techniques enabled a tentative characterisation of the paint mixtures and determined the potential sampling areas. Then, the micro-invasive methods involved the extraction of the paint fragments and their preparation as cross-sections and pigment dispersions for the characterisation of the optical features of the pigments using optical microscopy (OM) and polarised light microscopy (PLM). The tentative visual identification of pigments was combined with spectroscopic techniques, such as field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) followed by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR). The information obtained with these techniques enabled the identification of organic and inorganic constituents of the paint mixtures. The information was cross-referenced with local advertisements of the painting materials and contemporary colourmen catalogues such as Reeves & Sons (R&S), Winsor & Newton (W&N) and Lefranc which additionally gave insight into the local market of art materials.

The artist's family preferred to limit the investigation in regards their paintings to in-situ technical descriptions and detailed photography. Hence, due to the nature of the collected information, the Liu family collection supported the study of the artist's painting technique.

2.2.1. Technical Photography

All paintings were photographed by means of a full spectrum (360–1100 nm) Nikon D850 DSLR camera (Tokyo, Japan) with an AF Micro NIKKOR 60 mm focal length and f/2.8D lens (Tokyo, Japan). VIS and UVF photography was conducted by coupling X-Nite CC1 (Carlstadt, NJ, USA) and B+W 415 (Bad Kreuznach, Germany) filters together, whereas UVR required Andrea "U" MK II filter and NIR imaging used Heliopan RG1000 (North White Plains, NY, USA) filter [12–14]. The paintings were illuminated with two Lastolite Ray D8 (500 W tungsten bulb) lamps for VIS and NIR imaging. The light source for UV and UVR photography techniques was a pair of CLE Design (London, UK) lamps equipped with eight 120 cm long, 40 W, UV fluorescence tubes with a peak at 365 nm. The X-Rite ColorChecker Passport (Grand Rapids, MI, USA) was used for camera calibration and the creation of the colour correction profile for VIS photography in Adobe Photoshop CC software (San Jose, CA, USA). The American Institute of Conservation Photo Documentation target (Washington, DC, USA) was used for the adjustment of the white balance and correction of the exposure for VIS and NIR photography [12]. The IRFC images were obtained by converting NIR images into greyscale, followed by substituting the VIS images' R, G, B channels into IR, R and G using Adobe Photoshop CC software [15].

2.2.2. Preparation of Samples

Pigment mixtures selected for the PLM analyses were dispersed on microscope glass slide, embedded in Meltmount (nD = 1.662) from Cargille (Cedar Grove, NJ, USA) and secured with a glass cover. Samples for the cross-section analyses were mounted in acrylic resin—ClaroCit from Struers (Cleveland, OH, USA). The cured resin-casts were ground and polished wet on SiC Foils from Struers down to grade 4000 using grinder-polisher MetaServ 250 from Buehler (Lake Bluff, IL, USA).

2.2.3. OM and PLM

OM of the paint stratigraphy of the cross-sections and PLM of the pigments' scrapings were carried out using a Leica DMRX polarising microscope (Wetzlar, Germany) at magnification range of 100×–400×. The PLM observations were carried out in accordance with the workflow proposed by Peter and Ann Mactaggart [16]. The observations were recorded using a Leica DFC295 3 Mpx digital camera and further processed with Leica Application Suite 4.8 software.

2.2.4. FE-SEM-EDS

The elemental characterization and mapping of the paint cross-sections were performed using Hitachi SU5000 FE-SEM (Tokyo, Japan) equipped with Bruker XFlash® 6/60 EDS (Billerica, MA, USA). The SEM was operated with an accelerating voltage of 20 kV, 50–60 intensity spot, 10 mm working distance and 60 Pa vacuum. Acquisition time for the EDS elemental analyses and mapping was 180 s. Data acquisition and processing were conducted with Bruker ESPIRIT 2.0 software.

2.2.5. ATR-FTIR

ART-FTIR measurements were performed on the paint cross-sections using a Bruker Hyperion 3000 FTIR microscope supplied with a mid-band mercury cadmium telluride detector coupled with a Vertex 80 FTIR spectrometer. The ATR objective (20×) equipped with a germanium crystal was used for the compression of the samples. The background spectrum was measured with 64 scans before spectra acquisition of each sample. All spectra, including backgrounds and samples were obtained in a spectral region ranging from 4000 to 600 cm^{-1} at a 4 cm^{-1} spectral resolution over 64 scans. Bruker Opus 7.5 software was used to process and interpret the data. The spectra were also compared to references in the material collection of the Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, spectral library of the Infrared and Raman Users Group (IRUG) [17], database of ATR-FT-IR spectra of various materials [18] and reference spectra published in the literature.

3. Results

3.1. Art Materials in Shanghai in the 1930s

Despite the lack of information about the brands of paints preferred by Liu Kang during his artistic activity in Shanghai, the studies of the contemporary colourmen advertisements published in the *Shanghai Art Academy Graduation Yearbook* and Shanghai pictorials, *The Young Companion* and *Arts and Life* gave insight into the local market of art materials. Hence, the archival sources, although limited, turned out to be complementary to the analytical data collected from the paintings and supported the interpretation of certain materials as well as assisted in a determination of the artist-made or commercial pigment mixtures.

Both local brands, such as Marie's and Eagle, and imported ones like R&S and W&N, were available at stationery shops and bookstores. Although local colourmen catalogues from the 1930s were not available to the authors, combining the textual and pictorial information from the 1930s advertisements revealed the most common painting materials offered to the artists at that time. These included watercolours in tubes and cubes, oil colours in tubes, poster paints, Chinese ink, drying oil, brushes, canvases, pastels and drawing tools.

Interestingly, Marie's company advertisement from 1934 listed 12 pigments: orpiment, indigo, azurite, yellow ochre, burnt ochre, malachite, organic red (unspecified), vermilion, carmine, white powder (unspecified), gamboge and cinnabar (Figure 4a–m) [19]. The company additionally highlighted rose madder oil paint and watercolour chrome orange in their 1935 and 1937 advertisements (Figure 5a–d) [20,21]. Various advertisements from 1936 by the Eagle company highlighted oil tube paints with ultramarine and olive green as well as watercolour tubes with chrome yellow and carmine tint (Figure 5e–j) [22].

Figure 4. Advertisement by Marie from 1934 with marked listing of 12 pigments (**a**) and corresponding details of the Chinese characters referring to orpiment (**b**), indigo (**c**), azurite (**d**), yellow ochre (**e**), burnt ochre (**f**), malachite (**g**), organic red (**h**), vermillion (**i**), carmine (**j**), white powder (**k**), gamboge (**l**) and cinnabar (**m**).

Regarding the imported brands, R&S was the sole advertiser of art materials in *The Young Companion* and *Arts & Life* between 1932 and 1935. During that time, the company actively promoted the introduction of 16 watercolour tubes, 48 oil colour tubes and highlighted watercolours in tubes with Prussian blue and vermillion as well as oil paints in tubes with cobalt blue tint and yellow ochre (Figure 6a–c).

Growing recognition of the R&S brand in China resulted in fierce competition from local manufacturers, who found a niche market for imitations of R&S products. To protect the brand's reputation, R&S released advertisements warning clients of these poor-quality products (Figure 6a–c) [23–26]. Besides R&S painting materials, W&N was another overseas brand available in Shanghai, and their watercolours, drying oil and painting canvas were reported by T. Tsuruta [7].

Figure 5. Advertisements by Marie from 1935 (**a**), 1937 (**c**) and by Eagle from 1936 (**e**,**g**) with highlighted paint tubes (colour rectangles) and corresponding details showing types of paints (**b**,**d**,**f**,**h**–**j**).

Despite the wide range of local and imported painting materials available in Shanghai, Liu Kang also might have used paints purchased during his time in Paris (1929–1932). Although there is no direct evidence of the specific brand(s) that he used in Paris, it is known that he had some interest in Lefranc colours [27]. Moreover, he might have had access to painting materials from other French and overseas manufacturers whose advertisements were presented in the authors' earlier research [11,28].

3.2. Pigments

The colour scheme of the study group paintings is relatively simple, primarily incorporating hues of blue, green, yellow, and brown as well as white and black. For clarity of the discussion, the results are presented based on the frequently occurring colours. Results of the FTIR analyses of paint samples confirmed that pigments were bound in a drying oil detected by absorption peaks at 2920, 2855, 1735, 1161 and 720 cm^{-1} (Appendix A, Table A1) [18].

3.2.1. Blue

Liu Kang seems to have preferred ultramarine (PB29) for depicting sky, water, distant foreground mountains or for strong outlining of shapes. The pigment was assumed based on the IRFC purple imaging of the blue passages and PLM observation of blue, isotropic particles that have a low refractive index and appear red under a Chelsea filter. These outcomes were corroborated by the Na, Al, Si, and S elements detected using SEM-EDS and FTIR measurements exemplified by IR absorption peaks at 984, 693 and 666 cm^{-1} as in sample 6 from *Countryside in China* (1933) (Figure 7) or peak at 990 cm^{-1} detected in sample

1 from *Seaside* (1936). However, despite the positive PLM observation and detection of ultramarine constituting elements, the FTIR confirmation of this pigment in other blue paint mixtures was complicated due to interferences of functional groups related to different compounds. Therefore, FTIR allowed detection of only a single IR absorption peak at ca. 1000 cm^{-1} implying the presence of ultramarine in the sample 11 from *Backyard* (1934), sample 4 from *Countryside in China* (1933), sample 3 from *Chinese house* (1934) and sample 4 from *Waterfall* (1936).

Figure 6. Advertisements by R&S warning of local imitations of their products and highlighting (**a**) Prussian blue watercolour, (**b**) vermilion watercolour and (**c**) cobalt blue and yellow ochre oil colours.

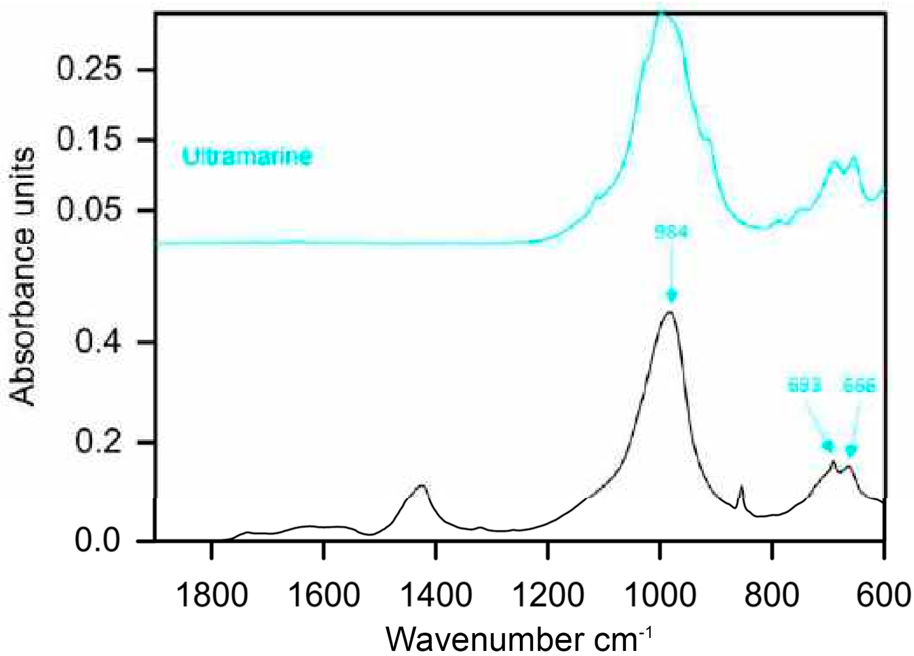

Figure 7. ATR–FTIR spectra derived from the blue paint of sample 6, collected from *Countryside in China*, 1933, with labelled marker peaks of ultramarine and reference spectra of the same pigment.

The blue hue was often modified by combining prevalent ultramarine with other blue, green and yellow pigments. For instance, the addition of Prussian blue (PB27) to ultramarine is assumed in paint sample 4 from *Waterfall* (1936). The pigment was tentatively identified with PLM (observation of dark blue isotropic particles that appear dark green with a Chelsea filter and have a low refractive index), by SEM-EDS detection of iron and an IR absorption peak at 2093 cm^{-1}. The results of the analyses conform with IRFC imaging, as the violet colour of the sampling area is determined by a blue representation of Prussian blue and a purple representation of ultramarine.

The analyses of sample 6 extracted from *Seaside* (1936) implied viridian (PG18) and yellow iron-rich earth pigment mixed with ultramarine (Figure 8). Viridian was assumed based on the combined PLM (observation of green, large and rough anisotropic particles with a high refractive index) and SEM-EDS detection of Cr. Yellow iron-rich earth pigment was considered based on the combined PLM observation (yellow, anisotropic particles with a high refractive index) and detection of Fe-signal. Both ultramarine and yellow ochre were easily available in Shanghai from Eagle and R&S, according to the companies' advertisements (Figures 5i and 6c). The addition of strontium yellow (PY32) to ultramarine was confirmed in the sample 11 from *Backyard* (1934) by FTIR absorption peaks at 907, 889, 873 and 843 cm^{-1} and a high concentration of Sr. A trace concentration of emerald green (PG21) found in the sample 6 from *Countryside in China* (1933) may suggest contamination of the paint mixture. Although known for its high toxicity, emerald green was available from major colourmen brands in the 1930s. Both R&S and W&N were operating in China and listed this green pigment in their catalogues from 1934. It was also available from Lefranc under the name vert Véronèse, according to the company's 1934 catalogue (Appendix A, Figures A1–A3). W&N and Lefranc catalogues from 1934 show the availability of strontium yellow (Appendix A, Figures A1 and A3).

Prussian blue was also identified as a principal blue pigment in the sample 3 from *Working in the fields* (1933). The PLM and SEM-EDS outcome was completed with FTIR by absorption peak at 2087 cm^{-1} assigned to C≡N stretching. It is worth noting that the violet IRFC imaging of the extraction area is determined by a blue representation of Prussian blue and purple representation of viridian in IRFC (Figure 9).

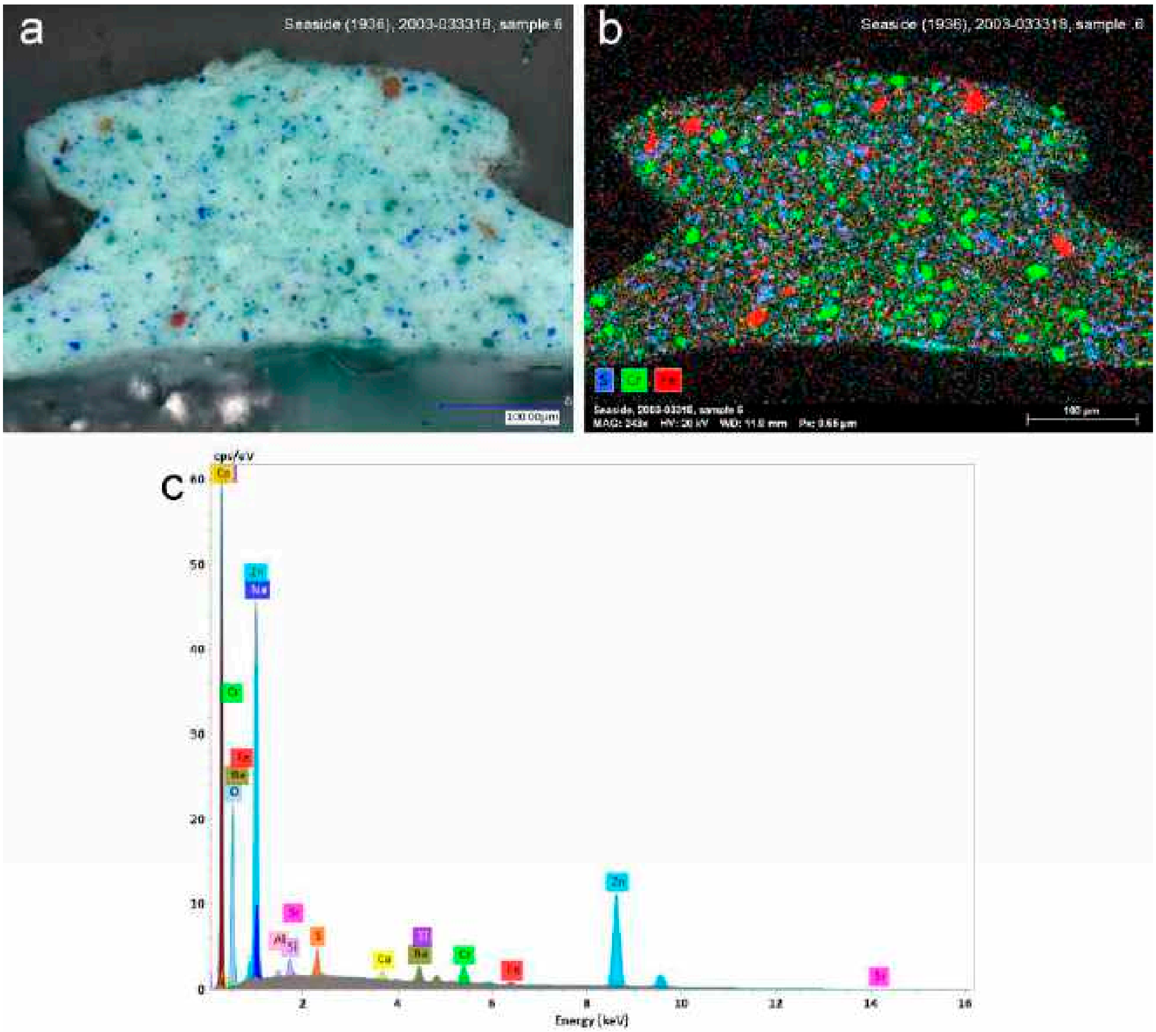

Figure 8. Microscopy image (**a**), corresponding SEM-EDS elemental map (**b**) and SEM-EDS spectra (**c**) of sample 6, extracted from *Seaside*, 1936. The SEM-EDS analyses show the distribution of S elements relating to ultramarine, Cr relating to viridian and Fe attributing to yellow iron-containing earth in the paint sample.

3.2.2. Green

The analyses of green hues revealed a frequent use of viridian, often in combination with ultramarine, Prussian blue, yellow iron-rich earth pigments and yellow chromate pigments.

Sample 4, taken from the green paint of *Countryside in China* (1933) was found to contain a high concentration of viridian. The pigment was confirmed by IR absorption peaks at 3083, 1285, 1252, 1064 and 794 cm^{-1}. The result was consistent with the PLM observation and SEM-EDS analysis. However, an unequivocal declaration of the presence of viridian in other green paint mixtures was challenging due to overlapping bands of other compounds.

Besides viridian, emerald green is another green pigment used. However, it was found only in two investigated green paint mixtures—samples 3 and 4, extracted from *Countryside in China* (1933). This pigment was evidenced by the coincident presence of copper and arsenic elements (Figure 10) as well as IR absorption peaks in the region 1555–1530 cm^{-1} and ca. 680 cm^{-1} and 630 cm^{-1} [29]. Minor use of this green pigment by Liu Kang was already reported in the research of his Paris painting practice (1929–1932) and paintings from the 1950s, suggesting a reluctance to give it a more pronounced role [28,30].

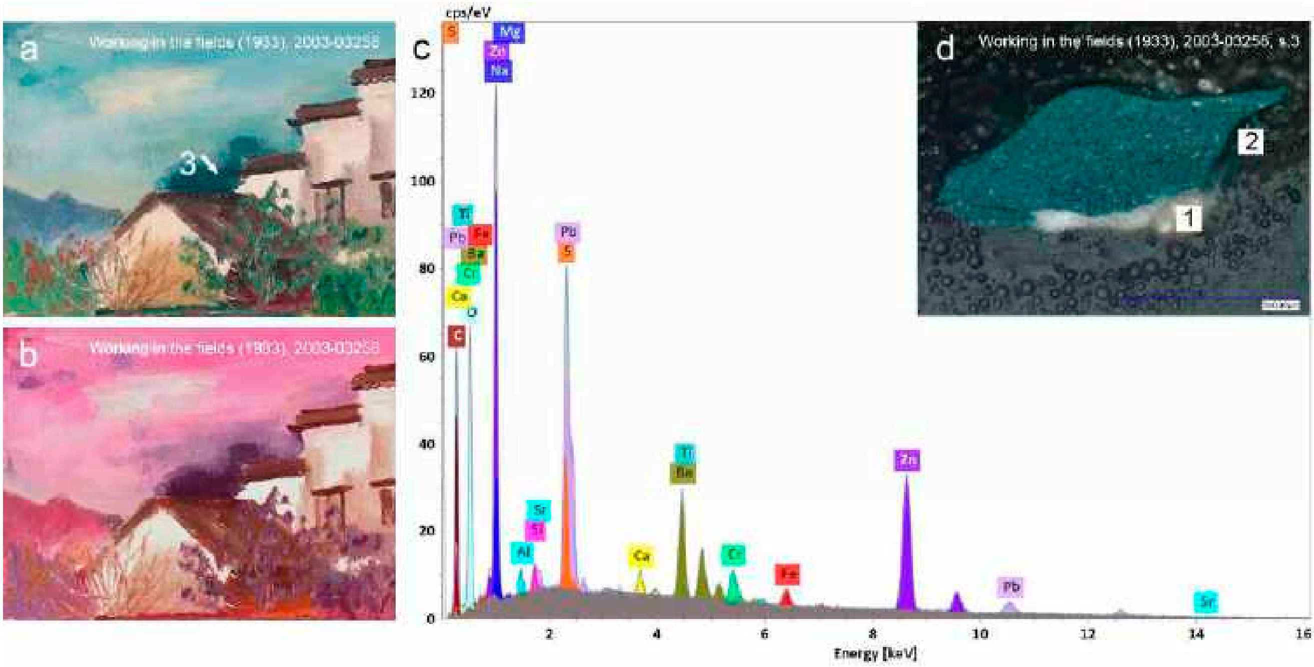

Figure 9. Detail of *Working in the fields*, 1933, photographed in VIS showing the location from which sample 3 was extracted (**a**) and IRFC image of the same area (**b**). SEM-EDS spectra of the blue paint, extracted from the sampling spot (**c**) and corresponding optical microscopy image of the cross-section of sample 3 at 200× magnification with the marked area of analysis in layer 2 (**d**). A blue colour recorded as dark violet in IRFC (**b**) and the presence of Fe and Cr (**c**) in layer 2 (**d**) suggested a mixture composed predominantly of Prussian blue and viridian.

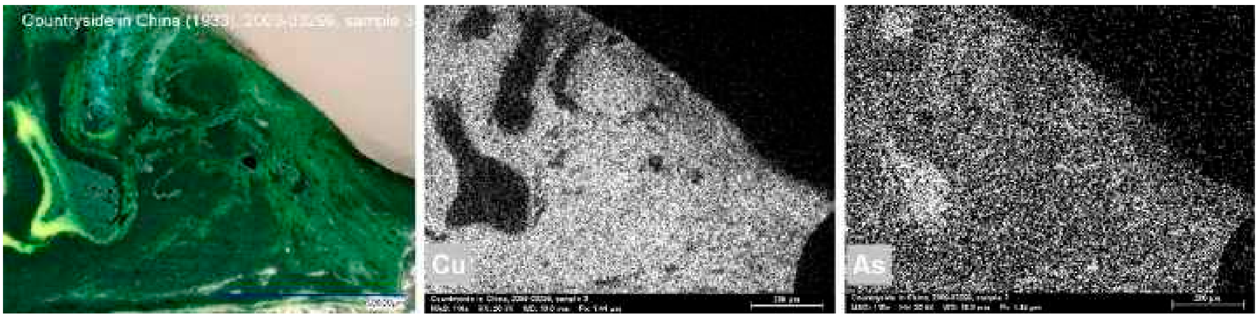

Figure 10. Optical microscopy image of the paint cross-section of sample 3 obtained from *Countryside in China*, 1933 and captured at 100× magnification (top-left), followed by SEM-EDS elemental distribution maps. The intensity of the signal of each element is represented by a range of grey tones: white represents high intensity and black represents low intensity. A concomitant presence of highly intensive copper and arsenic signals suggests the use of emerald green.

A green hue of sample 10 extracted from *Backyard* (1934), was achieved by mixing ultramarine, some Prussian blue and strontium yellow. The latter was verified by the SEM-EDS detection of Cr and Sr elements and FTIR absorption peaks at 903, 881, 873 and 840 cm^{-1} (Figure 11). Prussian blue was suspected based on the PLM characterisation of the particles, followed by trace Fe-signal and an IR absorption peak at 2089 cm^{-1}, whereas ultramarine was assumed based on strong S-, Na-, Si- and Al-signals, an IR absorption peak at 1000 cm^{-1} and PLM observation. The microscopic image of the paint cross-section shows partially mixed pigments allowing us to infer that the green was obtained on the palette by the artist (Figure 12).

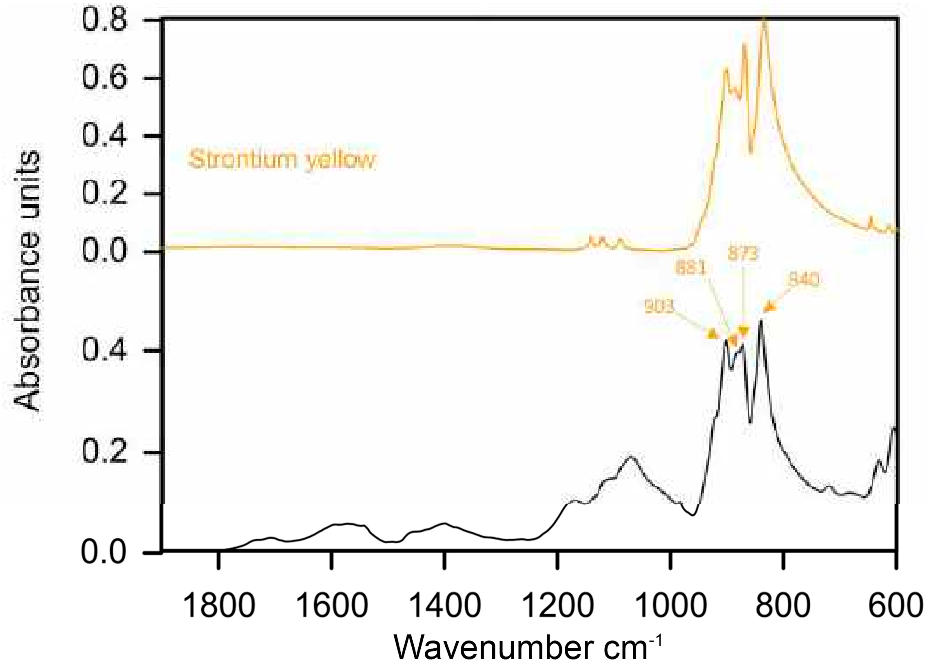

Figure 11. ATR–FTIR spectra obtained from the green paint of sample 10, extracted from *Backyard*, 1934 with labelled marker peaks of strontium yellow and reference spectra of the same pigment.

A combination of Prussian blue and yellow chromate pigment(s) is assumed in some green paint samples. Although Prussian blue was positively identified with FTIR, a precise attribution of yellow chromate pigments was challenging due to their overlapping bands and signal interferences of other compounds. For example, FTIR of the green paint in sample 4 from *Seaside* (1936) implies the presence of zinc yellow (PY36) (937, 872 and 820 cm^{-1}), chrome yellow (PY34) (839 and 820 cm^{-1}), barium yellow (PY31) or strontium yellow (872 and 839 cm^{-1}), chalk (PW18) (872 cm^{-1}) and viridian (797 cm^{-1}). In addition, a single IR absorption peak at 854 cm^{-1} detected in the green paint in the sample 6 from *Chinese house* (1934) and sample 6 from *Waterfall* (1936) as well as an absorption peak at 815 cm^{-1} detected in sample 3, extracted from *Countryside in China* (1933) may imply the use of chrome yellow and/or other yellow chromate pigments based on Zn, Ba and Sr [31,32].

Admixtures of yellow iron-rich earth pigments in the examined green paints were tentatively identified using PLM and SEM-EDS, whereas FTIR spectra could not provide sufficient information to determine the type of the pigment due to overlapping signals of other compounds.

3.2.3. Yellow and Brown

The principal components of yellow and brown brushstrokes were yellow iron-rich earth pigment and yellow chromate pigments. Brown hues were achieved with red iron-rich earth pigments, yellow chromate pigments and umber (PBr7). The latter was evidenced by co-presence of iron and manganese elements and IR absorption peaks at 3693, 3652, 3620, 1027, 1003, 910, 794, 750 and 667 cm^{-1} as in the sample 11 from *Working in the fields* (1933) (Figure 13) [33]. Moreover, the concomitant presence of calcium and phosphorus and the peculiar IR absorption peak at 1027 cm^{-1} are likely associated with bone black (PBk9) added to umber to produce a deeper shade of the brown paint.

Observation of red UV fluorescence of yellow particles in sample 15 from *Backyard* (1934) suggested Cd-based yellow [12]. Further SEM-EDS analyses detected Cd, S, Ba and Zn elements, which implied cadmium yellow (PY35) or cadmopone (co-precipitated cadmium sulfide and barium sulfate) or zinc-modified light cadmium yellow [34]. The pigment was used as an admixture with yellow chromate pigment(s) and red iron-rich earth pigment to obtain a brown hue.

A trace presence of emerald green in sample 8 from *Countryside in China* (1933) was considered as contamination as this green pigment was incorporated in the green passages (samples 3 and 4) and was found in the blue paint (sample 6) of the same composition. However, small concentrations of Prussian blue and viridian found in the brown paint (sample 5) from *Working in the fields* (1933) may be indicative of the intentional enhancement of the hue.

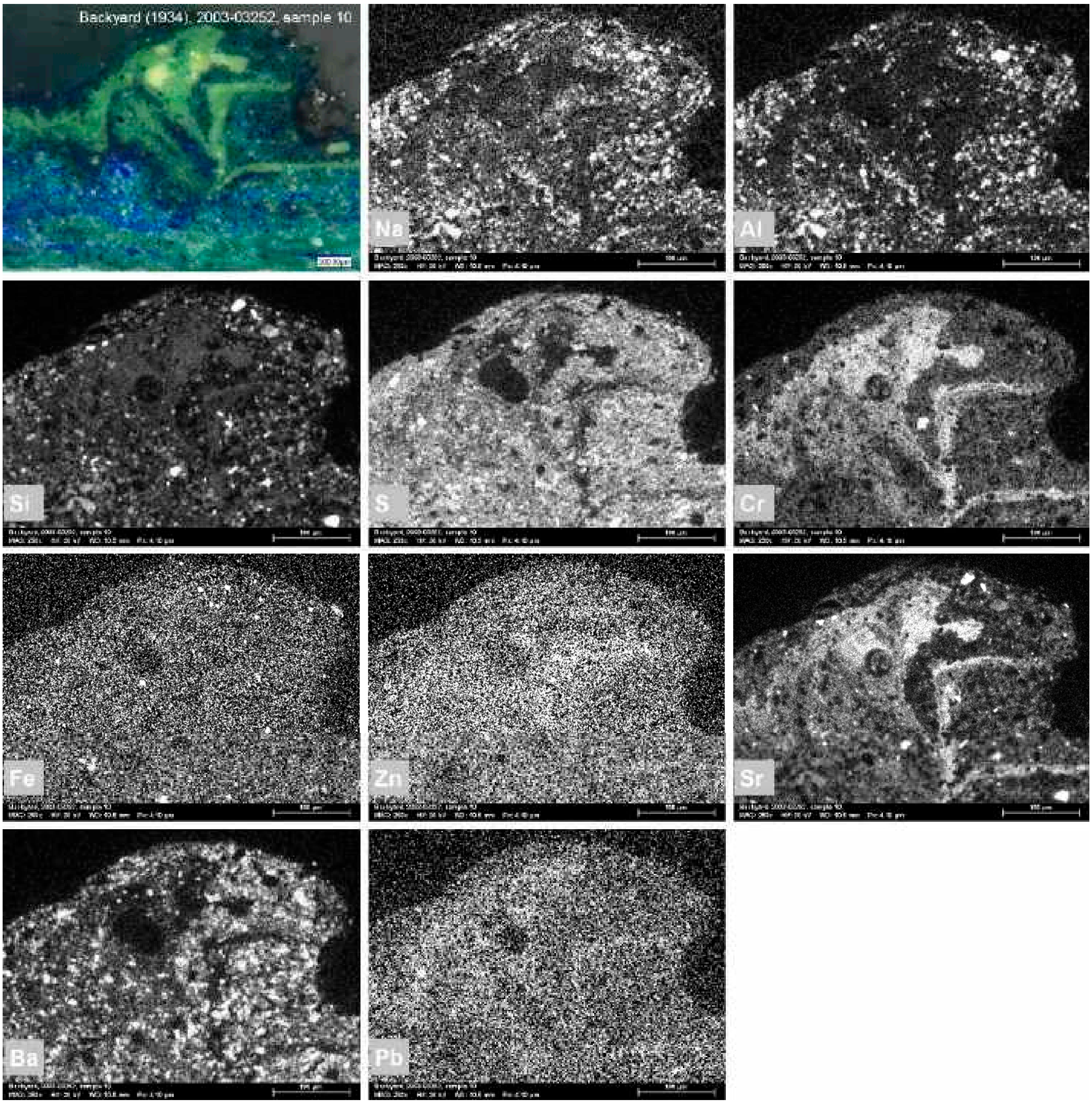

Figure 12. Optical microscopy image of the cross-section of sample 10, extracted from *Backyard*, 1934 and captured at 250× magnification (top-left), followed by SEM-EDS elemental distribution maps. The intensity of the signal of each element is represented by a range of grey tones: white represents high intensity and black represents low intensity. A co-presence of highly intensive Cr- and Sr-signals may indicate the use of strontium yellow. Na, Al, Si and S elements may suggest a presence of ultramarine. Fe-signal is attributed to Prussian blue.

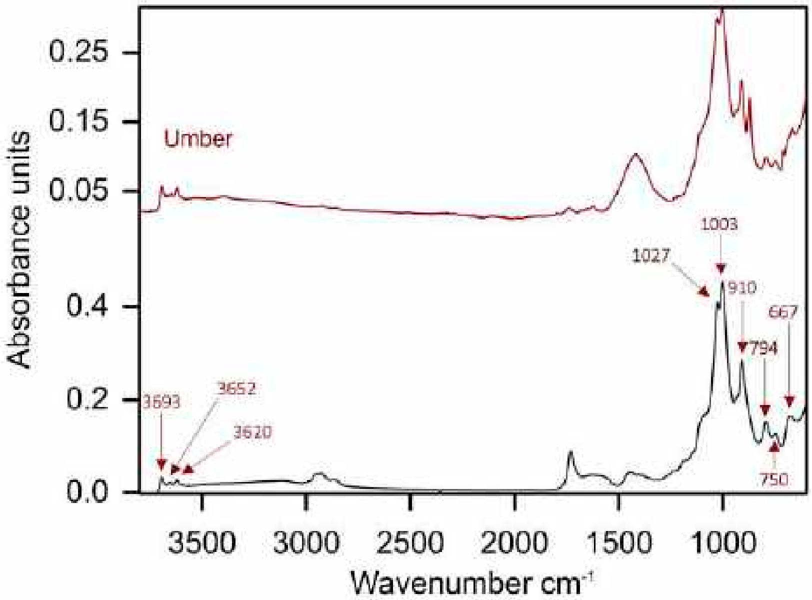

Figure 13. ATR–FTIR spectra of the brown paint of sample 11, extracted from *Working at the fields*, 1933, with labelled marker peaks of umber and reference spectra of the same pigment.

3.2.4. White and Black

The SEM-EDS elemental analyses of white paint samples revealed high concentrations of Zn coexisting with Ba and S elements, suggesting the use of lithopone (PW5) and/or barium white (PW21) and zinc white (PW4). The Zn element is commonly present in other investigated paint mixes; however, it is difficult to ascertain whether zinc white was used or whether zinc was present as part of the lithopone added by the manufacturer as an extender. Interestingly, an exclusive presence of zinc white was recorded in the white paint (sample 3) from *Seaside* (1936).

Low concentrations of Pb found in almost all investigated white paint samples may be indicative of trace presence of lead white (PW1). Frequent admixtures of lead white to zinc-based white paints may relate to the commercial modification of the latter. As zinc white is characterised by poor hiding power in the oil binder, manufacturers often employed lead white or titanium white to improve its properties [35]. Based on the SEM-EDS analyses, lead white features as the main compound only in the white paint (sample 5) from *Countryside in China* (1933). This finding was corroborated with the UVR imaging of the sampling area, which appears white, indicating highly reflective lead white (Figure 14) [12,13,15].

Figure 14. VIS (**a**) and corresponding UVR detail image (**b**) of *Countryside in China*, 1933, indicating a strong UV reflectance of white paint from the building (red arrow), suggesting a presence of lead white and/or lithopone.

Frequent occurrences of chalk at low concentrations were suspected based on the detection of Ca element. The presence of chalk may suggest its commercial use as an extender to other white pigments [36]. The detection of Ti only in the white paint (sample 14) from *Waterfall* (1936) seems to point to the minor addition of titanium white (PW6). This white pigment is known to be used as a commercial admixture of zinc white, barium white or lithopone to improve their properties [37]. According to the 1934 W&N catalogue, titanium white was extended with barium white (Appendix A, Figure A1), which is also present in the analysed sample. However, Lefranc listed this white pigment as pure titanium dioxide in the 1934 catalogue (Appendix A, Figure A3), whereas R&S did not sell it in the 1930s (Appendix A, Figure A2) [37]. Although titanium white was found in a single white paint sample, the SEM-EDS analyses lead us to believe that this pigment may be present in small amounts in other investigated colour mixtures. However, it is also known that titanium is a frequent impurity in mineral-based pigments [37].

Black brushstrokes were observed only in *Chinese house* (1934). The analyses of sample 5 from that painting revealed that instead of pure black pigment, the paint was composed of a mixture of Prussian blue, ultramarine, viridian and some bone black. The minimal admixture of bone black was suspected in other paint mixes to modify their shade.

3.3. Painting Technique

Although there is only one watercolour sketch for giving some insights into the artist's development of the composition and colour relationships prior to painting *Pagoda* (1936) (Figure 15), the execution of the remaining investigated artworks shows that the artist began painting with a clear idea of the intended compositions. Hence, the artist's reliance on the sketches is very likely.

Figure 15. (**a**) Liu Kang, *Pagoda*, 1936, watercolour, 28.5 × 18 cm. (**b**) Liu Kang, *Pagoda*, 1936, oil on canvas, 45 × 55 cm. Liu Kang family collection. Images courtesy of the Liu family.

Notably, no preparatory underdrawings have been detected in any of the paintings examined with VIS and NIR. Hence, it is assumed that the compositions were initially laid out with painterly contours, which were gradually coloured in, providing the base for further work. Although the compositions were well planned, they reveal spontaneous and rapid execution typical for outdoor painting within a limited time of a single sitting. This observation was confirmed by the OM of the paint layers, revealing partially mixed colours (Figures 10 and 12) and a wet-on-wet paint application. The appearance of immediacy is also reflected by the partially exposed white ground suggesting a lack of time for finishing touches to completely cover the painting support with paint. This can be exemplified by *Countryside landscape* (1933) and *Courtyard, Shanghai* (1933) (Figure 16). The compositions were achieved with washes of highly thinned colours, which were locally overlaid with a thick paint spread with brushes and palette knives in the subsequent stages. Although white ground provides additional contrast between the colours, it seems that this optical effect was not intentional, contrary to the paintings created in Paris [28].

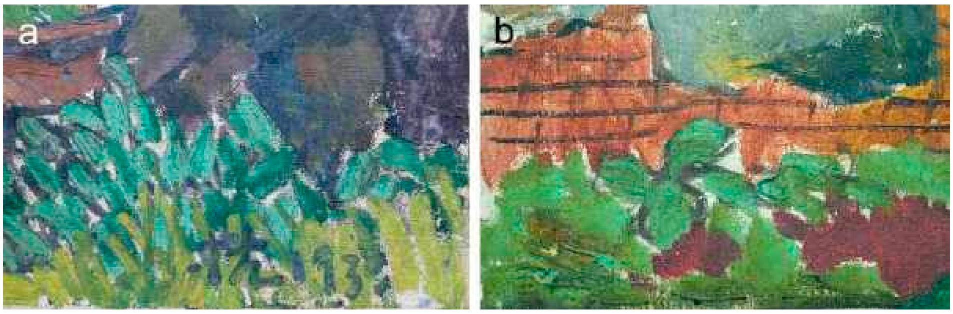

Figure 16. Details showing the intentionally exposed colour of the ground and thin application of colours in the painting process in: (**a**) *Countryside landscape*, 1933; (**b**) *Courtyard, Shanghai*, 1933.

Despite prevalent single-session execution of the investigated paintings, *Chinese house* (1934) is a rare example of a composition altered in a distinct stage in a wet-on-dry technique. The alteration concerned replacing the initially painted massive tree with the silhouettes of two young trees on the right side of the composition as reported earlier [38].

All paintings reflect the artist's ability with effortless and synthetic capturing of complex compositions. The painting *Seaside* (1936) is based on three colours—violet, turquoise and brown, whereas *Seascape in China* (1936) is based on a two-colour division—turquoise and yellow (Figures 2f and 3e). The complex composition of *Rustic landscape* (1934) is characterised by simplified colour passages, whereas the lack of painterly details was compensated by an attractive warm-cool interplay between the painted features (Figure 3d). Conversely, other paintings reveal the artist's ability to describe the forms by a combination of bold outlines, moderate impastos and scraping into wet paint (Figure 17). Although Liu Kang did not attempt to further develop the compositions, the paintings *Seaside* and *Seaside near Shanghai*, both from (1936), show his preference for maximising the potential of the subject matter and depict it from two different observation points (Figures 2f and 3f).

Figure 17. Details showing different descriptive painting techniques like calligraphic outlining, scraping into wet paint and building moderate impastos in: (**a**) *Chinese house*, 1934; (**b**) *Pagoda*, 1936; (**c**) *Seaside*, 1936.

4. Conclusions

A comprehensive investigation of Liu Kang's palette of colours and painting technique of his Shanghai artistic phase (1933–1937) was conducted. The analytical methods employed proved complementary to each other and provided data that led to the characterisation of the artist's pigmentary palette.

Based on the analyses, it can be determined that Liu Kang's palette of colours is conventional and in accord with the materials available in Shanghai from local and imported brands in the 1930s. The colour mixes are straightforward and do not have unexpected complexity. Liu Kang's principal blue pigment was ultramarine; however, it was often admixed with viridian, some yellow iron-rich earth pigment, yellow chromate pigments or Prussian blue. The pigment compositions of green painted areas are based on viridian, which was frequently combined with ultramarine, Prussian blue, iron-containing earths or yellow chromate pigments. Yellow and brown colours were obtained mainly with yellow and red iron-rich earth pigments and yellow chromate pigments. Umber and bone black additionally appear in brown paint mixes. White paints were composed mainly of zinc and barium white, although lithopone is also possible, whereas lead white is considered an admixture. Pure black painted areas were not observed; however, dark brush strokes were achieved by mixing ultramarine with Prussian blue and some bone black. Emerald green and cadmium yellow or its variant were hardly used peculiarities. Red paint was not used in most of the investigated paintings except *Pagoda* (1936); however, the paint was not analysed due to the Liu family's preference for non-invasive techniques. Admixtures of red iron-containing earth pigments were found in brown painted areas. All investigated paint mixtures were bound in a drying oil.

As for Liu Kang's painting technique, the visual evidence allowed identification of some key features. Flat and broad paint application with brushes and palette knives were the most adequate for the outdoor execution of the paintings. Liu Kang worked rapidly within single sitting sessions and did not return to his compositions to apply finishing touches. *Chinese house* (1934) is an exception to this rule. The preferred methods of expression combined the incorporation of dark calligraphic outlines to isolate the forms and scraping into the wet paint to describe details and substitute laborious brushwork. He turned away from shading, which resulted in no identifiable light source falling on depicted forms.

The characterisation of pigment choices and painting technique of Liu Kang's Shanghai phase is an essential step towards expanding the knowledge of the artist's painting practice in the context of his entire artistic output. Furthermore, this study provides information about the art suppliers and the availability of painting materials in Shanghai during the period under review.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of the materials identified or tentatively determined in the paint samples obtained from the investigated paintings.

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Working at the fields, 2003-03258	1933	Blue	3	**Zn**, **C**, **O**, **Pb**, Ba, Na, S, Cr, Fe, (Ti, Ca, Al, Si, Sr, Mg)	Lithopone and/or barium white and zinc white, lead white, viridian, yellow chromate pigment(s), Prussian blue, titanium white, chalk	Lithopone and/or barium white and zinc white, lead white, Prussian blue, chalk, viridian and/or zinc yellow or strontium yellow, oil
		Blue	4	**Zn**, **C**, **O**, **Na**, Si, Al, (S, Cr, Ca, Ba, Pb, Fe, Ti)	Lithopone and/or barium white and zinc white, ultramarine, viridian, lead white, yellow iron-containing earth pigment, titanium white	
		Green	7	**Zn**, **C**, **O**, Cr, Na, Pb, Ba, Ca, S, (Si, Al, Ti)	Lithopone and/or barium white and zinc white, viridian, yellow chromate pigment(s), lead white, ultramarine, chalk, titanium white	Lithopone, and/or barium white and zinc white, chalk, lead white, yellow chromate pigment(s), ultramarine, oil, zinc soap
		Green	8	**O**, **Zn**, **C**, **Ba**, Pb, Cr, Na, S, Ca, Ti, (Fe, Si, Al, Sr, Cl, K)	Lithopone and/or barium white and zinc white, lead white, viridian, chalk, titanium white, Prussian blue, ultramarine	
		Yellow	10	**Zn**, **C**, **O**, Na, Pb, Ba, Fe, (Ca, S, Si, Cr, Al, Ti, Sr)	Lithopone and/or barium white and zinc white, lead white, chalk, yellow chromate pigment(s), yellow iron-containing earth pigment, titanium white	Lithopone and/or barium white and zinc white, chalk, lead white, yellow chromate pigment(s), iron-containing earth pigment, oil, zinc soap
		Brown	5	**Zn**, **O**, **C**, Na, Ca, Fe, Pb, Ba, Si, (Al, S, P, Sr, Mn, Cr, Mg, K, Ti)	Lithopone and/or barium white and zinc white, chalk, yellow iron-containing earth pigment, umber, lead white, Prussian blue, bone black, viridian, titanium white	Lithopone and/or barium white and zinc white, chalk, lead white, iron-containing earth pigment, viridian, Prussian blue, oil, zinc soap
		Brown	11	**O**, **C**, **Fe**, Si, Al, Zn, Ca, Ti, (Mg, Na, Sr, P, K, Mn)	Umber, bone black	Umber, bone black, oil
		White	2	**Zn**, **C**, **O**, **Na**, (Pb, Si, S, Ba, Sr, Ca)	Lithopone and/or barium white and zinc white, lead white, chalk	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Countryside in China, 2003-03299	1933	Blue	6	**O**, **C**, **Ba**, Si, Na, Al, S, Cr, Ca, Ti, (K, Pb, Cl, As, Cu)	Barium white, ultramarine, viridian, emerald green, titanium white, lead white	Ultramarine, chalk, oil
		Green	1	**C**, **Zn**, **O**, Na, Pb, Al, Ca, Fe, Ti, (Si, Mg, Cl, Sr, S, P, Cr)	Zinc white, lead white, ultramarine, Prussian blue, yellow chromate pigment(s), titanium white, bone black, viridian	
		Green	3	**C**, **O**, **Cu**, Pb, As, Cr, Ca, (Ba, Fe, S, Al, Si, Zn, Cl)	Emerald green, yellow chromate pigment(s), Prussian blue, chalk, ultramarine	Emerald green, yellow chromate pigment(s), Prussian blue, ultramarine, lithopone and/or barium white and zinc white, chalk, oil
		Green	4	**O**, **C**, **Cr**, Pb, Ba, Zn, Ca, Na, (S, Si, Cu, Al, As, Sr, Ti, Fe, Mg, Cl, K)	Viridian, lead white, lithopone and/or barium white and zinc white, chalk, emerald green, titanium white, yellow iron-containing earth pigment, ultramarine	Viridian, lead white, lithopone and/or barium white and zinc white, chalk, ultramarine, oil
		Yellow	7	**Pb**, **O**, **C**, **Ca**, Cr, (Ba, Na, Cl, Si, Al)	Yellow chromate pigment(s), chalk, barium white	
		Brown	8	**C**, **Pb**, **O**, Ca, Fe, Ba, Si, Cr, (Al, As, Na, Ti, P, Cu, Mg)	Lead white, red iron-containing earth pigment, barium white, yellow chromate pigment, emerald green, titanium white, bone black	
		White	5	**Pb**, **C**, **O**, Ca, (Si, Mg, Cl, Al)	Lead white, chalk	
Backyard, 2003-03252	1934	Blue	11	**Zn**, **C**, **O**, Na, Ba, Sr, Cr, S, Pb, (Si, Ti, Al, Ca)	Lithopone and/or barium white and zinc white, yellow chromate pigment(s), ultramarine, lead white, titanium white, chalk	Lithopone and/or barium white and zinc white, strontium yellow, ultramarine, oil, zinc soap
		Green	9	**O**, **C**, **Pb**, **Sr**, Cr, Ba, S, Ca, Si, Fe, Al, Zn, (Na, Mg, K, Ti, Cl, P)	Lead white, yellow chromate pigment(s), lithopone and/or barium white and zinc white, Prussian blue, yellow iron-containing earth pigment, titanium white, bone black	
		Green	10	**C**, **O**, Ba, Sr, Cr, S, Si, Na, Pb, Al, Ti, Zn, Ca, Fe, K)	Lithopone and/or barium white and zinc white, yellow chromate pigment(s), ultramarine, lead white, titanium white, chalk, Prussian blue	Lithopone and/or barium white and zinc white, strontium yellow, ultramarine, Prussian blue, chalk, lead white, oil

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Backyard, 2003-03252	1934	Brown	6	**O**, **Zn**, **C**, Ba, Pb, Na, Ca, Fe, S, Si, Al, (Mg, Ti, Cr, Sr, P, K, Cl)	Lithopone and/or barium white and zinc white, lead white, chalk, red iron-containing earth pigment, titanium white, yellow chromate pigment(s), bone black	Lithopone and/or barium white and zinc white, lead white, chalk, iron-containing earth pigment, bone black, yellow chromate pigment(s), oil
		Brown	15	**O**, **Ba**, **C**, Fe, S, Pb, Si, Zn, Ca, Cr, Na, Ti, Al, (Cd, P, K)	Lithopone and/or barium white and zinc white, red iron-containing earth pigment, lead white, yellow chromate pigment(s), titanium white, cadmium yellow or its variant, bone black	
		White	14	**Zn**, **C**, **O**, **Na**, (Ca, Ba, Pb, S, Si)	Lithopone and/or barium white and zinc white, chalk, lead white	
Chinese house, 2003-03328	1934	Blue	3	**Zn**, **C**, **O**, Na, Ba, S, Cr, (Si, Ca, Al, Ti, Sr, Pb, Cl)	Lithopone and/or barium white and zinc white, ultramarine, viridian, yellow chromate pigment(s), chalk, titanium white, lead white, chalk	Lithopone and/or barium white and zinc white, ultramarine, viridian or yellow chromate pigment(s), lead white, chalk, oil, zinc soap
		Green	6	**C**, **Zn**, **O**, Pb, Ba, Na, Cr, S, (Ca, Fe, Al, Si, Ti, Sr, K, Mg)	Lithopone and/or barium white and zinc white, lead white, yellow chromate pigment(s), chalk, Prussian blue, titanium white	Lithopone and/or barium white and zinc white, Prussian blue, yellow chromate pigment(s), oil
		Green	7	**C**, **O**, **Ba**, Cr, Zn, S, Pb, Na, (Sr, Fe, Ti, Si, Al, Ca, Mg)	Lithopone and/or barium white and zinc white, viridian, lead white, yellow iron-containing earth pigment, ultramarine, chalk	
		Green	8	**Zn**, **C**, **O**, Pb, Na, Ba, S, Cr, (Ca, Si, Fe, Al, Ti, Mg)	Lithopone and/or barium white and zinc white, lead white, viridian, chalk, Prussian blue, ultramarine, titanium white	
		Yellow	4	**Zn**, **C**, **O**, Na, Si, Ba, Fe, (Al, S, Sr, Pb, Ti)	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, lead white, titanium white	Lithopone and/or barium white and zinc white, iron-containing earth pigment, lead white, oil, zinc soap

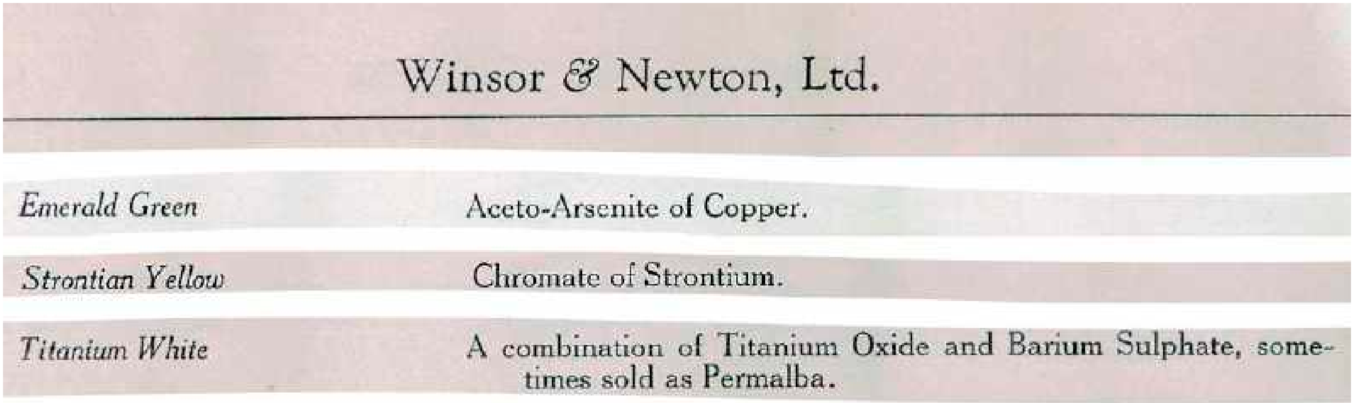
Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Chinese house, 2003-03328	1934	Brown	12	**C**, **O**, **Zn**, Fe, Na, Si, Ba, Ca, S, Al, Cr, (Sr, Pb, Mn, P, Ti, Cl)	Lithopone and/or barium white and zinc white, yellow chromate pigment s), umber, bone black, titanium white	
		Black	5	**C**, **O**, **Zn**, Na, Ba, Fe, S, Cr, Si, Ca, (Al, Pb, Sr, Ti, P)	Lithopone and/or barium white and zinc white, Prussian blue, viridian, ultramarine, lead white, bone black	
Waterfall, 2003-03247	1936	Blue	3	**C**, **O**, **Ba**, S, Zn, Ca, Ti, Na, (Si, Sr, Pb, Fe, Al, Cl, Cr)	Lithopone and/or barium white and zinc white, chalk, titanium white, ultramarine, yellow iron-containing earth pigment, Prussian blue, viridian	
		Blue	4	**C**, **O**, **Ba**, S, Zn, Ca, Pb, Ti, Na, Si, (Fe, Al)	Lithopone and/or barium white and zinc white, chalk, lead white, titanium white, ultramarine, Prussian blue, yellow iron-containing earth pigment	Lithopone and/or barium white and zinc white, chalk, lead white, ultramarine, Prussian blue, oil
		Blue	5	**Zn**, **C**, **O**, Na, (Ca, Si, Ba, S, Al, Cr, Sr, Pb, Mg, Fe)	Lithopone and/or barium white and zinc white, ultramarine, chalk, viridian, yellow iron-containing earth pigment	
		Green	6	**O**, **C**, **Ba**, Pb, S, Cr, Zn, Ti, Fe, Si, (Ca, Sr, Na, Al, P)	Lithopone and/or barium white and zinc white, lead white, chalk, yellow chromate pigment(s), titanium white, Prussian blue, bone black	Lithopone and/or barium white and zinc white, lead white, chalk, yellow chromate pigment(s), Prussian blue, oil
		Green	11	**O**, **C**, **Ba**, **Pb**, S, Fe, Cr, Ti, Zn, Al, Si, (Sr, Ca, K)	Lithopone and/or barium white and zinc white, lead white, Prussian blue, viridian, titanium white, chalk	Lithopone and/or barium white and zinc white, lead white, chalk, Prussian blue, oil
		Green	12	**O**, **C**, **Ba**, **Cr**, S, (Sr, Ca, Ti, Si, Fe, Zn, Na, Pb, Al)	Lithopone and/or barium white and zinc white, viridian, chalk, titanium white, yellow chromate pigment(s), yellow iron-containing earth pigment, lead white	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Waterfall, 2003-03247	1936	Brown	13	**C**, **O**, **Ba**, Zn, S, Ca, Fe, Na, Si, Ti, (Al, P, Pb, Cl)	Lithopone and/or barium white and zinc white, chalk, yellow iron-containing earth pigment, bone black, lead white	Lithopone and/or barium white and zinc white, chalk, iron-containing earth pigment and/or bone black, oil
		White	14	**C**, **O**, **Ba**, **Zn**, S, Ca, Na, Ti, (Sr, Cl, Si, Al, Fe, Pb, Cr, P)	Lithopone and/or barium white and zinc white, chalk, titanium white, ultramarine, yellow iron-containing earth pigment, lead white, viridian	
Seaside, 2003-03318	1936	Blue	1	**Zn**, **C**, **O**, Na, (Si, S, Al, Ca, Ba)	Lithopone and/or barium white and zinc white, ultramarine, chalk	Lithopone and/or barium white and zinc white, ultramarine, chalk, oil
		Blue	6	**C**, **Zn**, **O**, Na, Ba, Cr, S, (Si, Ca, Al, Fe, Ti, Sr)	Lithopone and/or barium white and zinc white, ultramarine, viridian, yellow iron-containing earth pigment, titanium white	
		Green	2	**Zn**, **C**, **O**, Na, Ba, Cr, S, (Ca, Ti, Fe, Si, Sr, Pb, Mg)	Lithopone and/or barium white and zinc white, ultramarine, viridian, titanium white, yellow iron-containing earth pigment, lead white	
		Green	4	**Zn**, **O**, **Ba**, Pb, Na, S, Cr, C, Fe, Ti, (Si, Al, Sr, Ca, Mg, K)	Lithopone and/or barium white and zinc white, lead white, yellow chromate pigment(s), viridian, Prussian blue, titanium white, chalk, bone black	Lithopone and/or barium white and zinc white, lead white, chalk, yellow chromate pigment(s), viridian, Prussian blue, oil
		Brown	5	**C**, **Zn**, **O**, Na, Fe, Ba, Ca, Si, (S, Al, Pb, Mn, Cr)	Lithopone and/or barium white and zinc white, chalk, umber, lead white	Lithopone and/or barium white and zinc white, iron-containing earth pigment, oil, zinc soap
		White	3	**Zn**, **C**, **O**, (Si)	Zinc white	

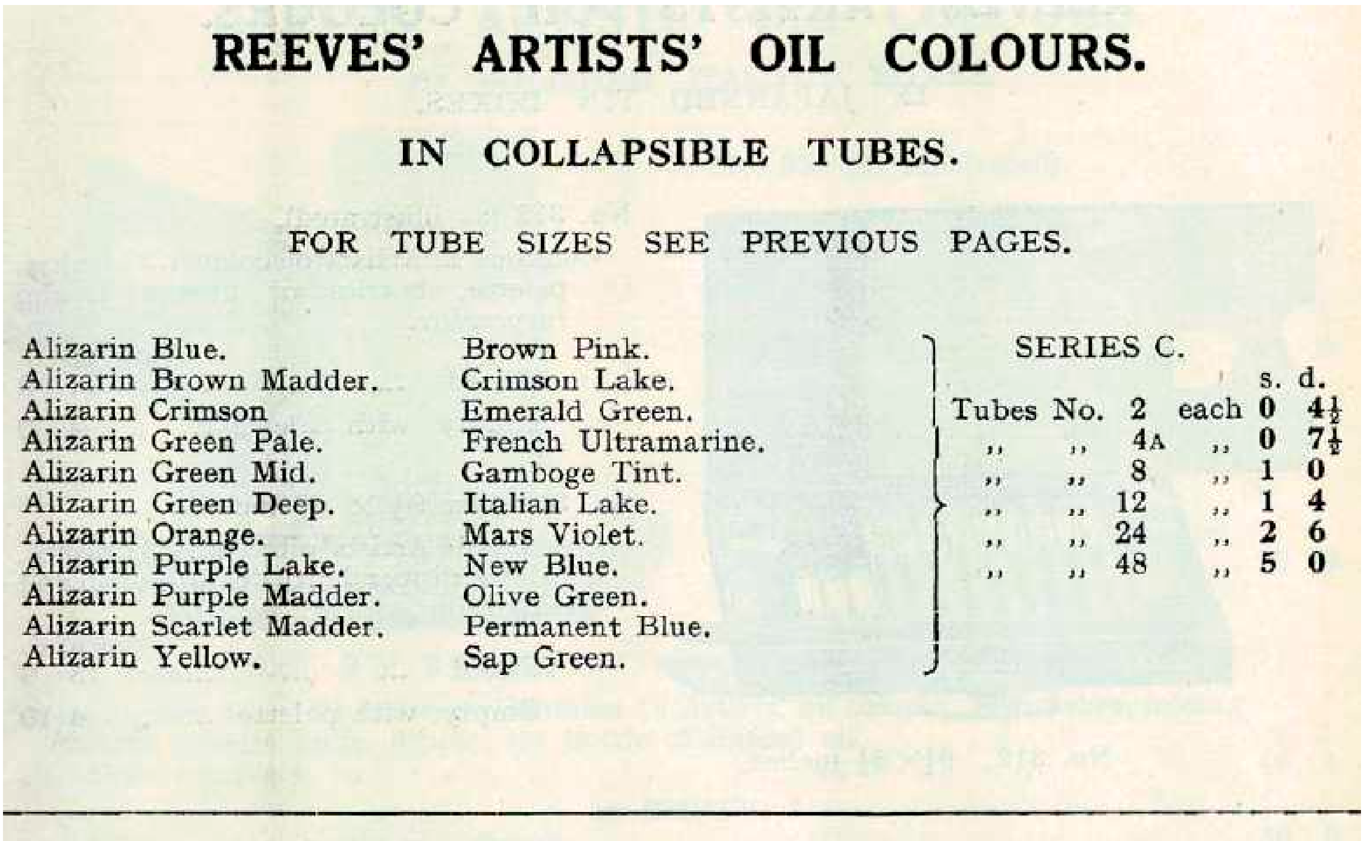
* Major elements are presented in bold type, minor elements in plain type and trace elements in brackets.



Winsor & Newton, Ltd.

Emerald Green	Aceto-Arsenite of Copper.
Strontian Yellow	Chromate of Strontium.
Titanium White	A combination of Titanium Oxide and Barium Sulphate, sometimes sold as Permalba.

Figure A1. Selected pigment compositions, listed in the catalogue of W&N from 1934.



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Alizarin Green Pale.	French Ultramarine.
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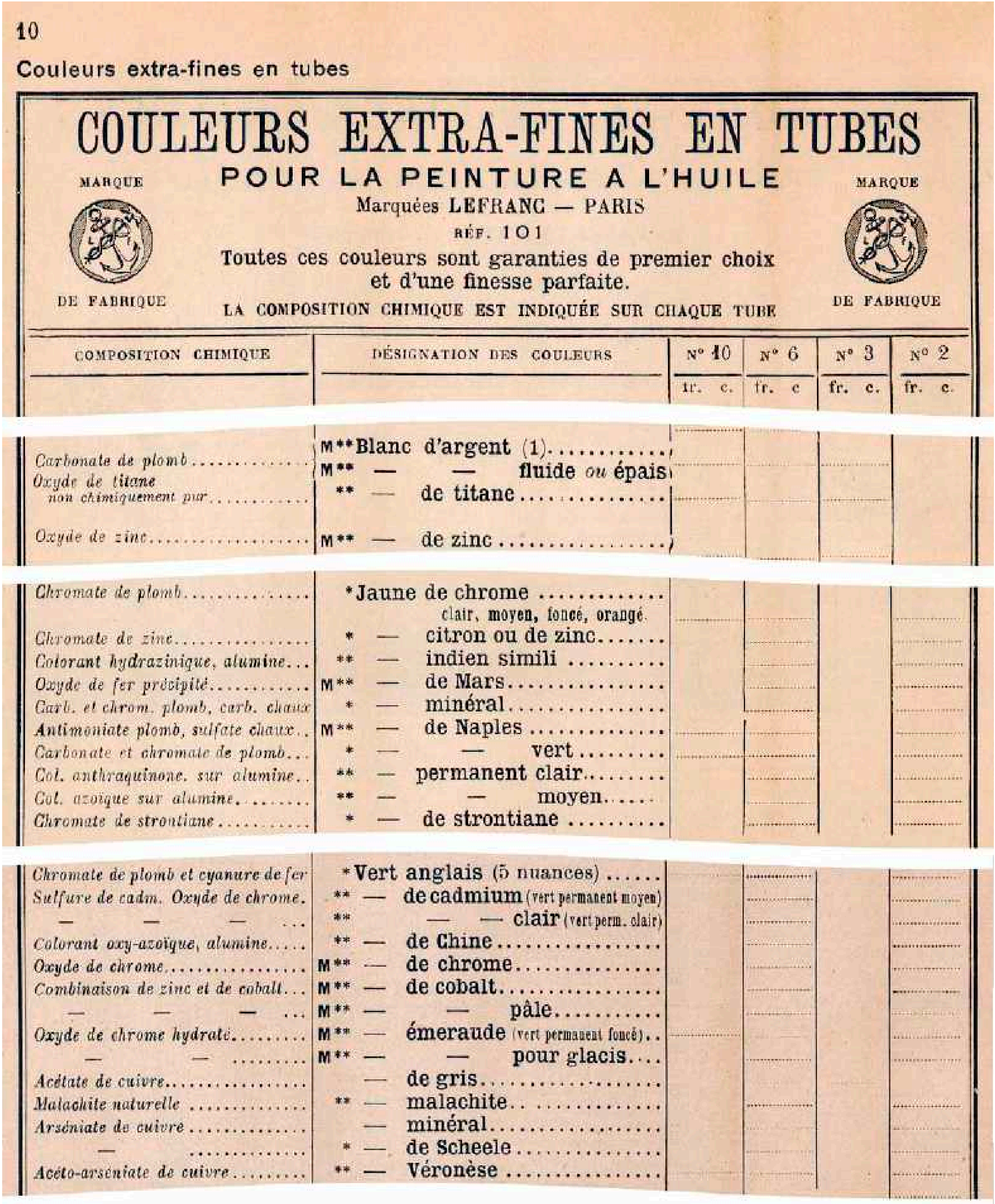
Alizarin Green Deep.	Italian Lake.
Alizarin Orange.	Mars Violet.
Alizarin Purple Lake.	New Blue.
Alizarin Purple Madder.	Olive Green.
Alizarin Scarlet Madder.	Permanent Blue.
Alizarin Yellow.	Sap Green.

SERIES C.

				s.	d.
Tubes	No.	2	each	0	4½
,,	,,	4A	,,	0	7½
,,	,,	8	,,	1	0
,,	,,	12	,,	1	4
,,	,,	24	,,	2	6
,,	,,	48	,,	5	0

Figure A2. Selected oil colours, listed in the catalogue of R&S from 1934.



10

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		fr. c.	fr. c.	fr. c.	fr. c.
Carbonate de plomb	M** Blanc d'argent (1)				
	M** — — fluide *ou* épais				
Oxyde de titane non chimiquement pur	** — de titane				
Oxyde de zinc	M** — de zinc				
Chromate de plomb	* Jaune de chrome clair, moyen, foncé, orangé				
Chromate de zinc	* — citron ou de zinc				
Colorant hydrazinique, alumine	** — indien simili				
Oxyde de fer précipité	M** — de Mars				
Carb. et chrom. plomb, carb. chaux	* — minéral				
Antimoniate plomb, sulfate chaux	M** — de Naples				
Carbonate et chromate de plomb	* — — vert				
Col. anthraquinone, sur alumine	** — permanent clair				
Col. azoïque sur alumine	** — — moyen				
Chromate de strontiane	* — de strontiane				
Chromate de plomb et cyanure de fer	* Vert anglais (5 nuances)				
Sulfure de cadm. Oxyde de chrome	** — de cadmium (vert permanent moyen)				
— — —	** — — clair (vert perm. clair)				
Colorant oxy-azoïque, alumine	** — de Chine				
Oxyde de chrome	M** — de chrome				
Combinaison de zinc et de cobalt	M** — de cobalt				
— — —	M** — — pâle				
Oxyde de chrome hydraté	M** — émeraude (vert permanent foncé)				
— —	M** — — pour glacis				
Acétate de cuivre	— de gris				
Malachite naturelle	** — malachite				
Arséniate de cuivre	— minéral				
—	* — de Scheele				
Acéto-arséniate de cuivre	** — Véronèse				

Figure A3. Selected oil colours and their pigment compositions, listed in the catalogue of Lefranc from 1934.

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Research Article

From Paris and Shanghai to Singapore: A Multidisciplinary Study in Evaluating the Provenance and Dating of Two of Liu Kang's Paintings

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ABSTRACT This paper focuses on the dating and provenance of two paintings, *Climbing the hill* and *View from St. John's Fort* by the prominent Singaporean artist Liu Kang (1911–2004). *Climbing the hill*, from the National Gallery Singapore collection, was believed to have been created in 1937, based on the date painted by the artist. However, a non-invasive examination unveiled evidence of an underlying paint scheme and a mysterious date, 1948 or 1949. These findings prompted a comprehensive technical study of the artwork in conjunction with comparative analyses of *View from St. John's Fort* (1948), from the Liu family collection. The latter artwork is considered to be depicting the same subject matter. The investigation was carried out with UVF, NIR, IRFC, XRR, digital microscopy, PLM and SEM-EDS to elucidate the materials and technique of both artworks and find characteristic patterns that could indicate a relationship between both paintings and assist in correctly dating *Climbing the hill*. The technical analyses were supplemented with the historical information derived from the Liu family archives. The results showed that *Climbing the hill* was created in 1948 or 1949 on top of an earlier composition painted in Shanghai between 1933 and 1937. As for the companion *View from St. John's Fort* from 1948, the artist reused an earlier painting created in France in 1931. The analytical methods suggested that Liu Kang used almost identical pigment mixtures for creating new artworks. However, their painting technique demonstrates some differences. Overall, this study contributes to the understanding of Liu Kang's painting materials and his working practice.

Key Words Liu Kang, SEM-EDS, IRFC, Painting supports, Hidden paintings, Authenticity, Pigments

1. BACKGROUND

Liu Kang (1911–2004) is recognised as a foremost Singaporean pioneer artist. He was born in Yongchun, Fujian province, China. He obtained an art education at the Xinhua Arts Academy in Shanghai in 1928 and continued his art studies at the Académie de la Grande Chaumière in Montparnasse in Paris, where he stayed from 1929 to 1932. During that time, Liu Kang painted intensively, and his technique reflects the influences of the Impressionist, Post-Impressionist and Fauvist styles he studied during museum and gallery visits (Kwok, 2000). He accepted the post of Professor at the Shanghai Art Academy in 1933, and continued teaching and painting until 1937, when the Second Sino-Japanese War (1937–1945) broke out. Forced to move to Malaya, he struggled to develop artistically due to poor living conditions during the Japanese Occupation (1941–1945). The scarcity of oil paints encouraged his practice of pastels keep the creative spark alive. Mao's victory in 1949 and the communists' demand for Chinese artists to adhere to the party line on art probably discouraged Liu Kang from returning to China (Croizier, 1993). Therefore, he decided to relocate permanently to Singapore in 1945. Liu Kang taught art in various schools, offered weekend private art tuition and designed cinema posters and adverts. Despite his demanding work schedules, he managed to find the time for his passion and continued painting during trips across Malaya. Liu Kang's works developed during that period differ significantly from those created in Paris and Shanghai suggesting that he was pursuing the quest of developing his own painting style (Liu, 1997).

Climbing the hill (1937) from the National Gallery Singapore (NGS) is an oil-on-canvas painting measuring 75 × 61 cm. It depicts St. John's Fort in Malacca, Malaysia (Figure 1a). According to the painted date, the painting was created just after Liu Kang's arrival to Malaya. An analysis of this artwork could give insights into the painting materials Liu Kang used during the war, while he was situated in a remote area and far from the art suppliers. However, the initial non-invasive examination of the paint layer revealed losses showing an underlying paint scheme, another signature by Liu Kang and an intriguing, later, date, which appeared to be 1948 or 1949. These findings extended the objective of the investigation into the provenance and dating of *Climbing the hill*. A comprehensive comparative technical study with another painting from 1948 seemed the best approach to verify the dating. Thus, *View from St. John's Fort* in the collection of the Liu family was selected for the comparative analyses (Figure 1c). The painting is oil-on-canvas, measuring 46 × 55 cm. The relationship between both paintings has never been debated as *View from St. John's Fort* had probably been considered by the artist as less successful and thus never exhibited. Both paintings appeared to have been created at the exact location, albeit

Figure 1. Liu Kang, *Climbing the hill*, 1937, oil on canvas, 75 × 61 cm, photographed in (a) VIS and (b) IRFC image. Gift of the artist's family. Collection of National Gallery Singapore. Image courtesy of National Heritage Board. White arrows indicate sampling areas. Liu Kang, *View from St. John's Fort*, 1948, oil on canvas, 46 × 55 cm, photographed in (c) VIS and (d) IRFC image. Liu Kang Family Collection. Images courtesy of Liu family. White arrows indicate sampling areas.

captured from different observation points. *Climbing the hill* is a vertical and symmetrical composition showing St. John's Fort in the central focal point on top of the hill. The main subject is framed by trees on the left and right. *View from St. John's Fort* is a horizontal composition depicting the fort's defence walls and an open view of the Malacca Strait towards the distant hills of Pulau Besar island. Moreover, an initial inspection of the painting revealed the presence of an underlying paint scheme. As both paintings appeared to be created over earlier compositions, it was crucial to cross-reference the analytical data obtained from the investigated artworks with the research results of Liu Kang's painting supports from his Paris (1929–1932) and Shanghai (1932–1937) artistic phases (Lizun *et al*., 2021b). Moreover, some references were made to the earlier research about Liu Kang's painting practice (Lizun, 2020; Lizun *et al*., 2021a; Lizun *et al*., 2021c). An additional insightful search of the Liu family archives provided unexpected evidence, which combined with the analytical techniques, assisted in determining the provenance and dating of *Climbing the hill*.

2. METHODS

The paintings were first investigated by means of non-invasive methods. Technical data was collected from both paintings, including the artworks dimensions and the characteristics of the textile supports, like the weave, density and twist of threads. Technical photography included visible light (VIS), ultraviolet fluorescence (UVF), and near-infrared (NIR), the objective being to record the condition of the paintings and conduct a preliminary characterisation of the pigments for guiding further in-depth analyses. A digital microscopy, X-ray radiography (XRR) and NIR imaging were carried out to determine the evidence of underlying paint layers. As *View from St. John's Fort* had to be examined in-situ, at the Liu family premises, it was not selected for the XRR. Then, the samples of the paint layers were extracted and studied using optical microscopy (OM), polarised light microscopy (PLM) and field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) to characterise the compositions of the paint mixtures. With regard to the textile supports, samples of fibres were extracted for morphologic identification, and staining test carried out with PLM. The data obtained from both paintings was studied to determine the presence of characteristic patterns that could assist in the verification of the provenance and dating of the *Climbing the hill* and confirm its relationship with *View from St. John's Fort*.

2.1. Technical photography

Paintings were photographed according to the workflow proposed by Cosentino (Cosentino, 2014; 2015; 2016) with a full-spectrum (360 to 1100 nm) modified Nikon 850 DSLR camera equipped with a Nikon AF Micro NIKKOR 60 mm f/2.8D lens. The camera was calibrated with X-Rite ColorChecker Passport and the American Institute of Conservation Photo Documentation (AIC PhD) target was used to fine-tune the white balance and exposure for the images. The images were captured in RAW format and further processed by Adobe Photoshop CC according to the standards described by the American Institute of Conservation (Warda *et al*., 2011).

VIS photography was performed with two 500 W halogen lamps and X-Nite CC1 and B+W 415 filters coupled together and mounted on the camera lens. The same set of filters was used for the UVF imaging with the illumination system consisting of two lamps equipped with eight 40 W 365 nm UV fluorescence tubes. NIR imaging was performed using the same illumination system as for VIS. A Heliopan RG1000 filter was placed in front of the camera lens.

Technical photography and in particular the IRFC imaging were the useful tool for the tentative identification of the pigments and the selection of potential sampling areas. A digital editing method proposed by Cosentino (Cosentino, 2016) was carried out using Adobe Photoshop CC and included the calibration of the exposure of both the VIS and IR images with the AIC PhD target followed by the greyscale conversion of the IR image, exchange of the RGB channels between the VIS and IR images, and final alignment.

2.2. XRR

Climbing the hill was X-ray radiographed with a Siemens Ysio Max digital system with a detector of dimensions 35 × 43 cm and a resolution of 7 million pixels. 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.

2.3. OM and PLM

The paint samples' structure was studied in reflected VIS and UV light on a Leica DMRX polarised microscope at magnifications of x100, x200 and x400 coupled with a Leica DFC295 digital camera. PLM of pigments and morphology of fibres were carried out in transmitted VIS light at magnifications of x100, x200 and x400. PLM of pigments was conducted according to the workflow developed by Peter and Ann Mactaggart (Mactaggart and Mactaggart, 1998).

2.4. High-resolution digital microscopy

The surface of the paint layers and canvases were examined with a Keyence VHX-6000 digital microscope, using a zoom lens coupled with a high-speed camera. Observations were conducted at magnifications of x20–x200. For measurement analyses, a built-in Keyence software – VHX-H2M2 and VHX-H4M – was used.

2.5. FE-SEM-EDS

The paint samples' cross-sections were mounted on carbon tapes and analysed with a Hitachi SU5000 FE-SEM coupled with Bruker XFlash® 6/60 EDS. The SEM, backscattered electron mode (BSE), was operated at 20 kV accelerating voltage, 60 Pa chamber pressure, 50–60 intensity spot, and 180 s acquisition time. Analyses were conducted at a working distance of 10 mm. The data acquisition and processing were performed with Bruker ESPIRIT 2.0 software.

2.6. Staining test

The phloroglucinol stain test was conducted on the natural fibres to determine the presence and concentration of lignin (Odegaard *et al*., 2000).

2.7. Preparation of samples

A total of 16 samples of the paint material were extracted from the areas of losses of the investigated paintings (nine samples from *Climbing the hill* and seven samples from *View from St. John's Fort*). The sampling spots are indicated in Figure 1a, c. Additionally, two fibre samples were taken from the threads of weft and warp of each canvas. The paint samples were mounted as cross-sections in a fast-curing acrylic resin, ClaroCit from Struers (USA). The PLM pigment scrapings were prepared as slides with a Meltmount nD=1.662 mounting medium from Cargille (USA). The samples of fibres were cleaned of contaminants by immersing them in boiled water. Then, they were mounted on microscope slides with a drop of water under the cover glass.

3. RESULTS AND DISCUSSION

3.1. Non-invasive examination of *Climbing the hill*

A digital microscopy of the painting's surface detected numerous paint losses in the area of the upper branches of trees, revealing a different paint scheme underneath the present composition (Figure 2). In addition, the microscopy revealed that the brushstrokes in the hidden composition were applied in different directions from those in the top paint layer. Further, XRR did not generate sufficient information about the underlying composition due to disruptions caused by a thick top paint layer, which is rich in heavy metal (Schalm *et al*., 2014). NIR imaging also did not aid in visualising the underlying composition, probably due to the thickness of the current paint layer. Nevertheless, the discovery of different paint scheme is not a unique occurrence in Liu Kang's artworks and is consistent with his earlier practice of reusing former paintings in Paris and Shanghai (Lizun, 2020; Lizun *et al*., 2021a; 2021b; 2021c).

However, the NIR photography of the bottom-left corner of the painting revealed the underlying artist's signature, a Chinese character Kang (抗), and a partially legible date in the Western style, resembling 1948 or 1949 (Figure 3a, b, c). This was a puzzling discovery as the existing artist's signature and date (1937) are in the opposite, bottom-right corner (Figure 3a, d). This discovery prompted the question of whether the existing signature and date (1937) are authentic and whether the underlying signature and date are part of the current composition, or belonging to a different composition that was later painted over. According to archival records, the painting was acquired as the artist's

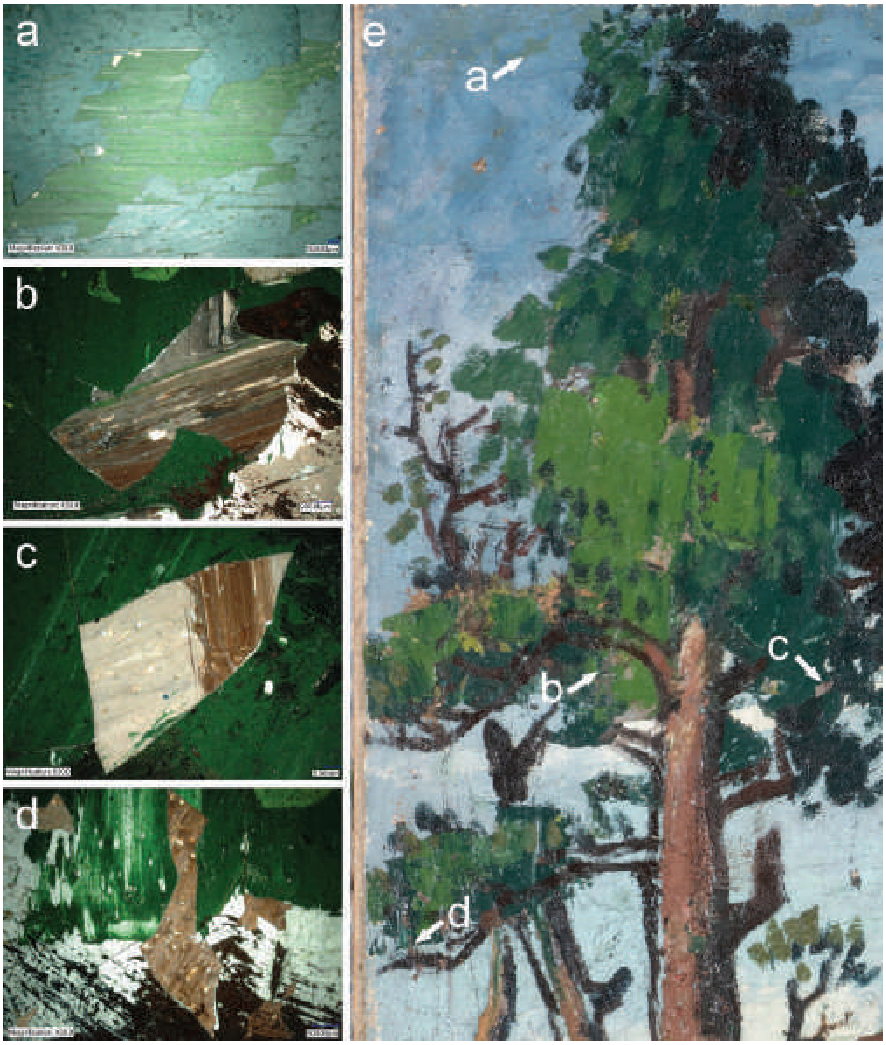

Figure 2. Digital microscope images of paint losses revealing a different paint scheme beneath *Climbing the hill* (a-d). The location of the losses (e).

donation in 2003, so any alterations detected in the course of this study would be attributed to him. Thus, the initial supposition of falsification was refuted. Considering that both sets of signatures and dates are of Liu Kang's authorship, it was crucial to find out which set was applied first as this would be critical for dating *Climbing the hill*. Unexpectedly, an undated photograph of *Climbing the hill*, provided by the Liu family, documents that the painting was signed and dated 1948 or 1949 in the bottom-left corner (Figure 3e). The location and graphical form of the signature and date captured by the photograph are similar to those recorded with NIR of the investigated painting (Figure 3c, f). It is also important to note that the signature and date (1937) are not present in the bottom-right corner of the photographed painting (Figure 3e).

Additional comparisons of the bottom-left corner of the painting captured in the archival photograph with the same area of the current painting imaged in black-and-white, colour and IRFC photography, distinguished several green brushstrokes that had been applied later by the artist. These brushstrokes appeared purple in the IRFC, suggesting the use of Cr- and/or Co-containing green pigment applied on top of earlier painted greenery, also seen in the vicinity and represented in IRFC by blue and violet, suggesting a mixture composed mainly of Prussian blue (Figure 4).

Liu Kang's motivation to overpaint that area remains

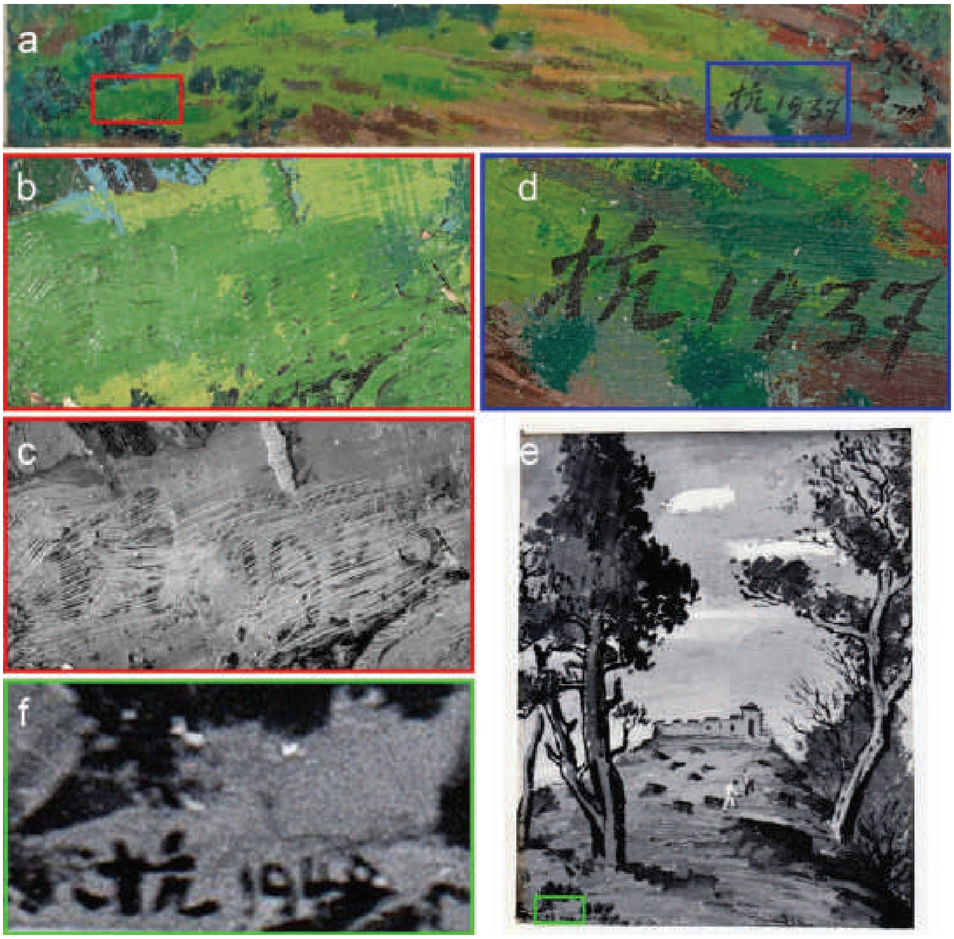

Figure 3. Details of *Climbing the hill* showing the: (a) positions of the overpainted signature with the date in the bottom-left corner (red rectangle) and existing signature with the date in the bottom-right corner (blue rectangle); (b) overpainted area of the signature and date photographed in VIS; (c) same area photographed in NIR; (d) existing signature photographed in VIS; (e) archival photograph of the *Climbing the hill* with the position of the original signature and date (green rectangle); (f) detail of the archival photograph of *Climbing the hill* showing the signature and date 1948 or 1949. Liu Kang Family Collection. Images courtesy of Liu family.

unknown as no evident paint losses were found that could have prompted such action. However, it could be speculated that the artist returned to the painting and decided to improve its aesthetics by adding new green hues covering the original signature and date as he did not have sale or exhibition plans for the work. It could be hypothesised that once the bottom-left corner was reworked, the painting remained unsigned and undated for a very long time, until the exhibition in 1993. The exhibition catalogue shows the painting in its current condition – with an overpainted bottom-left corner and a new signature and date (1937) in the bottom-right corner (Liu, 1993). Hence, a possible explanation is that in preparation for the exhibition, the artist was not able to recall the actual date of creation of the painting and unconsciously painted 1937.

Although the non-invasive imaging techniques supported by the archival photograph provided rationale of the mysterious hidden signature and date, a comparative investigation of the painting materials was conducted on *View from St. John's Fort*. The objective of the investigations was to reveal common patterns between both paintings, which would provide evidence to support the 1948 or 1949 dating of *Climbing the hill*, and shed light on its provenance.

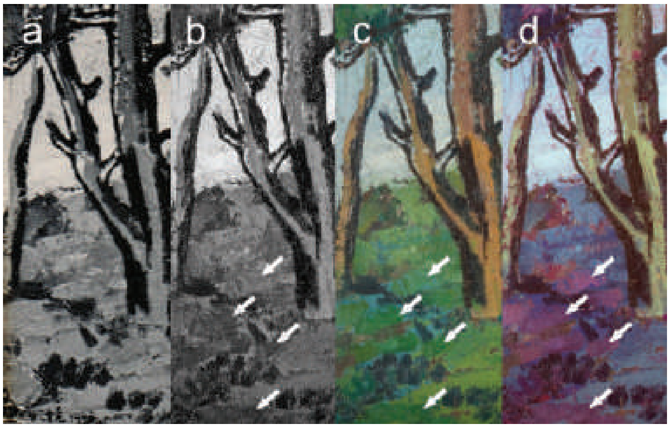

Figure 4. Detail of the bottom left corner of *Climbing the hill* from the archival photograph (a). Details showing the same area of the investigated painting imaged in: (b) black-and-white; (c) VIS; (d) IRFC. The white arrows indicated the areas of the overpaint.

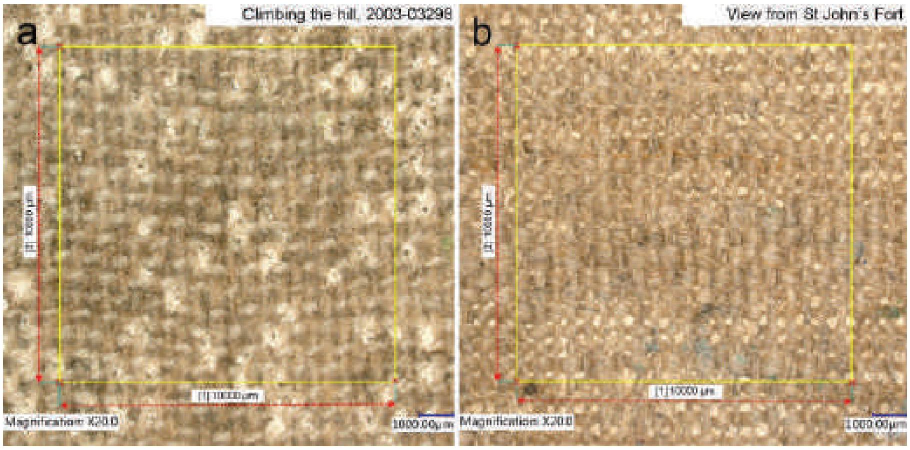

Figure 5. Photomicrographs of canvases from (a) *Climbing the hill* and (b) *View from St. John's Fort*.

3.2. Auxiliary supports and characteristics of the fabrics and grounds

The original auxiliary supports for both paintings were not preserved. Based on the visual assessment and according to the framer's label, *Climbing the hill* is stretched over the non-original plywood board, applied in 1992, while *View from St. John's Fort* remains unstretched. However, the presence of the irregularly distanced nail holes indicates that the paintings were originally stretched over stretchers or strainers. The dimensions of the paintings, measured from the painted edges, conform to common standards: *Climbing the hill* was created on portrait format number 20, and *View from St. John's Fort* adheres to portrait format number 10. It is known from earlier research that the artist tended to bend the rules when choosing painting support formats (Lizun *et al*., 2021b).

The canvases in both paintings were made in plain weave with Z-twisted threads of weft and warp. A thread count 19 × 17 per cm was recorded for *Climbing the hill* and 20 × 18 per cm was recorded for *View from St. John's Fort* (Figure 5a, b). Although both canvases are characterised by similar structure, cotton was identified in *Climbing the hill*, by flattened fibres with internal helical convolutions. Linen was identified in *View from St. John's Fort*, by transverse markings, dislocations and pink, uneven stain after phloroglucinol test (Odegaard *et al*., 2000).

Judging by the presence of the ground on the tacking margins, both canvases were commercially prepared.

Interestingly, the left and right tacking margins of *View from St. John's Fort* were covered with a paint layer that did not correlate to the present paint scheme. Moreover, the left tacking margin has painted digits "931" turned 180 degrees around with respect to the current composition, suggesting a relation to an underlying painting (Figure 6a, b). As Liu Kang did not have a habit of the numbering of his artworks, these digits could be a part of the 1931 date partially covered by the current painting. An unusual style of the characters prompted a comparison with other paintings by Liu Kang from the same period. A similar dynamic style of character "9" was found in *Portrait of a man with his hat, Belgium* (1930) from the Liu family collection (Figure 6c), while a simplified character "3" appeared in the *Boat near the cliff*

Figure 6. Detail of *View from St. John's Fort* and the underlying painting showing the position of the partially legible 1931 date (red rectangle) and 1948 date (green rectangle) (a). Detail showing the: (b) 1931 date, rotated at 180°, partially covered by the current composition of *View from St. John's Fort*; (c) 1930 date from *Portrait of a man with his hat, Belgium* from the Liu Kang Family Collection; (d) 1931 date from *Boat near the cliff* from the collection of National Gallery Singapore; (e) 1948 date from the *View from St. John's Fort*. Images courtesy of National Heritage Board and Liu family.

(1931) from the NGS collection (Figure 6d). Thus, the collected information could support the hypothesis that the painting beneath was probably created in 1931 in Paris and then painted over in 1948. The presence of the paint layer of the earlier composition along the shoter edge of the canvas suggests that artist re-stretched the canvas over a smaller auxiliary support and then cut off an excess of the material.

As Liu Kang followed common size standards when choosing painting supports (Lizun *et al*., 2021b) and the underlying composition has a height of 46 cm and a width of 60 cm (after trimming), it is hypothesised that, the recycled artwork would have been painted in a landscape format of dimensions 46 × 61 cm or a marine format with dimensions 46 × 65 cm (Figure 7a, b). However, the latter format is very unlikely as it was not reported for any of Liu Kang's artworks from Paris (Lizun *et al*., 2021b).

The optical microscopy of the cross-sections extracted from *Climbing the hill* and *View from St. John's Fort* confirmed that they were created on the underlying compositions without the application of an intermediate ground. Based on the optical microscopy and SEM-BSE imaging, the grounds for the earlier compositions are pale white and single-layered. The ground layer for the painting beneath *Climbing the hill* (sample c1) has a homogenous structure composed of lithopone (PW5, $BaO_5S_2Zn_2$) and/or barium white (PW21, $BaSO_4$) and zinc white (PW4, ZnO) with possible admixtures of lead white (PW1, $C_2H_2O_8Pb_3$) and titanium white (PW6, TiO_2) (Figure 8a, b). The structure of the ground layer for the painting beneath *View from St. John's Fort* (sample v1) is characterised by distinct particles of chalk (PW18, $CaCO_3$) mixed with lithopone and/or barium white and zinc white with trace amounts of titanium and lead whites (Figure 8c, d).

Considering that the underlying composition in *View from St. John's Fort* was created in 1931, a comparison of the canvas and ground characteristics was conducted with Liu Kang's paintings from the Paris period, and it confirmed a match with canvas type 2 and ground type 5 (Lizun *et al*., 2021b). Following on this lead, a similar comparison was done for the painting support of *Climbing the hill* as the current composition was created over the earlier painting. Cotton canvases of a similar density as the canvas from *Climbing the hill* were used predominantly by Liu Kang in Shanghai between 1933 and 1937, and they are classified as type 1. The identified ground mixture would conform to a type 2, found in one Shanghai painting from 1936 (Lizun *et al*., 2021b).

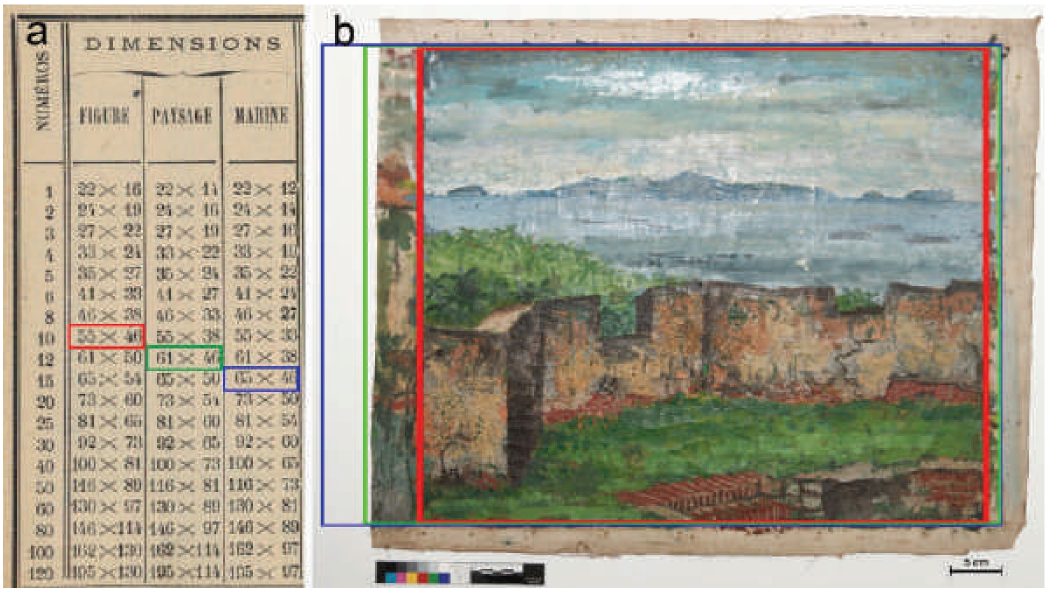

Figure 7. List of standard canvas formats from the 1929 Bourgeois Ainé catalogue (a) and *View from St. John's Fort* (b), with the dimensions of the current composition corresponding to portrait format number 10 (indicated in red), suggested dimensions of the underlying painting in landscape format number 12 (indicated in green) and suggested dimensions of the underlying painting in marine format number 15 (indicated in blue).

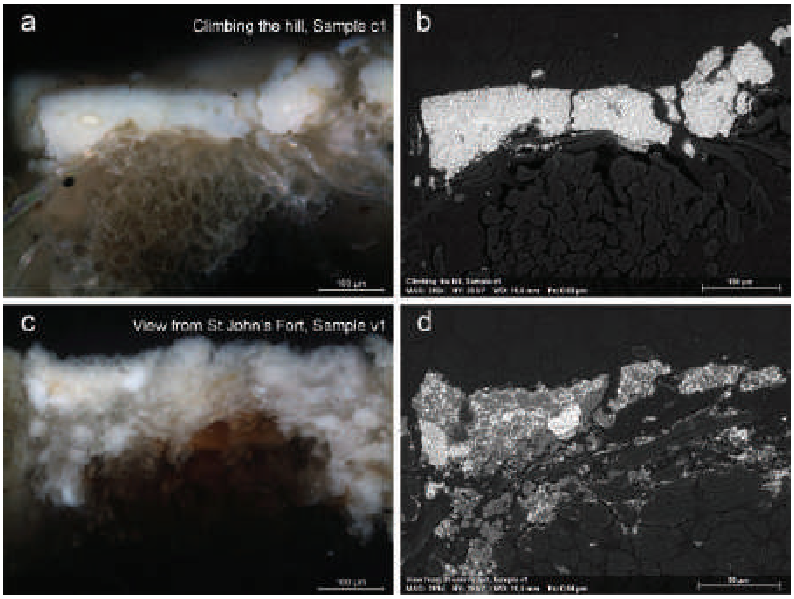

Figure 8. Microscopy and corresponding backscattered electron images (BSE) of cross-sections showing: the homogenous structure of ground layer extracted from: *Climbing the hill* (a, b); structure of the ground layer characterised by large particles of chalk (visualised in dark grey in BSE image) from *View from St. John's Fort* (c, d).

3.3. Art materials availability in Singapore in late 1940s

These unexpected attributions of the canvas support to the Paris and Shanghai periods of Liu Kang's career sparked a curiosity about the rationale for reusing old paintings. Liu Kang's decision could have been impacted by the availability of art materials or his financial constraints, or both. The local art materials market and artist's practice were probably still affected by frequent disruptions to the distribution channels caused by the outbreak of the Second World War. On the other hand, another factor contributing to the scarcity of materials could have been the low local demand from art students and professional artists. In Singapore, the Nanyang Academy of Fine Arts, inaugurated in 1938, had to close during the Japanese Occupation (1942–1945); it was reopened in 1946. Additionally, the pre-war art community was torn apart and needed time to rebuild (Ong, 2007). As the new President (1946–1958) of the oldest and most influential Society of Chinese Artists, Liu Kang had good insights into the condition of the local art scene during the second half of the 1940s. His comments from his 1948 essay reveal the scale of damage caused by the war: "It is a miserable fact that there was a total of 12 large and small exhibitions in Singapore last year, with an average of one a month. This is miserable. Of the 12 exhibitions, six were by European artists and five were by artists from China. Only one exhibition, the Seventh Annual National Day Art Exhibition, was organised by the local art community. This is regrettable (Liu, 2011)!"

His further comments in the same essay reveal the frustrations of an experienced artist who had spent several years in two cosmopolitan centres of the pre-war period: "Singapore is known as a metropolis with its population of one million people, of which at least 70 percent are Chinese. However, there are only a dozen artists, and the number of art organisations can be counted with the fingers of one hand. If we compare ourselves with four million people and 300,000 artists in Paris, the proportion is too pathetic and laughable (Liu, 2011)."

The poor condition of the local art community and its slow post-war recovery process undoubtedly influenced the demand for art materials, resulting in a lack of the specialised retailers in the post-war period. Nevertheless, archival search revealed that imported brands like Reeves & Sons and Winsor & Newton were distributed across the island through the stationery and book stores like E.J. Motiwalla & Co., Peter Chong & Coy (with many branches in Malaya), The Shanghai Book Company (with a branch in Kuala Lumpur), and Central Book Store (Figure 9) ("Central Book Store,"

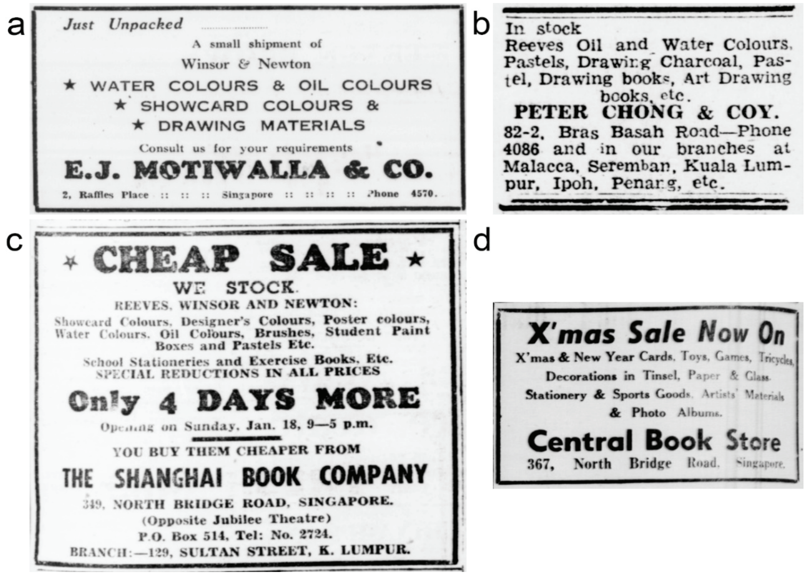

Figure 9. Advertisements by official retailers of art materials available in Singapore from 1947 to 1949: (a) E.J. Motiwalla & Co.; (b) Peter Chong & Coy; (c) The Shanghai Book Company; (d) Central Book Store.

1949; "E.J. Motiwalla & Co," 1947; "Peter Chong & Coy," 1947; "The Shanghai Book Company," 1948).

These few advertisements reveal that the availability of the art materials in Singapore in 1940s was impacted by stock limitations. They also do not mention canvas supports. Additionally, the art materials were also available from the Nanyang Book Company established in 1943 (with stores in Kuala Lumpur and Penang), and The Straits Commercial, established in 1947 in Singapore (Tse and Sloggett, 2008). Nevertheless, given that the prices of the imported materials were usually unattractive, Liu Kang might not have been interested in regular purchases as he was focused on providing for his young family (Liu, 1997). The harsh post-war economic realities did not stop him from painting but instead pushed him to the practice of reusing earlier artworks. In a 1981 interview, Liu Kang recalled that soon after his arrival to Malaya, his brother-in-law Chen Jen Hao joined him and brought some of Liu Kang's paintings from Shanghai (Mahbubani, 1981). In subsequent interviews from 1989 and 1996, Liu Kang said that he lost many of his works during the Japanese Occupation; however, he managed to find and recover some of them (Sabapathy, 1981; Sasitharan, 1989; Tan, 1997). Based on these accounts, it can be hypothesised that the canvas supports from the recovered artworks were good enough to be reused.

3.4. Pigments

The results of the pigment analyses are summarised in Tables 1 and 2 at the end of this section.

3.4.1. Blue

The IRFC imaging of both paintings showed that the most of the blue painted areas turned purple, suggesting the use of ultramarine and/or Co-containing blue (Figure 1b, d). The SEM-EDS measurements of samples c12 and v2 extracted from both paintings indicated a major use of ultramarine (PB29, $Al_6Na_8O_{24}S_3Si_6$), confirmed with PLM (isotropic particles with low refractive index appear red with Chelsea filter). The intensity of the blue paint was modified by adding lead white extended with lithopone and/or barium white and zinc white. However, the bottom part of the sky of *Climbing the hill* appeared light blue in the IRFC image (Figure 1b), indicating a possible use of Prussian blue. SEM-EDS measurements of the samples (c13 and c17 layer 1) revealed mixtures of ultramarine and Prussian blue (PB27, $C_{18}Fe_7N_{18}$). The latter was identified by the detection of a weak Fe-signal and PLM observation of dark blue isotropic particles, which appear dark green under a Chelsea filter and have a low refractive index. Prussian blue is present in the paint mixture at very low concentration, probably due to its high tinting strength (Berrie, 1997); however, that small admixture accounts for the blue hue of the area, recorded with the IRFC imaging.

3.4.2. Green

The comparison of green passages from both paintings unequivocally reveals that the artist produced a range of green hues in *Climbing the hill* to depict the upper branches of trees, whereas the greenery in *View from St. John's Fort* is executed with a limited definition of light effects and appears almost flat. The SEM-EDS analyses of light green areas revealed complex paint mixtures that appeared similar in both paintings (sample c14, v7). The detection of Pb, Ba, Zn, Cr and Fe suggested the use of Cr-containing green(s) and/or yellow(s), confirmed with PLM as viridian (PG18, $Cr_2H_4O_5$) by large and rough anisotropic particles with high refractive index and chrome yellow (PY34, $PbCrO_4$) by anisotropic, rod-shaped particles with a high refractive index. However, strong Pb-, Ba- and Zn-signals can also be associated with lead white, lithopone and/or barium white and zinc white, used for the modification of green tint, whereas barium white may also appear as a commercial extender for lead white (Feller, 1986), viridian (Newman, 1997) and chrome yellow (Kühn and Curran, 1986). Based on the PLM analyses, the Fe-signal can be linked with Prussian blue, used by artists to modify the hue of green colours. Dark green paints have a similar elemental composition to the light greens; however, they are characterised by the absence of chrome yellow and an increased concentration of Fe, indicating Prussian blue based on the PLM observation (samples c17 layer 2, v10). These findings are consistent with the IRFC imaging, as the blue and violet colours of the examined areas are notably determined by the presence of Prussian blue and viridian in the analysed paints (Figure 1b, d).

Certain green painted areas of both paintings are imaged purple in IRFC (Figure 1b, d), suggesting Cr- and/or Co-containing pigments. The evidence collected with a digital microscopy enabled to determine that these areas observed in *View from St. John's Fort* as well as from bottom-right corner of *Climbing the hill* relate to the earlier, underlying compositions intentionally exposed by the artists. The analyses of the paint sample (c24) from the bottom-right corner of the *Climbing the hill* confirmed a mixture composed predominantly of viridian and ultramarine applied directly on a white ground, which is considered the original preparation of the canvas (Figure 10). Meanwhile, the purple imaged green patches from the bottom-left corner of the *Climbing the hill* correspond to latter alterations conducted by the artist.

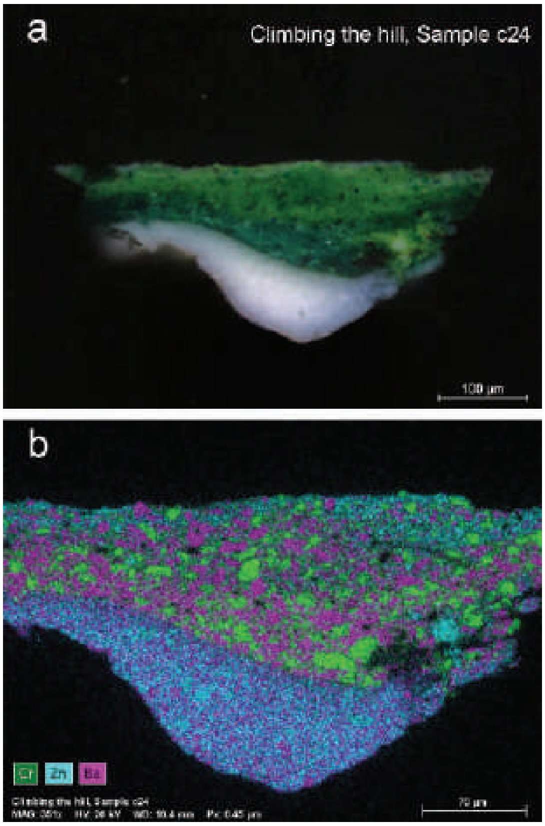

Figure 10. Microscopy image (a) and corresponding SEM-EDS mapping of sample c24 of *Climbing the hill* (b). The SEM-EDS mapping shows the distribution of chromium (Cr), zinc (Zn) and barium (Ba) in the paint sample.

3.4.3. Red

The optical microscopy and SEM-BSE images of the red paint samples extracted from both paintings (c21, v4) show a non-homogenous structure containing coarse particles of red, black and white, producing the same deep red colour. The SEM-EDS detection of Fe combined with the PLM observation of the anisotropic red particles with a high refractive index allowed the identification of red iron oxide (PR101, Fe_2O_3) as the principal component of the paint mixtures. A high concentration of lead white with extenders is noticeable in the sample c21 from *Climbing the hill*. Ca-and P-signals suggest the admixture of bone black (PBk9). The source of the other detected elements, such as Mg, Al, Si, K, Ti and Sr, was challenging to pinpoint during the SEM-EDS measurements; however, these elements coincide naturally with iron oxides (Helwig, 2007).

3.4.4. Yellow

PLM and SEM-EDS analyses suggest that chrome yellow was the principal yellow used in the tiny yellow brushstrokes of *Climbing the hill* (sample c10). A weak Fe-signal recorded in this paint mixture was assigned to yellow iron oxide (PY43, FeOOH), later confirmed with PLM by anisotropic brown particles with a high refractive index (Figure 11a, b). Chrome yellow was also found earlier as an admixture of light green paints of *Climbing the hill* (sample c14). In contrast, the yellow paint used in *View from St. John's Fort* was primarily composed of yellow and red iron oxides with probable traces of Cr-containing yellow(s) that could have been added by the artist or paint manufacturer (Helwig, 2007; Kühn and Curran, 1986) (sample v5) (Figure 11c, d). The other elements present in both samples, such as Pb, Ba, Zn, Ca and S, could correspond to lead white that is commercially admixed with barium white, zinc white and/or lithopone. Ba, Zn and Ca elements in combination with Cr would account for the presence of other Cr-containing yellows not identified by PLM.

3.4.5. White

In both paintings, lead white appears to be the primary white pigment. It was found in the investigated colour mixtures as well as in the white painted areas (sample c18, v3). However, a consistent concomitant presence of S, Zn and Ba suggests a commercial admixture of either zinc white and barium white and/or lithopone. A minor and trace concentration of Ti identified in both white paint samples may suggest a further modification of white paint with titanium white.

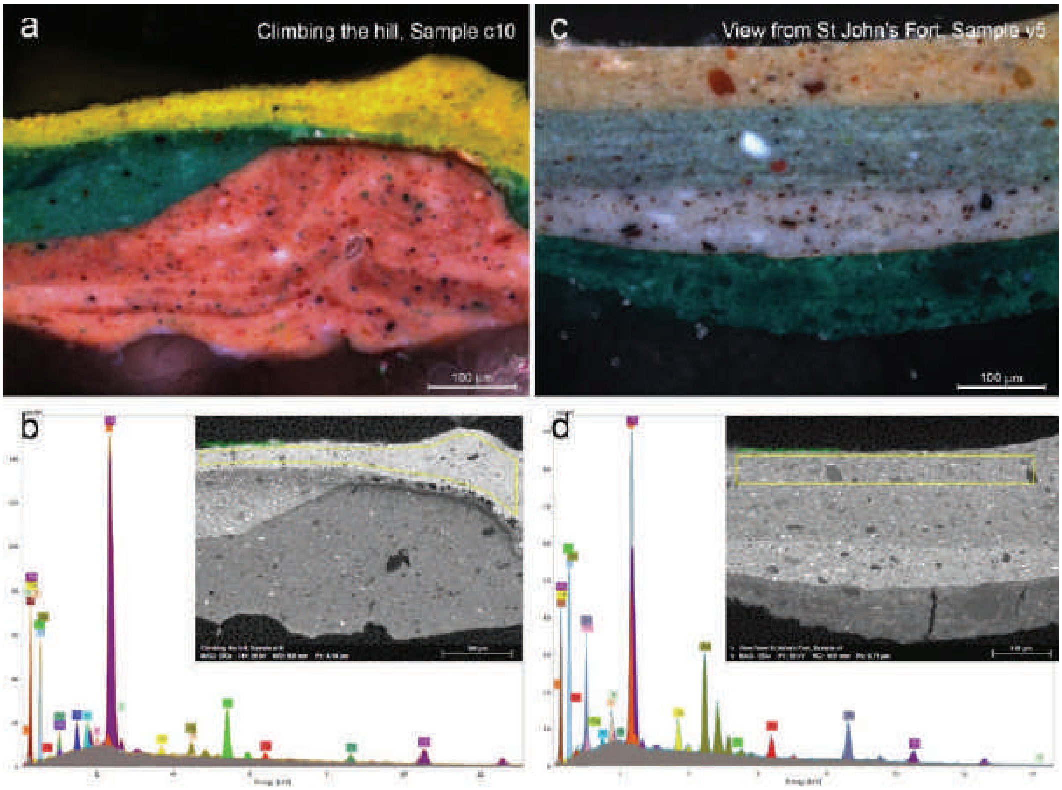

Figure 11. Microscopy images of cross-sections, corresponding SEM-EDS spectra of yellow layers, and inset backscattered electron (BSE) images with marked areas of analyses from sample c10 extracted from *Climbing the hill* (a, b), and from sample v5 extracted from *View from St. John's Fort* (c, d).

Table 1. Overview of the materials identified in the paint samples extracted from the painting *Climbing the hill*

			Climbing the hill
Colour	**Sample**	**SEM-EDS* detected elements**	**Possible PLM and SEM-EDS assignments**
White (ground layer)	c1	*C, O, Zn, Ba*, Na, S, Ti, (Si, Sr, P, Al, Pb)	Lithopone and/or barium white and zinc white, titanium white, traces of lead white
Blue	c12	*C, Pb, O, Zn, Ba*, Na, S, Al, Si, Ti, (Sr, Ca, P)	Lead white, lithopone and/or barium white and zinc white, ultramarine, titanium white, possible traces of bone black
Blue	c13	*Pb, O, Zn, Ba*, Na, S, (Ti, Si, Cr, Al, Fe, Ca, Cl, Mg)	Lead white, lithopone and/or barium white and zinc white, ultramarine, viridian, Prussian blue
Blue	c17, layer 1	*Pb, C, O, Zn, Ba*, Na, S, Ti, (Si, Al, Fe, Sr, P)	Lead white, lithopone and/or barium white and zinc white, ultramarine, Prussian blue, titanium white, traces of bone black
Green	c14	*Pb, O, C, Ba*, Zn, Cr, Na, S, (Ti, Al, Si, P, Fe)	Lead white, lithopone and/or barium white and zinc white, viridian, chrome yellow, Prussian blue
Green	c17, layer 2	*C, O, Ba*, Pb, S, Fe, Cr, Ti, Zn, (Sr, Si, Na, Al, Ca, P)	Lead white, lithopone and/or barium white and zinc white, Prussian blue, viridian, titanium white
Green	c24	*O, C, Ba, Cr*, S, Zn, Pb, Ti, Na, (Sr, Ca, Si, Al, Fe)	Viridian, lithopone and/or barium white and zinc white, lead white, titanium white, ultramarine, yellow iron oxide
Red	c21	*O, C, Pb*, Ba, Zn, Fe, S, Na, Ca, Si, Ti, (Al, P, Sr)	Lead white, lithopone and/or barium white and zinc white, red iron oxide, bone black
Yellow	c10	*Pb, C, O*, Cr, Ba, Zn, Al, Fe, (Si, Na, Ca, S, P, Ti, Cl)	Chrome yellow and lead white, lithopone and/or barium white and zinc white, yellow iron oxide
White	c18	*Pb, O, C, Ba, Zn*, Na, S, Ti, (Al, Si, P)	Lead white, lithopone and/or barium white and zinc white, titanium white

*Major elements are given in italic, minor elements in plain type and trace elements in brackets.

Table 2. Overview of the materials identified in the paint samples extracted from the painting *View from St. John's Fort*

			View from St. John's Fort
Colour	**Sample**	**SEM-EDS* detected elements**	**Possible PLM and SEM-EDS assignments**
White (ground layer)	v1	*C, O, Ba, Ca*, Zn, S, (Si, Na, Ti, Pb)	Lithopone and/or barium white and zinc white, calcium carbonate, traces of titanium white and lead white
Blue	v2	*C, O, Pb, Ba, Zn*, S, Na, Al, Si, (Cr, Ca, Mg, Ti)	Lead white, lithopone and/or barium white and zinc white, ultramarine, traces of viridian
Green	v7	*C, Pb, O, Ba, Zn*, S, Na, Cr, (Al, Si, Fe, Mg, Cl, Ca)	Lead white, lithopone and/or barium white and zinc white, viridian, chrome yellow, Prussian blue
Green	v10	*C, O, Ba, Pb*, Zn, S, (Na, Fe, Cr, Sr, Ca, Ti, Al, Cl, Si)	Lead white, lithopone and/or barium white and zinc white, Prussian blue, traces of viridian
Red	v4	*O, Fe, Ca*, C, Si, Ba, (Al, S, Pb, Mg, Zn, K, Sr, Ti, P)	Red iron oxide, lithopone and/or barium white and zinc white, lead white, bone black
Yellow	v5	*O, C, Pb, Ba*, Zn, S, Fe, Ca, Na, (Si, Al, Mg, Sr, Cr, P)	Lead white, lithopone and/or barium white and zinc white, yellow and red iron oxide, possible chrome yellow or other Cr-containing yellow(s), bone black
White	v3	*C, Ba, O*, S, Zn, Ca, Pb, Na, (Ti, Sr, Si, Al, Cr)	Lead white, lithopone and/or barium white and zinc white, titanium white

*Major elements are given in italic, minor elements in plain type and trace elements in brackets.

3.5. Execution of the paintings

The technical evidence collected from both paintings shows that Liu Kang reused his earlier artworks. He painted directly on the previous compositions without applying an intermediate ground layer. Although NIR did not reveal any preparatory sketches, an archival search provided an undated pencil drawing that could be a study conducted prior to his painting *Climbing the hill* (Figure 12a, b). The rapidly executed drawing expressively captures the view of the hill by means of free-flowing lines with a minimum of shading and gradation. Moreover, two undated black-and-white photographs of the hill, taken by the artist, seem to complement the study with documentary precision (Figure 12c, d). Considering that the drawing and photographs are consistent with the time that painting was created, they may be indicative of the artist's search for the composition and sources of inspiration. The photographs could also have been used as references for developing the painting upon the artist's return to Singapore. Nevertheless, these supplementary media demonstrate the process of the creation of a painting, from the initial study to the completed work.

With regard to the painting technique, both artworks were executed rapidly with a combination of a palette knife and brush. Palette knife touches are more evident in *Climbing the hill* as the artist used this tool for quickly covering the surface with colour. Meanwhile, the brush was used for more detailed and descriptive work. This technique significantly reduced

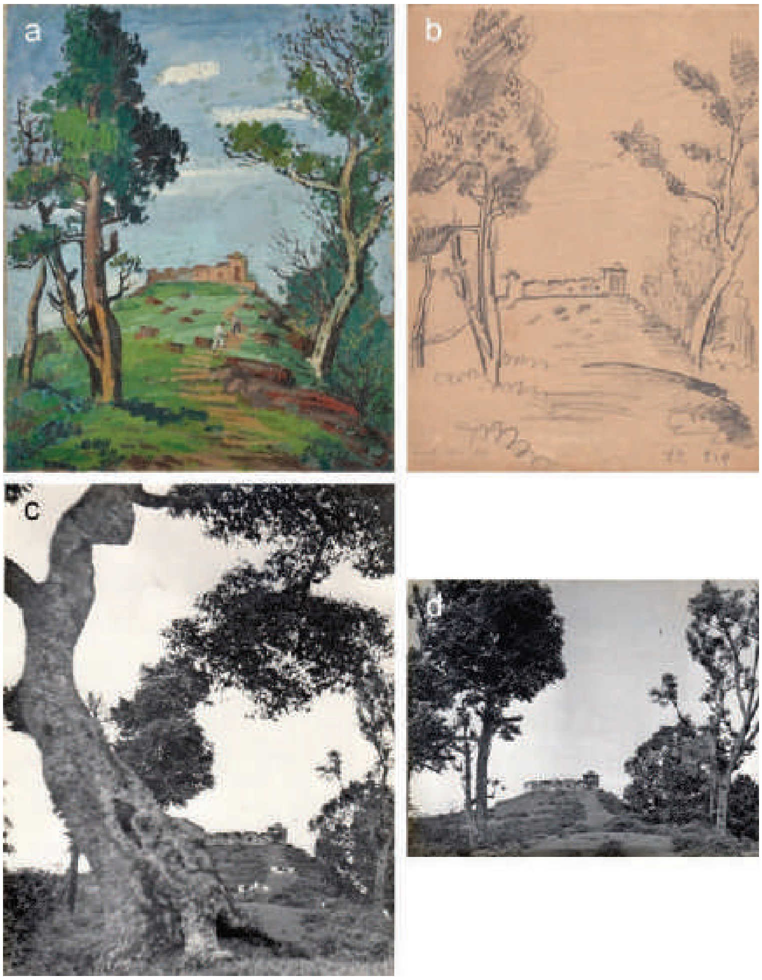

Figure 12. Image of (a) *Climbing the hill*. Image of Liu Kang's: (b) pencil drawing; (c, d) archival photographs of the studied scene. Liu Kang Family Collection. Images courtesy of Liu family.

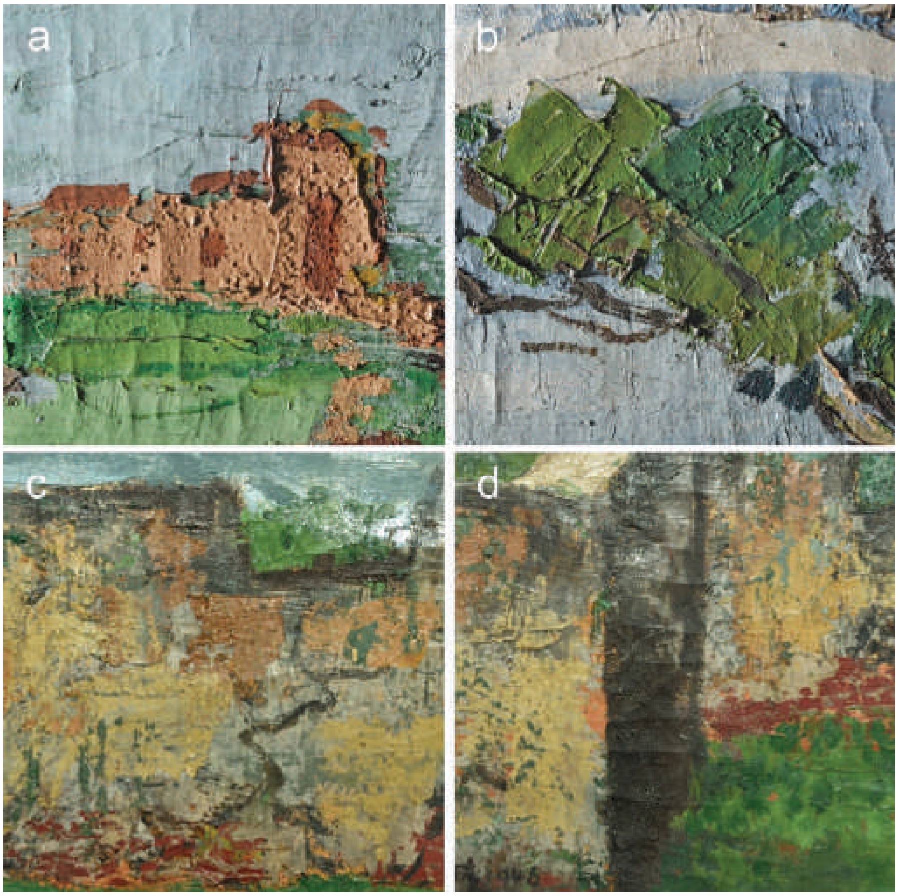

Figure 13. Details of *Climbing the hill* illustrating palette knife paint application completed with minor brush strokes (a, b). Details of *View from St. John's Fort* illustrating a combination of palette knife and brush paint application found in the area of fort wall (c, d).

the time required to complete the work (Figure 13a, b). In *View from St. John's Fort*, the brush played a major role while palette knife paint application was used only for the execution of the fort's wall (Figure 13c, d). Based on these observations it is clearly evident that, the painting technique of two artworks demonstrates some differences despite they have been created the same year. This may reflect Liu Kang's free approach to the technique in support of the artistic expression.

4. CONCLUSION

The multidisciplinary approach – combining analytical and historical data – enabled the dating of *Climbing the hill* to be approximated as 1948 or 1949 rather than 1937. Moreover, the archival photographs and drawing shed light on the artist's painting process. Digital microscopy proved to be effective in evidencing the presence of an earlier composition under the current paint layer, while IRFC imaging was crucial in the tentative identification of pigments and selection of sampling areas. A comparative technical study of *Climbing the hill* and *View from St. John's Fort* gives insights into the material preferences and also unveils a few converging features. Both paintings were created directly over the earlier compositions without an intermediate ground layer. However, the structure of the canvas and the ground composition for the painting beneath *Climbing the hill* exhibit features consistent with Liu Kang's Shanghai period (1933–1397), while the canvas and ground layer for the painting beneath *View from St. John's Fort* have features typical of the Paris period (1929–1932), which is further supported by the partially visible date 1931. This discovery may reflect the scarcity of the painting materials available to the artist in 1948 or his financial constraints, which forced him to reuse his earlier compositions in order to continue artistic career. With regard to the pigments, the range of colours used by the artist in *Climbing the hill* and *View from St. John's Fort* is restricted; however, the range is adequate for the painted scenes, which are dominated by blue, green and yellow colours. Hence, Liu Kang made an extensive use of ultramarine, Prussian blue, viridian, chrome yellow, yellow, and red iron oxides and lead white. Judging from the similar dating, subject matter, and involvement of nearly identical pigment mixtures in both artworks, it is hypothesised that there is a strong relationship between the paintings and that they were created by Liu Kang at approximately the same time.

However, the interpretation of the collected data highlighted some areas that should be addressed in the further research. As the XRR of *Climbing the hill* did not produce sufficient information, the visualisation of the hidden composition could be achieved with MA-XRF. This technique could also guide potential sampling for the in-depth study of the pigments used in the creation of the hidden artwork. Additionally, to improve the comparison of the pigments used by the artist in *Climbing the hill* and *View from St. John's Fort* a more extensive study using a range of vibrational spectroscopic techniques is required.

Ultimately, the results obtained from the investigation of both paintings may add to the growing body of knowledge about Liu Kang. Nevertheless, a more extensive study of his works created after the war will contribute further to a better overview of his painting materials and technique.

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RESEARCH ARTICLE

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The emergence of Liu Kang's new painting style (1950–1958): a multi-analytical approach for the study of the artist's painting materials and technique

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Abstract

Liu Kang (1911–2004) was renowned Singapore artist trained in Shanghai and Paris, and known for his contributions to the Nanyang style—an art movement practised by migrant Chinese painters in Singapore between the late 1940s to the 1960s. The style depicts aspects of the tropical way of life, synthetising the artistic traditions of the School of Paris and Chinese ink painting with remarkable stylistic innovations. The aim of this study was to characterise Liu Kang's painting materials and technique by way of ten paintings from a significant period in his oeuvre, 1950–1958, during which his Nanyang style emerged. The selected artworks are from the National Gallery Singapore. A broad range of analytical techniques was employed to study the painting supports and paint layers. The results indicate the prevailing use of commercially prepared linen canvases with double-layered oil-based ground. Single- and triple-layered structures of the ground, as well as semi-absorbent ground, were used sporadically. The identified group of pigments partially overlaps with those already known from Liu Kang's earlier practice and also incorporates some noteworthy peculiarities like manganese, cerulean and phthalocyanine blues, phthalocyanine green, zinc yellow, and naphthol red AS-D. Some of these newly identified pigments made a distinctive appearance in the individual artworks, but ultimately Liu Kang was not convinced about increasing their role in his painting practice of the 1950s as presented in this research. This study highlights the significance of drawing and photography as integral elements of his artistic process. It also delves into the artist's different painting approaches and discusses their evolution, which culminated in the stylistic innovation that became Liu Kang's signature for decades to come. The obtained data may assist art historians and conservators in authenticity and attribution studies, evaluating the condition of artworks and designing conservation strategies. Moreover, this study contributes to the growing body of knowledge about twentieth-century artists' materials, which are characterised by the complex mixtures of inorganic and organic compounds. It also provides information about the availability of art materials in Singapore in the 1950s.

Keywords: Liu Kang, Pigment identification, Hidden paintings, SEM–EDS, FTIR, IRFC, X-RAY, RTI

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Introduction

Liu Kang (1911–2004) was one of the most eminent painters of modern art in Singapore. Following his graduation from Xinhua Arts Academy in Shanghai in 1928, he moved to Paris where his career gained momentum and was marked by a highly creative period from 1929 to 1932. During that time, the artist studied at the Académie de la Grande Chaumière in Montparnasse and painted intensively in an attempt to assimilate the artistic essence of the Western masters. In 1933, he accepted the post of Professor at the Shanghai Art Academy and focused on teaching and painting. The heretofore rapid artistic development was impacted by his decision to emigrate to Malaya in 1937 due to the Second Sino-Japanese War (1937–1945). After the war, in 1945, Liu Kang permanently relocated to Singapore. He continued painting, mainly during trips across Malaya. His painting style began to evolve, showing less resemblance to the Post-Impressionist mode from the Paris and Shanghai periods; this suggests an attempt to develop a personal painting style [1]. However, it was only in the 1950s that he formulated his pivotal painting concepts, which furthered his artistic career. Following in the footsteps of the Belgian artist Adrien-Jean Le Mayeur de Merpres and inspired by the French Post-Impressionist artist Paul Gauguin, Liu Kang embarked on a month-long painting journey to Indonesia in 1952 with fellow painters Cheong Soo Pieng, Chen Wen Hsi and Chen Chong Swee, who were also Chinese emigrants to Singapore. In particular, the trip to the Indonesian island of Bali inspired them to establish the artistic concept known as the Nanyang style, and was a turning point in their artistic development.

The term "Nanyang" in the Chinese language means "Southern Seas", referring to the geographical area situated south of mainland China, known today as Southeast Asia [2]. The Nanyang style is associated with paintings that express a consciousness of regional identity amongst the migrant Chinese painters in Singapore, stemming from an erosion of ties with China, especially after the start of communist rule in 1949 [3]. The painting style reflects an eclectic amalgamation of two artistic traditions, the School of Paris and Chinese ink painting [4–6], representing Southeast Asian subject matter. However, according to some scholars, a formal description of the Nanyang style remains elusive as it did not evolve into a coherent art movement with an agreed manifesto [5–7]. Thus, the common denominator among the Nanyang style artists was Nanyang, the geographical locality to which the artworks are related [8]. Artists also responded to the founder of Singapore's Nanyang Academy of Fine Arts (NAFA) Lim Hak Tai's call for art that embodies the tropical sensibility and complex ethnic consciousness of the region, and is, concurrently, socially engaged [9, 10]. Artists selected their own artistic languages to represent local subjects and evoke local sentiments. Thus, Liu Kang reflected retrospectively in 1997: "In my opinion it [Nanyang style painting] should consist of these components: One, the subject matter must be of Nanyang (the South Seas). Generally, this would include the tropical region, [...] confined only to scenes of nature and social activities. Highly modernised and industrialised regions and prosperous commercial areas would not make this category. Two, technique and expression. The Nanyang artist expresses in a subjective manner, utilising technical expression that would, in a simple, plain and lyrical manner, depict the natural or human landscapes of Nanyang. Excessive objectivity and unimaginative depictions should be avoided. Three, style and tone. The use of bright and cheery light and colours should be maximised and co-ordinated with brushstrokes and lines that are fluid yet steady." [11].

Although Liu Kang stated that an accurate representation of the Nanyang style should exclude modern aspects of life, his artworks from the 1950s show that he did not restrict the subject matter. Besides the expression of a local tropical flavour, his paintings frequently depicted urban activities and scenes of street hawkers in the immediate surroundings [4, 12]. Although these scenes do not evoke the idyllic lifestyle [13], they could be a response to Lim Hak Tai's call for social engagement of Nanyang art [9, 14]. Another reason for depicting modern life in the paintings could be poor accessibility to the Malayan countryside as well as movement restrictions imposed on the local communities by the British Administration due to the threat of communist insurgency [12].

In an attempt to depict Nanyang style, Liu Kang integrated Western painting techniques with Chinese traditional ink painting, the latter representing his cultural inheritance. Along with these two art traditions, a remarkable stylistic innovation in the form of a batik-inspired painting technique also emerged, characterised by unpainted outlines of objects and figures.

Liu Kang has been recognised as one of the most famous Nanyang artists, and extensive literature has been devoted to discussing the roots of the Nanyang style. However, no comprehensive study of Liu Kang's painting practice from the 1950s, when the style emerged, has been carried out. Hence, this study focuses on the investigation of the painting supports, pigments and techniques Liu Kang used in his early Nanyang style paintings. The collected data may be useful to scholars who wish to further explore the art of Liu Kang and to conservators in charge of his works, which reveal the rapid evolution of the technique. The interest in Liu Kang's painting process extends beyond Singapore and Southeast Asia as the artist bridged Western and Eastern artistic trends and relied on the materials imported from overseas. Hence, this study adds to the existing international research of twentieth-century artists' materials, which are characterised by the complex mixtures of inorganic and organic compounds. Moreover, this research points out some art supplies in Singapore in the 1950s, and hence contributes to the knowledge of their distribution and accessibility.

This study is a part of an ongoing research that aims to present the painted oeuvre of Liu Kang and the emergence of his early Nanyang style as the next breakthrough after the Paris and Shanghai periods, which were investigated earlier by the authors [15, 16].

Research materials

Paintings

The focus of this study is the collection of ten paintings by Liu Kang from the National Gallery Singapore (NGS), spanning the important period in the emergence of the Nanyang style (1950–1958) (Figs. 1, 2). The selection of artworks was guided by the range of painting techniques by which they were executed, thus providing a unique opportunity for investigating their technical and stylistic evolution. Thus, the research base includes the paintings created shortly before the well-known trip to Indonesia—*Village* (1950) and *Kampong scene* (1951). They show a stylistic relationship with the paintings created after 1952 in their depiction of lush tropical landscapes as well as the daily life of people from different ethnic groups [17]. The study involves the characterisation of the painting supports and paint layers.

Samples

The research material also consisted of 82 samples of the paint material and seven XRF spot measurements collected from the artworks (Figs. 1, 2). Additionally, 20 samples of fibres were extracted from the threads of weft and warp of each textile painting support for the identification.

Research methods

The applied analytical methods for studying the painting materials and the artist's technique included both non- and micro-invasive techniques. As an informative first-step approach, a technical description of the artworks was made. Then, digital microscopy was engaged to obtain information about the structure of the textile supports, such as weave, density and twist of threads. Next, technical photography comprising visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR) and infrared (IR) was conducted to tentatively identify the pigments and select the sampling areas. Reflectance transformation imaging (RTI) and surface digital microscopy were used to study the texture of the paintings and collect evidence of the underlying compositions, which were later visualised with IR and X-ray radiography (XRR). The following step involved sampling from the areas of the existing paint losses. Then, analyses of the collected material were carried out with optical microscopy (OM), polarised light microscopy (PLM) and field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM–EDS). These techniques allowed us to characterise the structure and constituents of the ground layers and paint mixtures. The indication of the organic and inorganic components was given by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) as a supplementary technique. The morphology of the textiles' fibres and the results of the chemical staining tests were studied using OM. The results obtained through the analytical methods were cross-referenced with a variety of archival sources.

Technical photography

Technical photography was performed according to the workflow proposed by Cosentino [18–20] with a full-spectrum (360–1100 nm) modified Nikon 850 DSLR camera equipped with a Nikon AF Micro NIKKOR 60 mm f/2.8D lens. The camera was calibrated with X-Rite ColorChecker Passport. The American Institute of Conservation Photo Documentation (AIC PhD) target was used to adjust the white balance and exposure of the RAW format images.

VIS photography illumination was provided by two 500 W halogen lamps. X-Nite CC1 and B+W 415 filters were coupled together and placed in front of the camera lens for VIS imaging. The same set of filters was used for the UVF imaging with the illumination system consisting of two lamps equipped with eight 40 W 365 nm UV fluorescence tubes. UVR photography was achieved using the same lighting conditions as for the UVF and Andrea "U" MK II filter was used on the lens. IR imaging, with an additional objective of false-colour infrared imaging (IRFC), was performed using the same illumination system as for VIS, and a Heliopan RG1000 filter was mounted on the camera lens.

Further processing of the images, including IRFC manipulation, was conducted using Adobe Photoshop CC according to the standards described by the American Institute of Conservation [21].

High-resolution digital microscopy

Digital microscope images of the recto and verso of the paintings were taken with Keyence VHX-6000, using a zoom lens coupled with a high-speed camera. Observations were conducted at magnifications of ×20 to ×200. For measurement analyses, built-in Keyence software—VHX-H2M2 and VHX-H4M—was used.

RTI

RTI was carried out following the workflow proposed by Cultural Heritage Imaging [22]. The captured images were processed using Adobe Photoshop CC and RTIBuilder. The results were visualised through RTIViewer

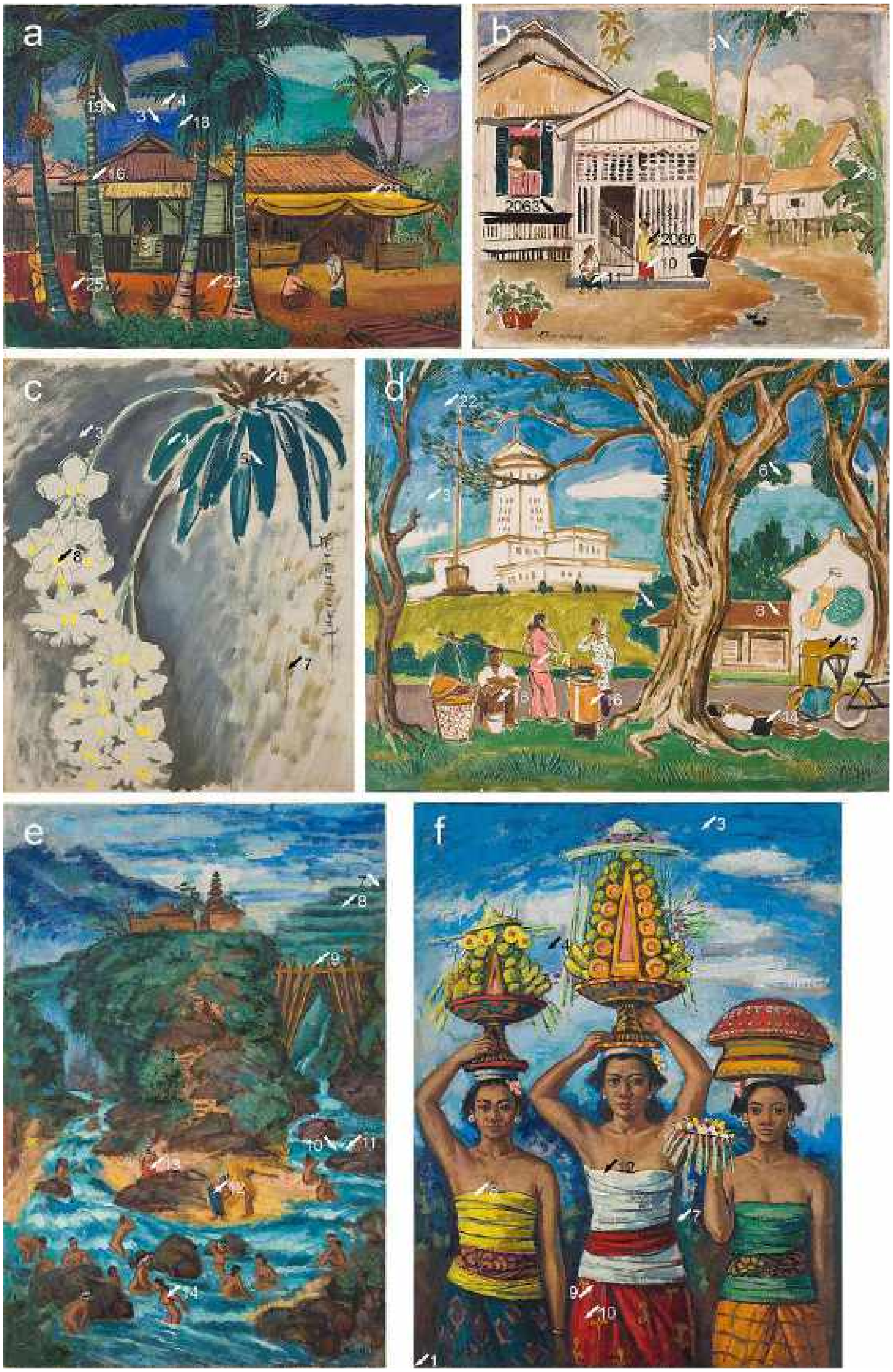


Fig. 1 The paintings by Liu Kang: **a** *Village*, 1950, oil on canvas, 99 × 131.5 cm; **b** *Kampong scene*, 1951, oil on canvas, 60 × 72.5 cm; **c** *Orchids*, 1952, oil on canvas, 50 × 40.5 cm; **d** *Government office in Johore Bahru*, 1953, oil on canvas, 63.2 × 76.3 cm; **e** *Scene in Bali*, 1953, oil on canvas, 127 × 85.5 cm; **f** *Offerings*, 1953, oil on canvas, 131.5 × 98.5 cm. Gifts of the artist's family. Collection of National Gallery Singapore. White arrows indicate sampling areas

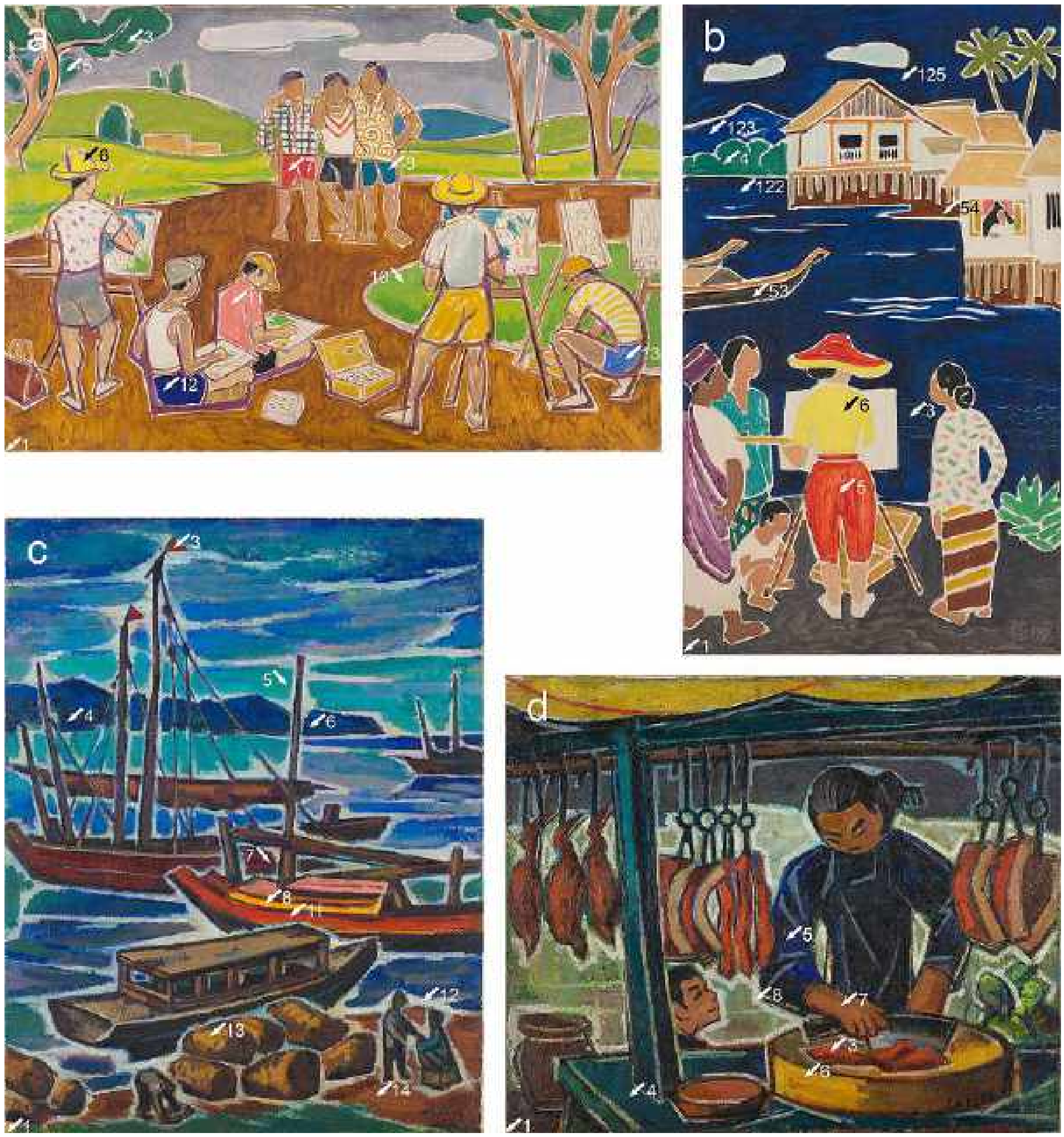


Fig. 2 The paintings by Liu Kang: **a** *Outdoor painting*, 1954, oil on canvas, 85 × 127 cm; **b** *Painting kampong*, 1954, oil on canvas, 120.5 × 71 cm; **c** *Boats*, 1956, oil on canvas, 91 × 70 cm; **d** *Char Siew seller*, 1958, oil on canvas, 59.5 × 72.5 cm. Gifts of the artist's family. Collection of National Gallery Singapore. White arrows indicate sampling areas

software, as proposed by Cultural Heritage Imaging [23, 24].

XRR

Paintings were X-ray radiographed with a Siemens Ysio Max digital system with a detector of dimensions 35 × 43 cm and a resolution of 7 million pixels. The X-ray tube operated at 40 kV and 0.5–2 mAs. The radiographic images were visualised and processed using dedicated X-ray medical imaging software, iQ-LITE, then exported to Adobe Photoshop CC for final alignment and merging.

XRF

XRF measurements were performed using Thermo Scientific™ Niton™ XL3t 970 portable spectrometer with a GOLDD+detector and an Ag anode X-ray tube with a 6–50 kV voltage and up to 0.2 mA current. A mining mode with four elemental ranges and a measurement duration of 50 s each (total acquisition time of 200 s) were used to better differentiate the light elements from the heavy ones. The spectra were obtained at a working distance of 1 mm and an analytical spot diameter of 3 mm. The spectra were processed with Thermo Scientific™ Niton Data Transfer (NDT™) 8.4.3 software.

OM and PLM

The paint samples' structure was examined in reflected VIS and UV light on a Leica DMRX polarised microscope providing ×100, ×200, and ×400 magnifications. PLM of the pigments and morphology of the fibres were carried out in transmitted VIS light at the same range of magnifications. PLM of the pigments was conducted according to the workflow developed by Peter and Ann Mactaggart [25]. The samples were digitally photographed using a Leica DFC295 camera.

Staining tests

The phloroglucinol stain test was carried out on the natural fibres to determine the presence and concentration of lignin [26].

FE-SEM–EDS

The paint samples' cross-sections were mounted on carbon tapes and analysed with a Hitachi SU5000 FE-SEM coupled with Bruker XFlash® 6/60 EDS. The SEM, backscattered electron mode (BSE), was operated at an accelerating voltage of 20 kV, 60 Pa chamber pressure, 50–60 intensity spot and 180 s acquisition time. Analyses were conducted at a working distance of 10 mm. The data collection and processing were performed with Bruker ESPIRIT 2.0 software.

ATR-FTIR

ATR-FTIR analyses were performed using a Bruker Hyperion 3000 FTIR microscope equipped with a mid-band MCT detector, coupled with a Vertex 80 FTIR spectrometer. The spectra were acquired in the spectral range of 4000–600 cm^{-1} and resolution of 4 cm^{-1}. A total of 64 scans were recorded for each sample. Spectra collection and processing were carried out using Bruker Opus 7.5 software. The interpretation of data was performed using the reference spectra in the material collection of the Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, as well as spectral library of the Infrared and Raman Users Group (IRUG) [27].

Preparation of samples

Selected paint samples were prepared as cross-sections by mounting in acrylic resin—ClaroCit from Struers (USA). The PLM pigment scrapings were prepared as dispersions on microscope slides in a mounting medium Meltmount from Cargille (USA) with a refractive index of 1.662, and covered with a cover glass. The samples of fibres were immersed in a boiled water to soften and clean off contaminants. Then, they were mounted on microscope slides with a drop of water under the cover glass.

Archival sources

Although to the best knowledge of authors, the information about the brands of the paints used by Liu Kang in the 1950s is non-existent, the local newspapers', magazines' and trade directories' advertisements from the period under investigation provided background information about the availability of the art materials in Singapore. Based on the advertisements, contemporary colourmen catalogues, such as Rowney from 1951 and 1955, Winsor & Newton (W&N) from 1955 and 1957, and Reeves & Sons (R&S) from 1958, were referenced to expand the discussion about the possible use of certain materials that were identified in the investigated paintings. However, conclusions about the brands of materials used by the artist should not be hastily drawn. The authors came across only one source that listed some commercial names of the paints used by Liu Kang in 1955, and this information is cross-referenced with the data acquired from the analysed paint mixtures. Old photographs and the artist's drawings from the Liu family archives were invaluable for understanding the artist's approach to painting.

Results and discussion

Auxiliary supports

Of the ten examined paintings, nine are stretched over bevelled strainers and one is stretched over plywood board. The paintings are mounted through the tacking margins with steel staples. Additionally, the observation of the tacking margins revealed a presence of empty nail holes, which do not correspond to the holes in the auxiliary supports. This allowed us to infer that the auxiliary supports are not original and that the nail holes could correspond to the original mounting method. Judging by the absence of original auxiliary supports, one can guess that they were of poor quality and were likely to have been made locally. The inventory and technical data of the paintings are summarised in Table 1.

Fabric types

All investigated paintings were executed on plain-weave canvases made of Z-twisted threads of weft and warp. Linen fibres were identified by their morphology features, such as transverse markings and dislocations, as well as uneven pink stains obtained by the phloroglucinol test [26].

Four weave matching groups were determined. Group 1 is represented by one canvas with a thread count approximating 14 × 17 per cm. Group 2 is the most dominant and is characterised by a consistent thread count

Table 1 Inventory and technical details of the investigated paintings

Title & inventory number	Date	Dimensions H × W (cm)	Orientation	Type of auxiliary support strainer/stretcher/rigid support	Painted on an earlier composition
Village, 2003-03270	1950	99 × 131.5	Horizontal	Strainer	No
Kampong scene, 2003-03245	1951	60 × 72.5	Horizontal	Strainer	No
Orchids, 2003-03379	1952	50 × 40.5	Vertical	Plywood board	No
Government Office in Johore Bahru, 2003-03300	1953	63.2 × 76.3	Horizontal	Strainer	No
Scene in Bali, 2003-03333	1953	127 × 85.5	Vertical	Strainer	Yes
Offerings, 2003-03269	1953	131.5 × 98.5	Vertical	Strainer	Yes
Outdoor painting, 2003-03290	1954	85 × 127	Horizontal	Strainer	No
Painting kampong, 2003-04149	1954	120.5 × 71	Vertical	Strainer	No
Boats, 2003-03275	1956	91 × 70	Vertical	Strainer	Yes
Char Siew seller, 2003-03311	1958	59.5 × 72.5	Horizontal	Strainer	Yes

of 13 × 15 per cm. It was found in six paintings. Group 3 comprises two denser canvases with a thread count of 16 × 17 cm. Group 4, with a thread count of 11 × 10 per cm, was identified in one painting (Fig. 3).

Characteristics of the grounds

All examined paintings have white and textured ground extended over the tacking margins, indicating a commercial preparation of the canvases. Analyses of the structure and composition of the ground layers allowed us to identify five types of preparation of the canvases.

The ground of type 1 is double-layered, and it was found in *Village* (sample 9). The bottom layer is homogenous and predominantly composed of lead white (PW1) mixed with lithopone (PW5) and/or barium white (PW21) and zinc white (PW4), and some titanium white (PW6) (Fig. 4a, b). The top layer is composed of the same constituents as the bottom layer but with an abundance of titanium white. A drying oil as a binder was confirmed with FTIR in both layers by peaks at 2933, 2852 (both C–H stretching bands), 1728 (C=O stretching band), 1432, 1238, 1161 and 723 cm^{-1} [28].

The ground of type 2 is predominant and was identified in five paintings. It has a double-layered structure with a bottom layer that is usually thicker than the top. Both layers are composed of the same ingredients but mixed in different concentrations. Thus, the bottom layer is characterised by large particles of chalk (PW18) and clumps of lead white admixed with lithopone and/or barium white and zinc white. The top layer is formed mainly from lead white well mixed with lithopone and/or barium white and zinc white, some chalk and titanium white (Fig. 4c, d). A drying oil was positively identified in both layers with FTIR by peaks at around 2956, 2918, 2850, 1732, 1240, 1180 and 720 cm^{-1}. Additionally, zinc soaps were evident in three samples of the ground layer by a typical infrared peak at 1540 cm^{-1} corresponding to COO^- asymmetric stretching band [29–31].

The morphology of the ground of type 3 is characterised by a single and homogenous layer of zinc white (Fig. 4e, f). This type of ground was detected in two paintings: *Outdoor painting* (sample 1) and *Painting kampong* (sample 1). FTIR spectra showed drying oil binder by peaks at 2956, 2918, 2849, 1732, 1460, 1376, 1242, 1165 and 722 cm^{-1}, and zinc soaps formation by typical IR absorption at 1541 cm^{-1}.

The ground of type 4 is single-layered and predominantly composed of poorly ground particles of lead white (Fig. 4g, h). Trace amounts of Ca and Ba suggest an admixture of chalk and barium white; however, the latter was not detected with FTIR. A presence of drying oil confirmed with FTIR by peaks at 2957, 2924, 2851, 1729, 1240, 1160, 1100 and 710 cm^{-1}, and proteins indicated by signals recorded at 1639 (amide I) and 1517 cm^{-1} (amide II) allowed us to infer a semi-absorbent emulsion of oil and animal glue binders. This kind of ground layer composition was identified in *Offerings* (sample 1).

The ground of type 5 was determined by the triple-layered structure. The upper layer is thin and the elements identified are attributable to titanium white, lithopone and/or barium white and zinc white, as well as lead white and chalk. However, the structure and composition of the bottom and middle layers strongly resemble the ground of type 2 (Fig. 4i, j). Considering that this type of ground was found only in one painting, it seems reasonable to conclude that the ground layer was originally of type 2 and later modified by the artist by the application of a thin coat of white paint containing mainly titanium white.

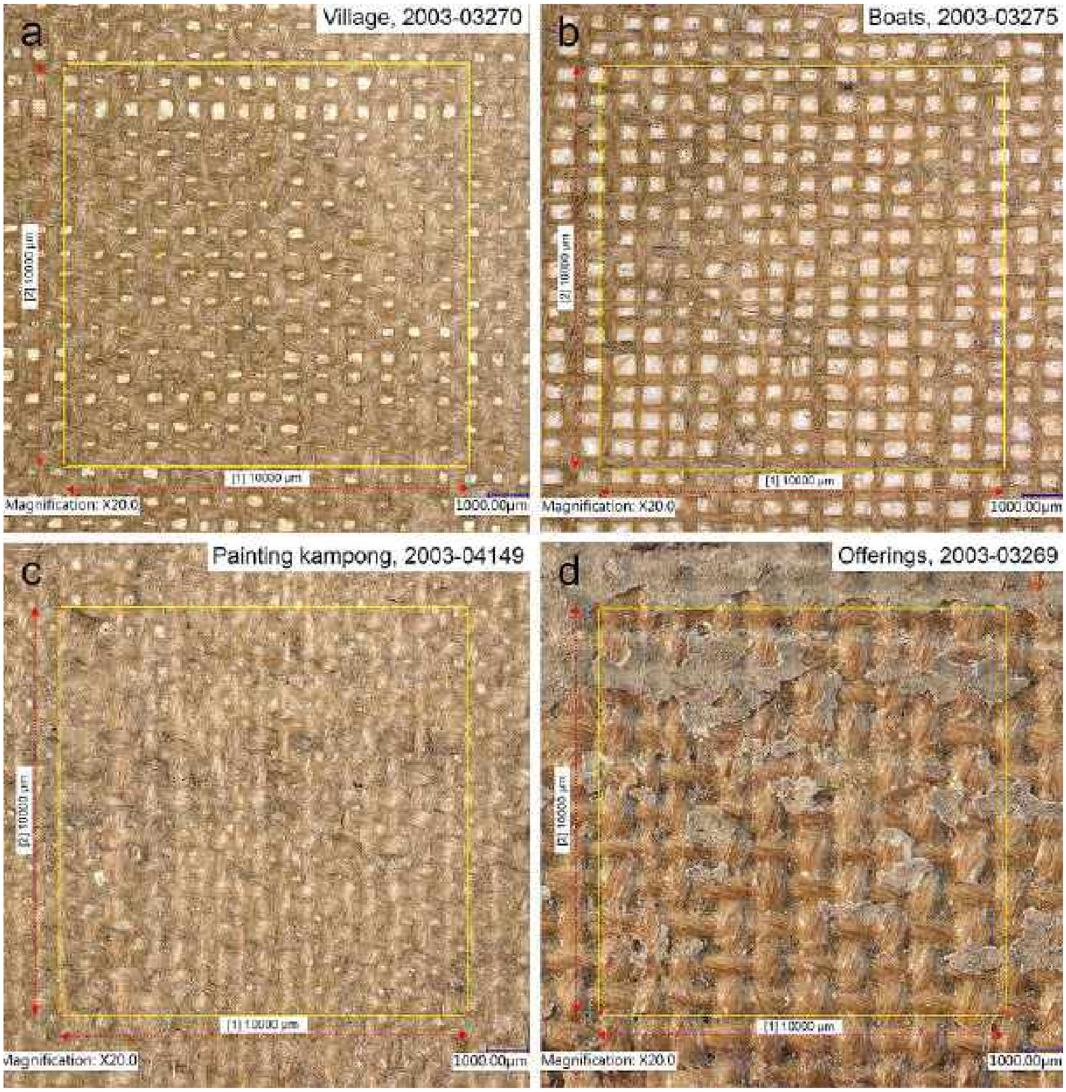


Fig. 3 Photomicrographs of four weave matching groups identified in the investigated paintings: **a** group 1; **b** group 2; **c** group 3; **d** group 4

The acquired data allowed us to find a notable correlation between the structure of the grounds and the canvases. Thus, the canvas and ground of type 1 were found only in *Village*. Interestingly, two similar stamps were found on the reverse side of this painting. Despite the poor legibility of the print, the IR enhanced photography suggests that the stamps show a capital S, a painting brush and the word "CANVAS" above (Fig. 5). The presence of the stamps may suggest that the canvas for *Village* was commercially prepared and stretched. Unfortunately, the authors could not attribute the stamps to any colourmen known to them.

In the 1950s, the art materials were available in Singapore from the specialised retailer The Straits Commercial [32, 33], as well as from stationery and book shops, such as E. J. Motiwalla & Co. and The Shanghai Book Co., Ltd. [34, 35]. However, it is unknown what specific brands the shops had distributed at that time (Fig. 6a–c). The 1947 and 1948 advertisements of the two latter companies inform that they imported R&S and W&N brands [36]. Moreover, according to the 1955 advertisement, the art materials from the Dutch company Talens were imported by Jacobson van den Berg Ltd (Fig. 6d) [37]. There is also a possibility that other overseas brands of artist materials were available in Singapore as the city enjoyed a free trade status under the British rule.

By far the most common type of painting support encountered in Liu Kang's works from the period under review was canvas and ground of type 2. This observation allows us to conclude that the artist bought this type of

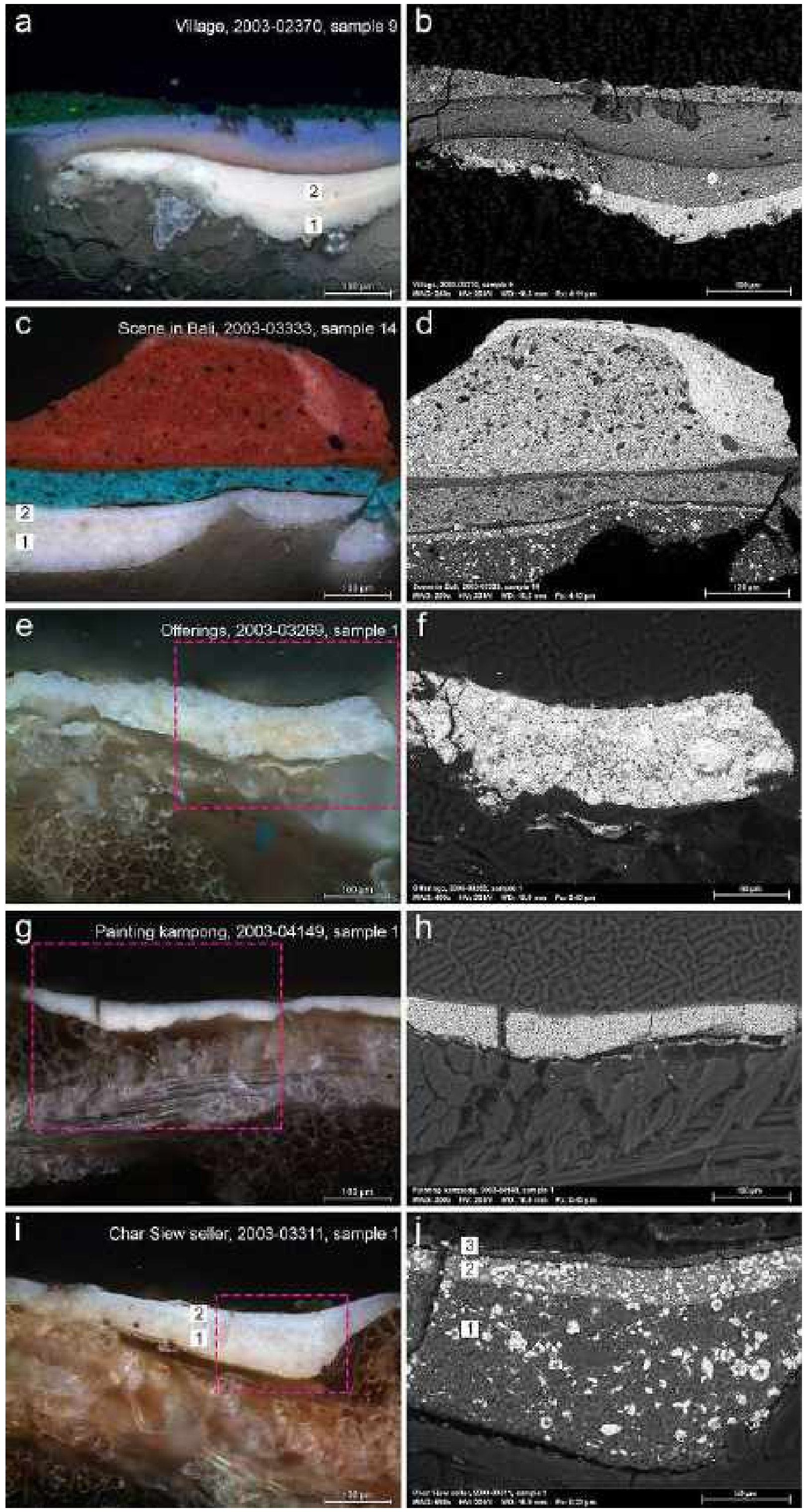


Fig. 4 Optical microscopy and corresponding backscattered electron (BSE) images of cross-sections representing five different types of the ground layer: **a**, **b** double-layered ground of type 1 with a characteristic high concentration of lead white in the bottom layer and titanium white in the upper layer; **c**, **d** double-layered ground of type 2 with a high concentration of chalk and clusters of lead white in the bottom layer and predominant lead white in the upper layer; **e**, **f** single-layered ground of type 3 composed of zinc white; **g**, **h** homogenous single-layered ground of type 4 formed from lead white and chalk; **i**, **j** triple-layered ground of type 5 with the bottom layer mainly composed of chalk and lead white agglomerated in large aggregates, middle layer characterised by a high concentration of lead white, and top layer containing mainly titanium white

Fig. 5 Detail of the colourmen stamp on the reverse side of *Village* (1950), photographed in IR to enhance the legibility of the print

Fig. 6 Advertisements by retailers of art materials available in Singapore in 1950, 1951 and 1955: **a** E. J. Motiwalla & Co.; **b** The Shanghai Book Co., Ltd.; **c** The Straits Commercial Art Co.; **d** Jacobson van den Berg (S'pore) Ltd

commercially prepared painting support in lengths and later cut it to the required size. The absence of a manufacturer's or retailer's stamp on the investigated paintings could support this notion [38]. Selling a canvas in lengths was a common industry practice; for instance, primed canvases from W&N, R&S and Rowney were offered by the yard or roll, typically 27 inches to 84 inches wide and 6 yards long.

The grounds of type 3 were applied over dense canvases of type 3. Likewise, the ground of type 4 was identified on a loose canvas of type 4. Exceptionally, the analyses showed that the ground of type 5 was applied over the canvas type 2.

The imaging techniques as well as microscopic and spectral analyses revealed that four of the examined paintings were created over earlier rejected artworks and without the application of an intermediate ground layer. These observations support the notion that Liu Kang heavily relied on commercially prepared canvases and did not usually do self-preparation of the painting supports. The results obtained from the investigation of the painting supports are listed in Table 2: Appendix 1.

Sketches, photographs and underdrawings

Sketches form an important part of Liu Kang's painting practice as they demonstrate the process of the images' evolution, from studies to completed works. Most of the sketches discussed in this paper were executed by means of a pen, with crayon used sporadically. Confidently laid lines depict the forms and build the compositions with minimal grading, suggesting a rapid capturing of the scenes or subjects.

A comparison of the dates of the sketches and corresponding paintings indicates that some of Liu Kang's artistic ideas were taken up few years after initial conceptualisation on paper. For instance, *Orchids* was sketched in 1945, but the painted version was created in 1952 (Fig. 7a, b). A sketch of *Boats* bears the date 1950, whereas the painting was executed in 1956 (Fig. 7c, d). This observation strongly supports the hypothesis that sketching served as a convenient way of capturing interesting subjects that could be recalled for future use as reference material or as a starting point for a more ambitious painting project.

Some sketches reveal a process of searching for the best composition or form of expression. The painting *Bali scene* is accompanied by three sketches, which depict a gradual development of the idea for the painting.

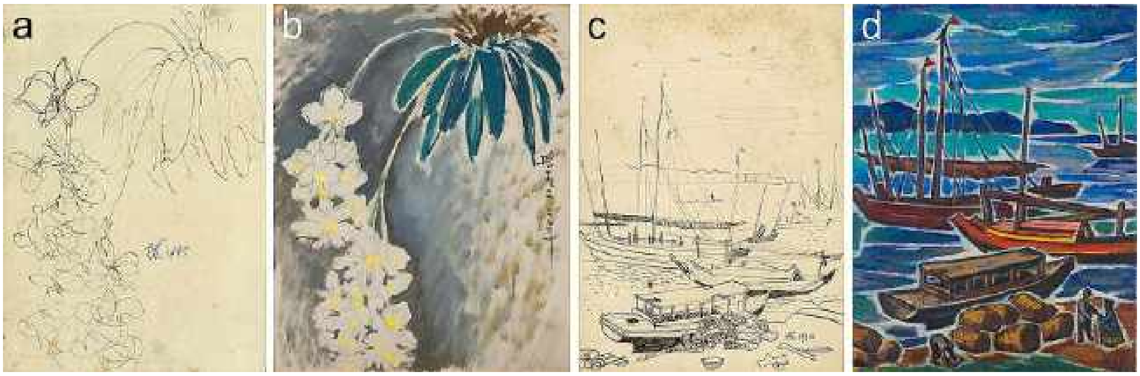


Fig. 7 **a** Liu Kang, *Orchids*, 1945, pen on paper, 25 × 17.5 cm. **b** Liu Kang, *Orchids*, 1952, oil on canvas, 50 × 40.5 cm. **c** Liu Kang, *Boats*, 1950, pen on paper, 34 × 25.5 cm. **d** Liu Kang, *Boats*, 1956, oil on canvas, 108.5 × 88.5 cm. Images **a**, **c** are from Liu Kang Family Collection. Images courtesy of Liu family

The first sketch (Fig. 8a) consists of several lines, which progressively evolve into a more detailed composition (Fig. 8b) finalised in the study of certain parts of the scenery (Fig. 8c). Hence, the painting appears to be a summary of the ideas studied in the three sketches (Fig. 8d).

The primary idea of the *Char Siew seller*, imaged in the classical pen sketch, explores a composition and studies a detail of a hand holding a chopper (Fig. 8e), whereas its crayon version reveals the artist's attempt at cubist expression (Fig. 8f), which evolved into the painting with evidently simplified and geometric forms (Fig. 8g). Likewise, the sketch *Boats* is striking in its precision, but there were far fewer details in the painted version of the scene, which also may resemble a cubist expression (Fig. 7c, d).

The sketch *Painting kampong* shows that the artist had initially considered a horizontal composition, but the painting evolved into a more detailed artwork, which was painted in the vertical orientation (Fig. 9a, b). By contrast, the simplicity of sketches for *Orchids* (Fig. 7a, b) and *Kampong scene* (Fig. 9c, d) was reflected in their painted versions, suggesting that the artist could have been satisfied with the initially imaged subject matter and composition and thus made no further changes.

In addition to sketching, Liu Kang frequently used pastels and a camera to document the subjects and motifs that inspired him. His pastel drawing and photograph capturing a procession of Balinese women with ritual offerings could have been used as a reference for depicting the details of the scene in *Offerings* upon his return to Singapore (Fig. 10). This suggests that he viewed the camera primarily as a tool to replicate the surrounding world in a precise manner [39].

Liu Kang's preparatory underdrawing stage was undoubtedly part of his working method. However, its evidence was recorded with VIS and IR only in *Kampong scene* and *Painting kampong*. As both artworks utilised the white colour of the exposed ground, the artist ensured that the underdrawings did not disturb an intended aesthetic effect. Thus, subtle pencil lines were drawn in *Kampong scene* (Fig. 11a, b), whereas in *Painting kampong*, the main shapes were lightly scratched into the white ground layer such that the grey colour of the canvas became visible (Fig. 11c). In *Orchids*, the composition was laid out directly with vigorous and effortless brushwork and diluted green paint, the latter seen especially in the decorative representation of the flower petals (Fig. 1c). A similar approach was evident in *Village*, *Government office in Johore Bahru* and *Outdoor painting* (Figs. 1a, d, 2a). The compositions of these three paintings were established with the painterly contour of light brown and violet paint and later reinforced with a calligraphic type of brushwork.

Pigments

Currently, there is, unfortunately, no information about the brands of the painting materials that Liu Kang used during the period under review. However, in his 1955 essay, the prominent Singapore artist and former President of the Singapore Art Society Ho Kok Hoe listed some pigments used by the artist at that time: "Viridian has become his favourite colour, with vermilion and Prussian blue to harmonize with it" [40]. The mentioned pigments are the primary colours of light—red, green and blue—and the most dominant colours in Liu Kang's paintings. Although viridian and Prussian blue were consistently used in the artist's earlier practice, vermilion is a new addition to the pictorial palette [15, 36, 41, 42]. Thus, this information needed to be validated through the analytical methods.

Fig. 8 **a** Liu Kang, *Scene in Bali*, undated, pen on paper, 32 × 24.5 cm. **b**, **c** Liu Kang, *Scene in Bali*, 1952, pen on paper, 32 × 24.5 cm. **d** Liu Kang, *Scene in Bali*, 1953, oil on canvas, 127 × 85.5 cm. **e** Liu Kang, *Char Siew seller*, 1955, pen on paper, 26.5 × 34.5 cm. **f** Liu Kang, *Char Siew seller*, 1955, crayon on paper, 27 × 37.5 cm. **g** Liu Kang, *Char Siew seller*, 1958, oil on canvas, 59.5 × 72.5 cm. Images **a**–**c**, **e**, **f** are from Liu Kang Family Collection. Images courtesy of Liu family

For clarity of the discussion, we decided to exclude the detailed characterisation protocols leading to the identification of the pigments commonly used by the artist based on the study of his earlier painting practice. The pigments frequently used by Liu Kang and characterised by the authors as employing the same methodology as in the current study are as follows: Prussian blue, ultramarine, cobalt blue, viridian, chrome yellow, yellow and red iron oxides, umber, organic reds, lithopone, barium white, zinc white, lead white, titanium white, chalk and carbon blacks [15, 36, 41, 42]. Therefore, in this paper, the methodology and interpretation of the outcomes are focused on new pigments as well as other pigments used less frequently by the artist.

Blue

The analytical results of the blue painted areas showed that ultramarine (PB29) was the preferred blue pigment. It appears as a primary blue and is frequently used in combination with Prussian blue (PB27) and occasionally with viridian (PG18) to achieve different hues. The admixture of manganese blue (PB33) in *Scene in Bali* (sample 12) is a significant peculiarity, indicated first with SEM–EDS by the concomitant presence of Mn, Ba and S elements. FTIR completed this outcome by the detection of less intensive absorption peaks at 1417, 1403, 1364, 874, 794, 774 and 752 cm^{-1}, and strong absorption peaks at 1065 ($(SO_4)^{2-}$ stretching band), 631 and 600 cm^{-1} (both $(SO_4)^{2-}$ bending band), which may be attributed to both manganese blue and lithopone (Fig. 12a–c).

Interestingly, the analyses of dark and light blue paints from the sky of *Government office in Johore Bahru* (samples 22 and 3) revealed complex mixtures of pigments. Although both paints appeared red in the IRFC, this outcome suggested the use of ultramarine and/or Co-, and Cr-containing pigments. It also suggested the absence of Prussian blue, which usually contributes to the blue hue of IRFC images. The PLM observation of the blue particles in sample 22, extracted from the upper, darker part of the sky, was inconclusive. It only allowed us to distinguish between ultramarine (isotropic particles with low refractive index turn red with Chelsea filter) and other isotropic blue particles that also appear red with Chelsea filter but which have high refractive indexes. Thus, cobalt blue and cerulean blue were considered as they share similar optical features. The co-location of Co and Sn elements recorded with SEM–EDS suggested the presence of cerulean blue (PB35). As for cobalt blue, the elemental analysis provided an ambiguous result because the Al-signal recorded in the sample may be attributed to both ultramarine and cobalt blue (PB29). The coincident PLM and SEM–EDS analyses also suggested a trace admixture of viridian in the blue paint. FTIR confirmation of viridian, cerulean and cobalt blues was hindered due to

Fig. 9 **a** Liu Kang, *Painting kampong*, 1952, pen and crayon on paper, 30 × 38 cm. Liu Kang Family Collection. Image courtesy of Liu family. **b** Liu Kang, *Painting kampong*, 1954, oil on canvas, 120.5 × 71 cm. **c** Liu Kang, *Kampong scene*, undated, pen on paper, 14 × 19 cm. Gift of the artist's family. Collection of National Gallery Singapore. **d** Liu Kang, *Kampong scene*, 1951, oil on canvas, 60 × 72.5 cm

Fig. 10 **a** Liu Kang, *Balinese woman carrying offering*, 1952, pastel on paper, 63 × 46 cm. Gift of the artist's family. Collection of National Gallery Singapore. **b** Archival photograph from Bali by Liu Kang, undated. Liu Kang Family Collection. Image courtesy of Liu family. **c** Liu Kang, *Offerings*, 1953, oil on canvas, 131.5 × 98.5 cm

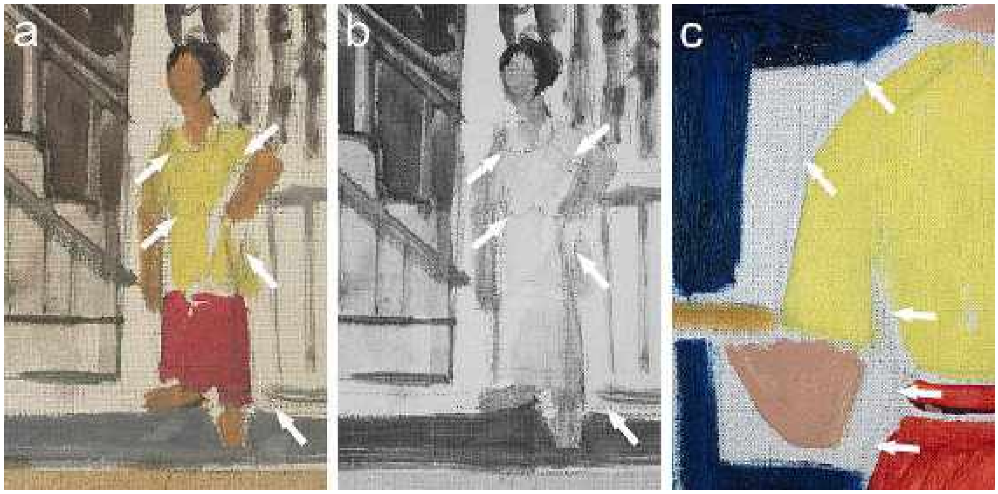


Fig. 11 VIS and corresponding IR detail images of *Kampong scene* (**a**, **b**), and VIS detail image of *Painting kampong* (**c**). The arrows indicate the presence of the preparatory underdrawing (**a**, **b**) and scratched contour into the white ground (**c**)

the strong IR absorption induced by other compounds overlapping with less intensive peaks of the pigments in question [43]. Moreover, their fundamental bands were outside of the spectral range of the instrument. The analyses of sample 3, extracted from the bottom, brighter part of the sky of *Government office in Johore Bahru*, were conducted only with PLM and SEM–EDS, which suggested the presence of cerulean blue and the absence of ultramarine and viridian. Thus, the admixture of cobalt blue can be considered based on the presence of Al in the examined paint mixture.

The use of phthalocyanine blue (PB15) was suggested by the consistent XRF recording of Cu-signal in the areas of water, mountain and sky of *Painting kampong* (spots 122, 123, 125). It was additionally confirmed with the SEM–EDS detection of Cu in sample 3. The FTIR spectra corroborated this result with a complex array of the absorption peaks at 1508 attributed to C=N stretching in the aromatic rings, 1334, 1166, 1088 and 729 corresponding to the phthalocyanine skeleton vibrations and other typical absorption bands at 1462, 1420, 1378, 1287, 1264, 1005, 957, 900, 801, 780 cm^{-1}. The low frequency peak at 754 cm^{-1} corresponds to the phthalocyanine ring vibrations (Fig. 12d–f) [44, 45]. The execution of the painting indicates a thorough planning process that probably included the choice of pigments. Thus, the use of phthalocyanine blue is not an accidental but a deliberate decision to replace ultramarine and/or Prussian blue with a new pigment of similar optical quality. However, it is puzzling why the artist did not incorporate this new blue pigment in his further practice in the 1950s. The reason could be the lack of availability of the pigment or a conscious decision to reject it.

The contemporary colourmen catalogues confirmed that phthalocyanine blue was available from W&N as Winsor blue (Fig. 13), from Rowney as Monastral blue, and from R&S as Reeves blue. Manganese blue was listed by W&N in two hues, as manganese blue and mineral blue (Fig. 13). Based on the analyses, Liu Kang did not seem to have been particularly attracted to Prussian blue, contrary to the observation made by Ho Kok Hoe. This blue pigment appears only in mixtures while ultramarine seems to be a preferred blue, although some experimentation with cerulean, cobalt, manganese and phthalocyanine blues was confirmed.

Green

Greens, more than any other colour, symbolise the lush tropical vegetation that impressed Liu Kang. Hence, he preferred viridian, probably for its intense brilliance; however, viridian was frequently blended with ultramarine and Prussian blue to modify the hue. As cerulean blue and cobalt blue were probably used for depicting the sky in *Government office in Johore Bahru*, their presence in the green passages of the same painting is understandable (sample 6). However, PLM and SEM–EDS provided some indications of cerulean blue, while the presence of cobalt blue remains uncertain.

Besides viridian, another green pigment, emerald green (PG21), was identified in *Orchids* (sample 5) by the SEM–EDS detection of Cu- and As-signals and FTIR spectra depicting less intensive ester group stretching absorption peak at 1552 cm^{-1}, peaks at 1451 and 754 cm^{-1} (both masked by the intensive peaks of the acrylic resin used for the embedding sample 5) and an absorption peak of 632 cm^{-1} overlapped by the signal from

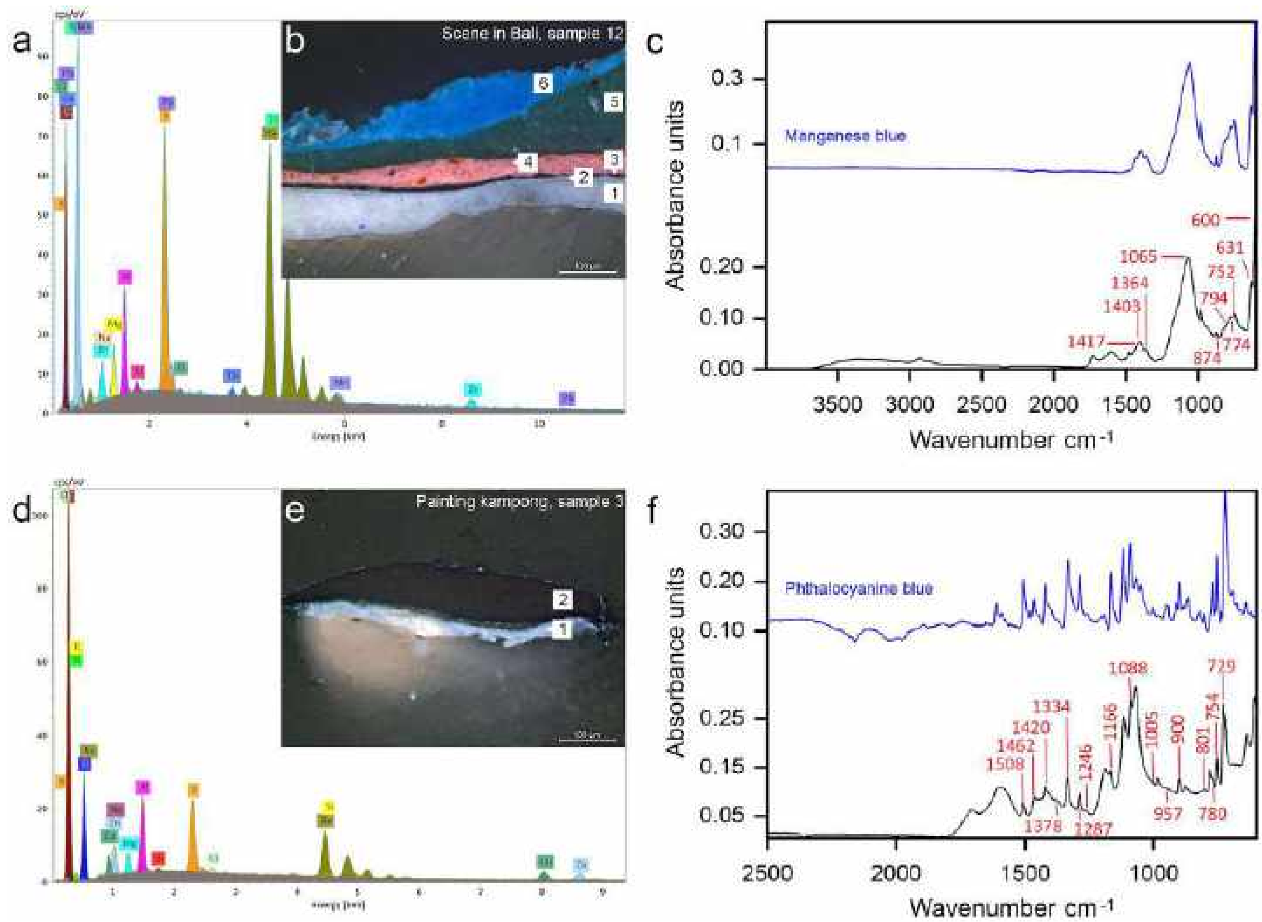
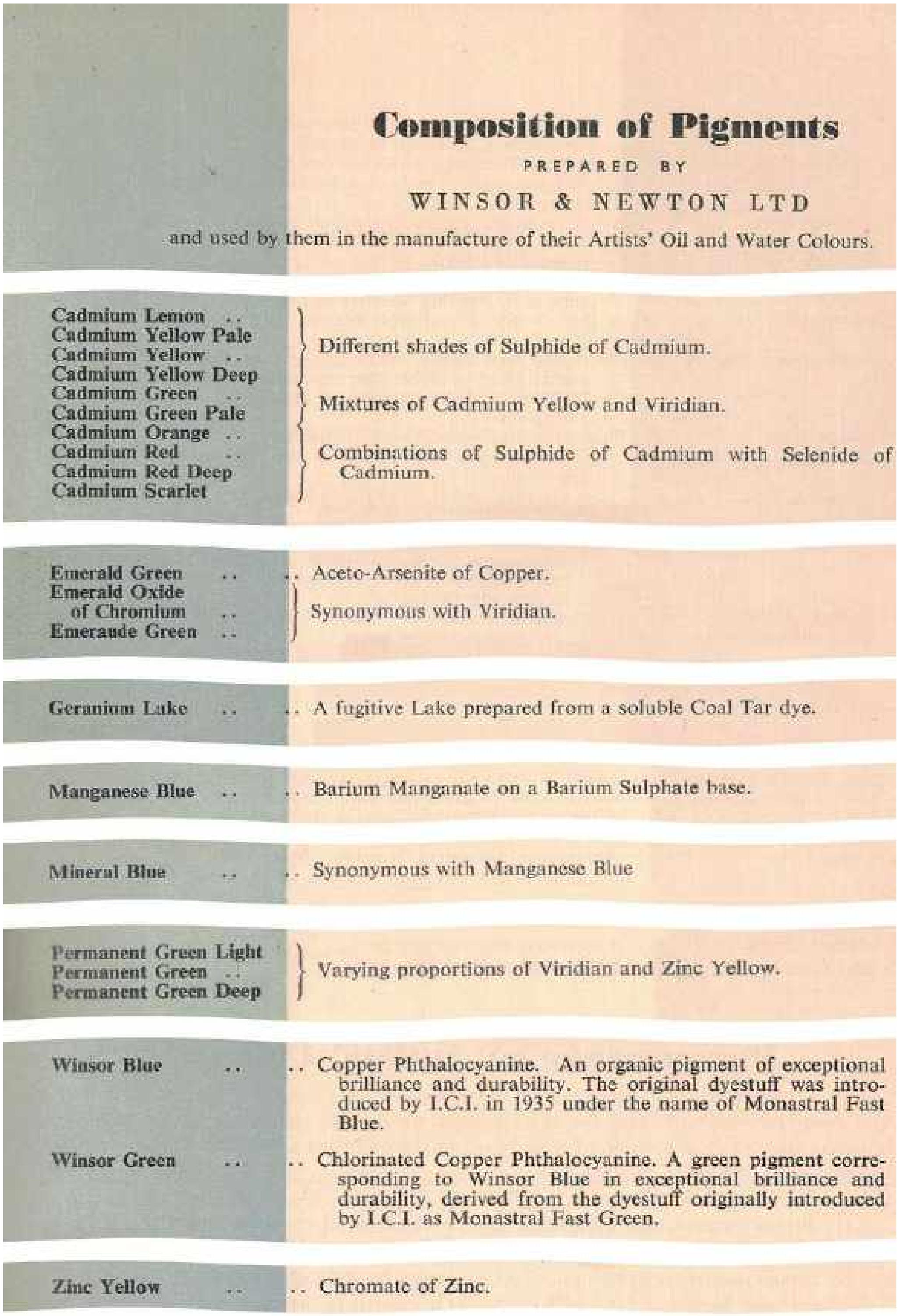


Fig. 12 **a** SEM–EDS spectra of the blue paint from layer 6 of sample 12 extracted from *Scene in Bali*; **b** optical microscopy image of the cross-section of the sample; **c** corresponding ATR-FTIR spectra of the layer 6 with labelled marker peaks of manganese blue and reference spectra of the same pigment; **d** SEM–EDS spectra of dark, blue paint from layer 2 of sample 3 extracted from *Painting kampong*; **e** optical microscopy image of the cross-section of the sample; **f** corresponding ATR-FTIR spectra of the layer 2 with labelled marker peaks of phthalocyanine blue and reference spectra of the same pigment

lithopone [46]. Emerald green is considered in sample 9 from *Village*, based on the concomitant presence of Cu and As elements; however, their minimal concentration may indicate that this pigment was used as an admixture. The trace presence of elemental copper alone in the same painting (sample 18) suggests paint contamination from emerald green. This result resembles Liu Kang's barely discernible use of emerald green in France (1929–1932), during which time he was also not convinced about giving the hue a more pronounced role in the painting process [15, 42]. The SEM–EDS recording of Cu accompanied by strong Cl-signal, as well as FTIR detection of the strong absorption bands occurring at 1496, 1391, 1321, 1305, 1277, 1208, 1152, 948, 770 and 748 cm^{-1}, matching with the IRUG reference [47], enabled the phthalocyanine green (PG7) to be identified in the green paint mixture from *Char Siew seller* (sample 4) (Fig. 14a–c) [48]. This green pigment was also detected in *Outdoor painting* (sample 5) based on the trace Cu-signal and absorption peaks at 1390, 1305, 1273, 1095, 951 and 767 cm^{-1}. According to W&N (Fig. 13), Rowney and R&S catalogues of oil paints, emerald green was still available despite its high toxicity. Phthalocyanine green was sold as Winsor green by W&N (Fig. 13), as Monastral green by Rowney and as Reeves green by R&S.

Brighter and warmer green hues were achieved by adding cadmium yellow (PY35) or its variant—light cadmium yellow (co-precipitated cadmium sulfide and zinc sulfide) or cadmium yellow lithopone (co-precipitated cadmium zinc sulfide and barium sulfate) [49]—which was detected in more than half of the investigated green paint mixtures. The detection of a concomitant presence of Cd,



Composition of Pigments

PREPARED BY

WINSOR & NEWTON LTD

and used by them in the manufacture of their Artists' Oil and Water Colours.

Cadmium Lemon .. Cadmium Yellow Pale Cadmium Yellow .. Cadmium Yellow Deep	Different shades of Sulphide of Cadmium.
Cadmium Green .. Cadmium Green Pale	Mixtures of Cadmium Yellow and Viridian.
Cadmium Orange .. Cadmium Red .. Cadmium Red Deep Cadmium Scarlet	Combinations of Sulphide of Cadmium with Selenide of Cadmium.
Emerald Green ..	.. Aceto-Arsenite of Copper.
Emerald Oxide of Chromium .. Emeraude Green ..	Synonymous with Viridian.
Geranium Lake ..	.. A fugitive Lake prepared from a soluble Coal Tar dye.
Manganese Blue ..	.. Barium Manganate on a Barium Sulphate base.
Mineral Blue ..	.. Synonymous with Manganese Blue
Permanent Green Light Permanent Green .. Permanent Green Deep	Varying proportions of Viridian and Zinc Yellow.
Winsor Blue ..	.. Copper Phthalocyanine. An organic pigment of exceptional brilliance and durability. The original dyestuff was introduced by I.C.I. in 1935 under the name of Monastral Fast Blue.
Winsor Green ..	.. Chlorinated Copper Phthalocyanine. A green pigment corresponding to Winsor Blue in exceptional brilliance and durability, derived from the dyestuff originally introduced by I.C.I. as Monastral Fast Green.
Zinc Yellow ..	.. Chromate of Zinc.

Fig. 13 Selected compositions of pigments, listed in the catalogue of W&N from 1957, used for the manufacturing of oil and watercolours

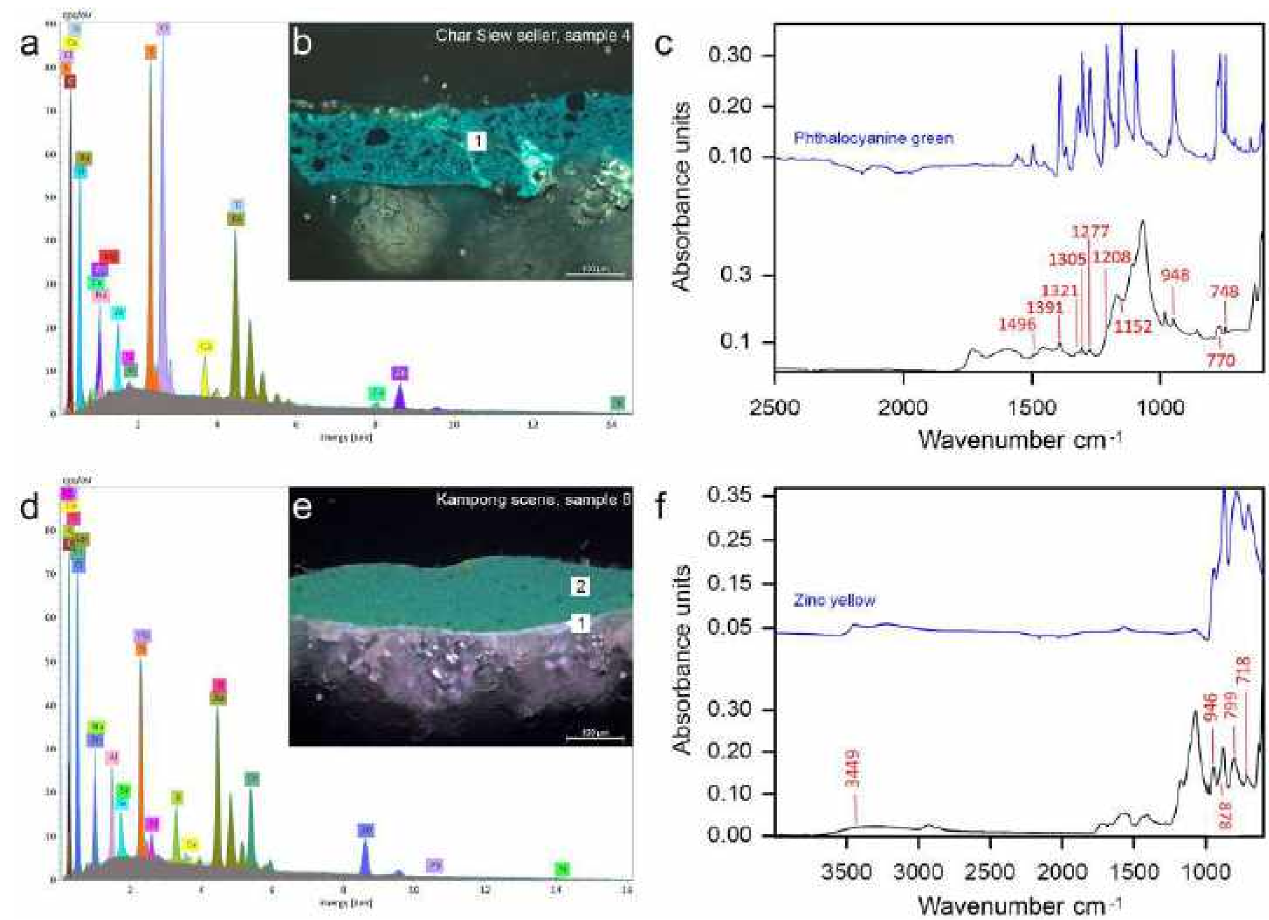


Fig. 14 **a** SEM–EDS spectra of the green paint of sample 4 extracted from *Char Siew seller*; **b** optical microscopy image of the cross-section of the sample; **c** corresponding ATR-FTIR spectra of the green paint with labelled marker peaks of phthalocyanine green and reference spectra of the same pigment; **d** SEM–EDS spectra of the green paint from layer 2 of sample 8 extracted from *Kampong scene*; **e** optical microscopy image of the cross-section of the sample; **f** corresponding ATR-FTIR spectra of the green paint with labelled marker peaks of zinc yellow and reference spectra of the same pigment

S, Se and Ba in sample 9 from *Village* seems to point to cadmium orange (PO20) and barium white or cadmium orange lithopone (co-precipitated cadmium sulfide selenide and barium sulfate). However, a precise characterisation of cadmium-based pigments was difficult due to their incorporation with other pigments. A concomitant presence of cadmium yellow and viridian can also be related to the commercial mixture of these two pigments, known as cadmium green (PG14) [50]. Such composite paint was available in two hues from W&N (Fig. 13) and in one hue from Rowney.

Chrome yellow (PY34), which is known from Liu Kang's earlier practice, was found as a frequent admixture to green paints. However, a concomitant presence of chrome yellow and Prussian blue may suggest commercially and commonly available chrome green (PG15).

In addition, the green paints, obtained by combining either Prussian blue or ultramarine, or both, and Cd- and/or Cr-containing yellow(s), were found in four of the investigated paintings. Interestingly, FTIR signatures for zinc yellow (PY36) admixture were confirmed in five investigated green paints. This admixture was clearly evident in the spectra recorded from the green paint of *Kampong scene* (sample 8) by characteristic peaks at 3449, 946, 878, 799 and 718 cm^{-1} (Fig. 14d–f) [51]. The detection of this pigment is particularly rewarding as, according to the literature, it was unpopular among artists [52]. Rowney and R&S did not list the pigment, although it was available from W&N (Fig. 13). Moreover, W&N advertised a commercial mixture of viridian and zinc yellow under the name of permanent green, and it was available in three hues (Fig. 13).

The analyses reflect Liu Kang' predilection for viridian, which conforms with Ho Kok Hoe's statement. Moreover, they point towards the conclusion that viridian and its intensive combinations with ultramarine, Prussian blue and cadmium yellow were used to obtain various hues of green colour.

Yellow

The analyses suggest that most of the investigated yellow paint mixtures are composed of cadmium yellow or its variant. Cadmopone is very likely in the yellow paint from *Kampong scene*, based on the concomitant presence of Cd, Ba and S recorded with XRF (spot 2060). The trace presence of Se, identified only in sample 8 from *Offerings*, suggests either cadmium orange or cadmium orange lithopone due to the Ba-signal recorded with SEM–EDS [49]. Chrome yellow and zinc yellow very seldom appear in the yellow paints; however, the artist used these yellow pigments more frequently as admixtures to green paints. Overall, there is a noticeably reduced role of chrome yellow in favour of cadmium yellow when compared to Liu Kang's paintings from the Paris period (1929–1932) [15], where chrome yellow was a prevailing yellow pigment. Yellow iron oxide (PY43) appears intermittently and usually in combination with other yellows. Its pronounced presence was detected only in sample 12 of *Government office in Johore Bahru*. The concomitant presence of K and Co elements in the yellow paint samples from *Bali scene* (sample 9) and *Char Siew seller* (sample 6) pointed to the use of cobalt yellow (PY40). The SEM–EDS elemental analysis of the latter sample was additionally validated with FTIR by peaks at 2709, 2651, 1387, 1328, 1179, 828 and 632 cm^{-1}, matching with the IRUG reference [53] (Fig. 15a–c).

Brown

Brown colours primarily consist of yellow and red iron oxides, sometimes modified with Cr- and/or Cd-containing yellow(s). Darker shades were obtained by adding bone black (PBk9) or umber (PBr7). Judging from the XRF analysis of a dark-brown passage in *Painting kampong* (spot 54), the paint probably involves umber and eosin-derived geranium lake (PR90:1). The latter is assumed based on the Br $K\alpha_1$ signal at 11.92 keV and Br $K\beta_1$ signal at 13.29 keV [54–56].

Red

The PLM of the red paints allowed us to observe a good deal of the red particles characterised by the unique low refractive index, indicative of the organic reds. Further FTIR characterisation of the organic reds was complicated due to the interference of the oil and compounds relating to other pigments present within the bulk of the investigated mixtures. For instance, yellow iron oxides, chrome and cadmium yellows were mixed with organic reds by the artists to produce different red hues. Cooler and/or deeper shades were achieved by adding bone black or ultramarine. Nevertheless, the Br-signal recorded with SEM–EDS in four investigated samples could be linked with the geranium lake. It features strongly in *Boats* (sample 7), where it was probably applied in a less modified form than in other paintings. Hence, the SEM–EDS additionally allowed us to detect Pb-, Ba-, Al-, and S-signals, suggesting precipitation of eosin onto a Pb- or Al-based substrate [50, 54–60] and probable commercial admixture of barium white extender. A comparison of the FTIR spectra of sample 7 from *Boats* with the reference spectra of eosin Y allowed us to observe some evident

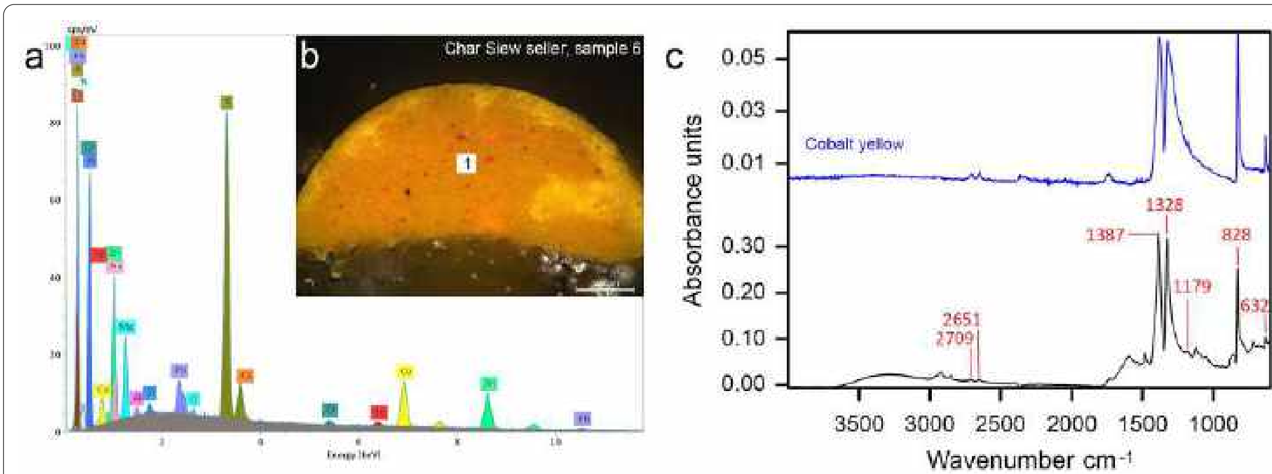


Fig. 15 **a** SEM–EDS spectra of the yellow paint of sample 6 extracted from *Char Siew seller*; **b** optical microscopy image of the cross-section of the sample; **c** corresponding ATR-FTIR spectra of the yellow paint with labelled marker peaks of cobalt yellow and reference spectra of the same pigment

similarities of the IR absorption peaks at 3353, ca. 1549, 1459, 1341, ca. 1231, ca. 975, 882, 761, and ca. 715 cm^{-1} (Fig. 16a) [61, 62]. FTIR analyses of the remaining three samples did not produce sufficient results to univocally assign the Br-containing pigment to eosin.

The FTIR spectra of a red paint from *Char Siew seller* (sample 3) allowed us to reveal features consistent with red azo pigment naphthol red AS-D (PR112) by various absorption bands matching the reference sample at 3276, 3237, 3188, 3125, 3074, 3039, 3027, 1667, 1603, 1593, 1544, 1492, 1477, 1447, 1420, 1404, 1364, 1323, 1279, 1257, 1237, 1154, 1012, 965, 905, 890, 856 and 814 cm^{-1}, and the IRUG reference (Fig. 16b) [63, 64].

An anthraquinone derivative was characterised with FTIR in *Kampong scene* (sample 10) by absorption bands at 1631, 1590, 1529, 1463, 1383, 1358, 1267, 1187, 1025, 905, 839, 769, 720 and 669 cm^{-1} (Fig. 16c), indicating synthetic alizarin lake (PR83:1) [65], whereas a high concentration of Al in the sample could be related to an aluminium-containing substrate [63, 66]. Similar FTIR spectra features were recorded in the red paint from *Village* (sample 25).

In *Outdoor painting* (sample 7), a strong Al-signal, recorded with SEM–EDS and FTIR absorption bands at 1636, 1577, 1527, 1463, 1363, 1287, 1097, 982 and 841 cm^{-1}, might be indicative of an aluminium-based substrate for the organic red pigment.

The catalogue search revealed that the geranium lake from W&N was derived from coal tar (Fig. 13), which is different from that identified in Liu Kang's paintings. Rowney listed geranium lake without a description of the chemical composition and R&S did not sell it at all. It is interesting to note that an eosin-based red lake pigment was identified earlier in one of Liu Kang's paintings, which was created in France in 1931. However, its isolated appearance could be explained by the high price of the paint [15].

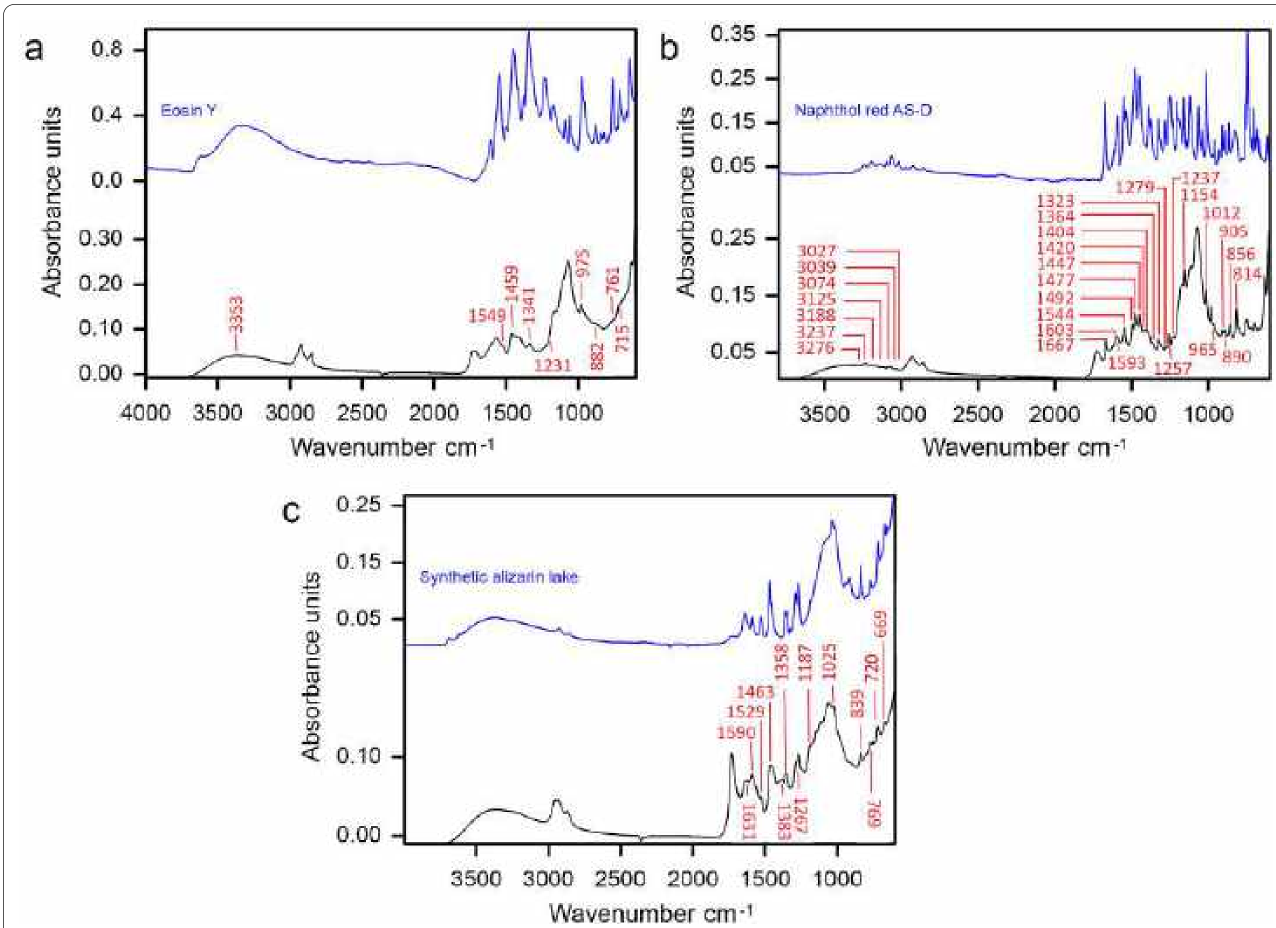


Fig. 16 **a** ATR-FTIR spectra of the red paint of sample 7 extracted from *Boats* with labelled marker peaks of organic red and reference spectra of eosin Y; **b** ATR-FTIR spectra of the red paint of sample 3 extracted from *Char Siew seller* with labelled marker peaks of organic red and reference spectra of naphthol red AS-D; **c** ATR-FTIR spectra of the red paint of sample 10 extracted from *Kampong scene* with labelled marker peaks of organic red and reference spectra of synthetic alizarin lake

The analyses also support the use of cadmium red (PR108) or its variant cadmium red lithopone (co-precipitated cadmium sulfide selenide and barium sulfate), detected in four paint mixtures. Red iron oxide (PR101) appears only once in *Village* (sample 25). Interestingly, we did not detect vermilion (PR106) in the investigated red paint samples, although it was reported by Ho Kok Hoe as being Liu Kang's "important" red [40]. As the pigment was listed by W&N, R&S and Rowney, it can be hypothesised that it was available in Singapore. While the absence of vermilion in the analysed samples may seem surprising, the possible explanation could be that Ho Kok Hoe's account is inaccurate, or the artist used some substitute for vermilion sold under a similar name. For instance, composite paints like vermilionette or American vermilion involved eosin-based lake pigment or scarlet dye combined with red lead or chrome red [50, 67, 68]. Moreover, the recent study of the Royal Talens paints identified a composite of three synthetic organic pigments, PR51, PR3 and PR63, in a vermilion imitation tube [69]. Although it is challenging to identify the organic red pigments, the analytical data suggested their discernible presence in the studied samples, leading to the hypothesis that some of these pigments could form the commercial substitution of vermilion. However, more analyses involving chromatography and a range of mass and vibrational spectroscopy techniques are needed to better characterise the red paint mixtures [70, 71].

White

The analyses of white paints did not reveal the preferential use of any white pigment. For instance, the UVR imaging of the *Village* suggests that the grey paint used for the clouds was achieved with different white pigments (Fig. 17a, b). The SEM–EDS analysis of the cloud imaged dark in UVR (sample 4) suggested a high concentration of zinc white with trace presence of chalk and lead white. Although sampling from the adjacent cloud was restricted, lead white and/or lithopone was probably involved in painting, based on their unique ability to reflect UV [18, 19]. Based on the UVR imaging and SEM–EDS analyses, lead white was primarily used in the white passages of *Scene in Bali*. The analyses of white brushstrokes in *Offerings*, *Boats* and *Char Siew seller* suggested a greater use of lithopone and/or barium white and zinc white with minor admixtures of chalk, lead and titanium whites.

It is worth noting that in *Kampong scene*, *Orchids*, *Government office in Johore Bahru*, *Outdoor painting* and *Painting kampong*, Liu Kang intentionally exposed a white ground layer during the painting process instead of using white paint for highlights (Figs. 1b–d and 2a, b).

Fig. 17 VIS (**a**) and corresponding UVR detail image (**b**) of *Village*, indicating that white paint from the cloud on the left (black arrow) has a strong UV reflectance, suggesting a presence of lead white and/or lithopone, whereas the cloud on the right (white arrow) shows UV absorbance, suggesting application of zinc white, confirmed through SEM–EDS analysis

Black

Black paint brushstrokes appear intermittently only in *Kampong scene*, *Government office in Johore Bahru* and *Painting kampong*. From the XRF point measurements and SEM–EDS analyses of samples, we deduce the preferential use of bone black. This pigment also appears in combination with other colours as a minor admixture.

Binding media and other identified compounds

The analyses of the binding media carried out using FTIR showed that an oil binder had been used in every painting. The analyses also revealed that, in a few paint samples, the oil was converted into metal soaps from the chemical reaction between the saturated fatty acids of the lipidic binder and the metal ions of the lead white and zinc white present in the paint layers. The results of the paint analyses are summarised in Table 3: Appendix 2.

Painting technique

The investigated paintings show an evolution of the artist's technique during the period under review. His artworks from 1950 to 1953 are executed with a broad and flat application of the local colours, a marginal suggestion of light effects and minimal introduction of details. *Village* and *Government office in Johore Bahru* attract attention through a strong colour block division resembling the influence of the Post-Impressionists, while the bold outlines hint at the influence of Chinese calligraphy. A confident establishment of the compositional and colouristic structures is distinct in *Kampong scene*, *Orchids* and *Government office in Johore Bahru*. In these paintings, the compositional outlines were skilfully filled in with washes of heavily diluted paint; however, the artist left certain parts of white ground exposed, producing attractive optical effects (Fig. 18a).

The painting technique in two other artworks from 1953, *Scene in Bali* and *Offerings* (Fig. 1e, f), significantly differs from the previous artworks. Probably due to his fascination with the subject matter, which is rich in details and decorative motifs, the artist has chosen a descriptive way of expression. The static, portrait-like composition of three women and their batik costumes and offering stands in *Offerings* reveals a temptation to realistically depict the female beauty in and richness of the indigenous Balinese culture. In contrast, the *Bali scene* is characterised by crowds of nude figures taking a bath in a river, which is flowing down the mountain, and surrounded by the picturesque landscape. The extent of the visual impact of that exotic place on Liu Kang can be elucidated from his essay, written in the year following his Bali sojourn. The essay creates an image of Bali as a place where idyllic landscapes, great architecture and young and charming women coexist harmoniously [72]. As these two artworks were created over earlier compositions, the artist had to modify his painting technique. The colour of the ground layer could not be exposed to play the aesthetic role seen in his earlier works; therefore, he executed the paintings with thickly applied paint that covers the entire painting surface.

Outdoor painting and *Painting kampong*, both from 1954, represent the stylistic innovation of Liu Kang's painting technique, which were emergent in his earlier works, between 1950 and 1953 (Fig. 2a, b). The illusion of depth is entirely abandoned and replaced by a conscious affirmation of the flatness of the forms, which is achieved with solid colours and minimal paint texture. These features reflect the artist's striving toward greater simplicity in his artistic expression and his focus on pure colours. The shapes are enhanced by dark paint outlines as well as exposed white ground, a style that reveals inspiration by the dye-resist technique found in batik textiles (Fig. 18b). Although his new painting technique is stripped of unnecessary details, it required planning and great discipline. A fundamental element of the technique was painting support with a white ground layer.

Reusing earlier compositions for the batik-inspired painting technique produced lower-quality visual effects. In *Boats* and *Char Siew seller*, the lack of a white ground was substituted with a white paint applied in a combination of wet-on-wet and wet-on-dry to delineate the forms (Fig. 18c). This approach resulted in less precise divisions between the coloured areas, as the white paint used for the outlines was very often contaminated with pigments of the surrounding colours. Thus, these two artworks lack the freshness and precision that Liu Kang's pure batik-inspired paintings are appreciated for. Moreover, utilising the earlier compositions forced the artist to laboriously cover the uneven and already-painted surface, producing unintended impastos and multicolour patches instead of single-colour patches.

Liu Kang was creative in manipulating the paint and painting tools to achieve different artistic effects. His preferred painting tools were varied size brushes. However, in *Village*, he quickly and effortlessly used a palette knife to apply the paint on large areas, followed by brushwork to introduce some details and outlines (Fig. 18d). *Offerings* was created primarily with a brush; however, palette knife paint application can be seen on the women's costumes and food stands (Fig. 18e). Heavy impastos appear in *Village* and in the artworks created on the reused compositions as they required plentiful paint to cover uneven surfaces. However, in *Offerings*, the impastos play an important role in enhancing the shapes of the fruits as well decorative motifs of the costumes. In *Kampong scene*, *Government office in Johore Bahru* and *Painting kampong*, Liu Kang experimented with distinctive

Fig. 18 Details showing intentionally exposed white ground playing a key role in the painting process of: **a** *Orchids*; **b** *Outdoor painting*. Detail of the white paint application substituting the incorporation of the colour of the ground in the painting process in *Char Siew seller* (**c**). Details showing different types of the paint manipulation by the artist. Palette knife and brush application of the paint produced high impastos in *Village* and *Offerings* (**d**, **e**). Scraping down to the ground reflects the minimalist paint effect in *Government office in Johore Bahru* (**f**)

scraping strokes into the wet paint, substituting a descriptive paint application (Fig. 18f).

Artist's modifications and reusing earlier paintings

Like other artists, Liu Kang occasionally recycled his rejected compositions and painted them over (Table 1). In *Offerings*, the pronounced brushstrokes that do not correlate to the final composition were observed on the face of the Balinese model on the left-hand side of the painting (Fig. 19a), whereas the evidence of a dark paint layer was discernible through the paint losses of the sky area (Fig. 19b, c). Moreover, a comparison of the painting with its archival photograph, which was probably taken in the 1950s, revealed some alterations to the current

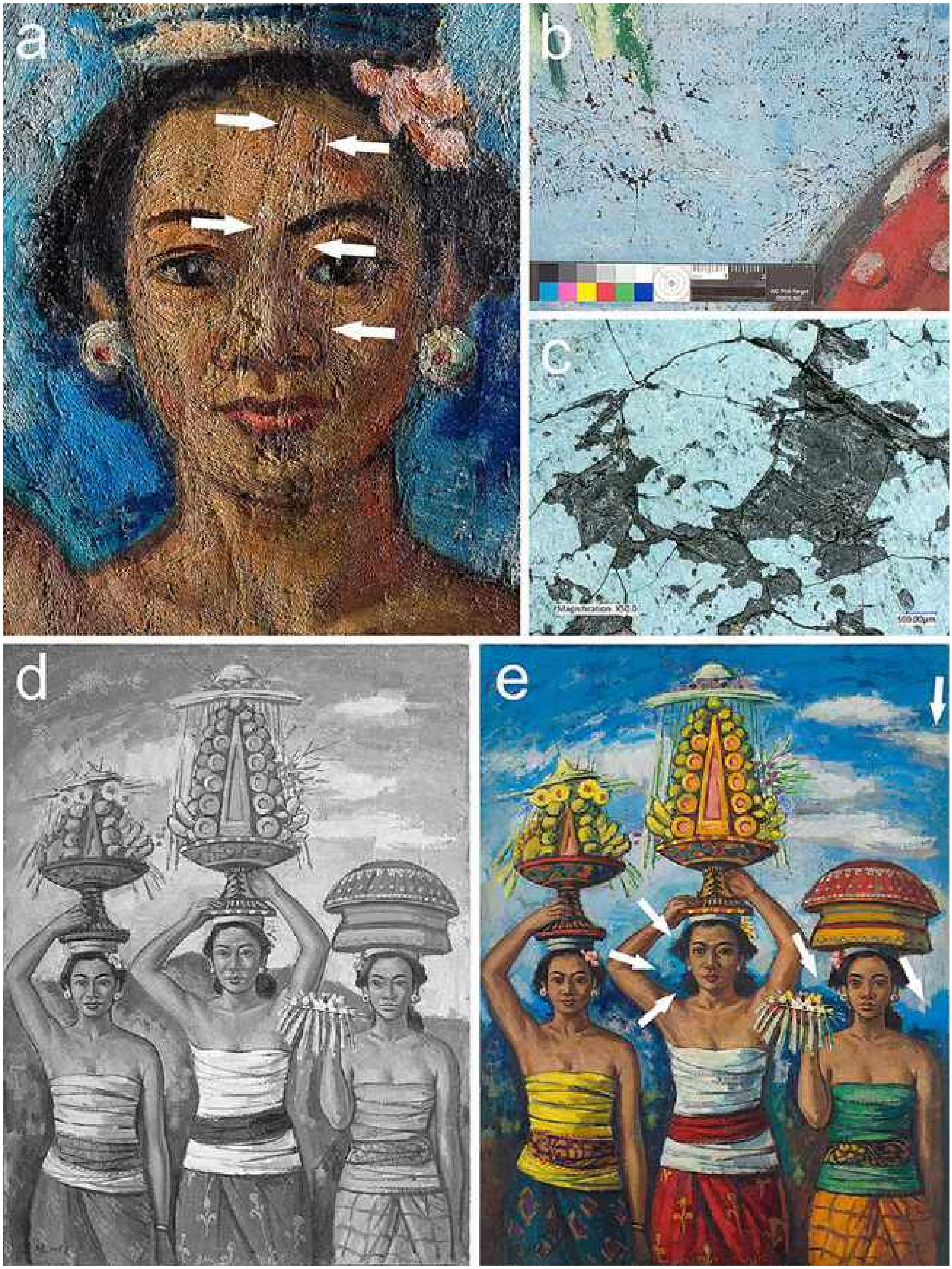


Fig. 19 **a** Detail of *Offerings*, showing the brushstrokes corresponding to the earlier composition. **b** Detail of *Offerings* revealing dark paint in the sky area. **c** Digital microscope image of the same area evidencing a dark paint layer scheme, seen through the losses of the current composition. **d** Archival photograph of *Offerings*. Liu Kang Family Collection. Image courtesy of Liu family. **e** Image of the painting showing alterations of the current composition

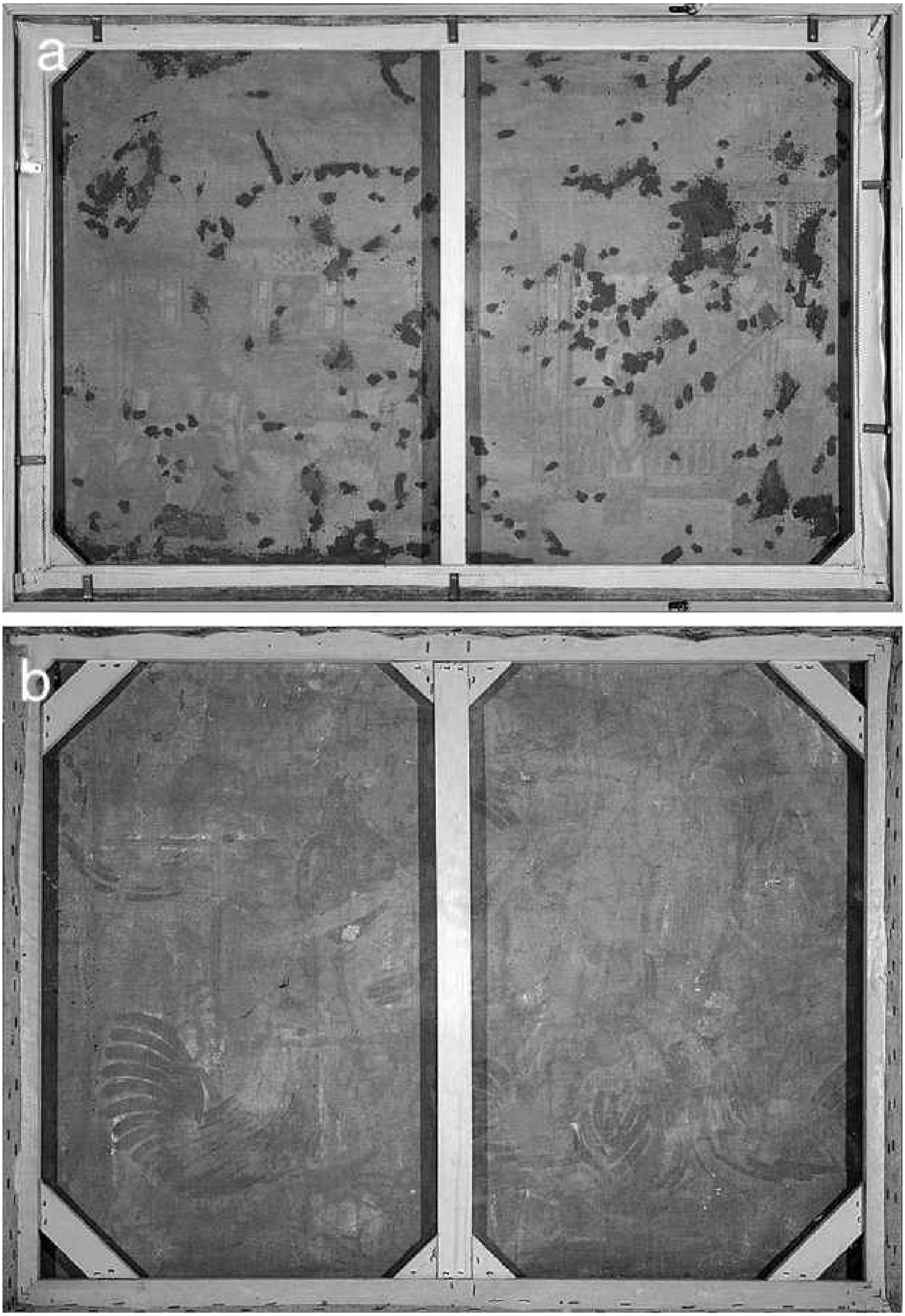


Fig. 20 IR images of the reverse sides of **a** *Scene in Bali* rotated at 90° clockwise; **b** *Boats* rotated at 90° anticlockwise

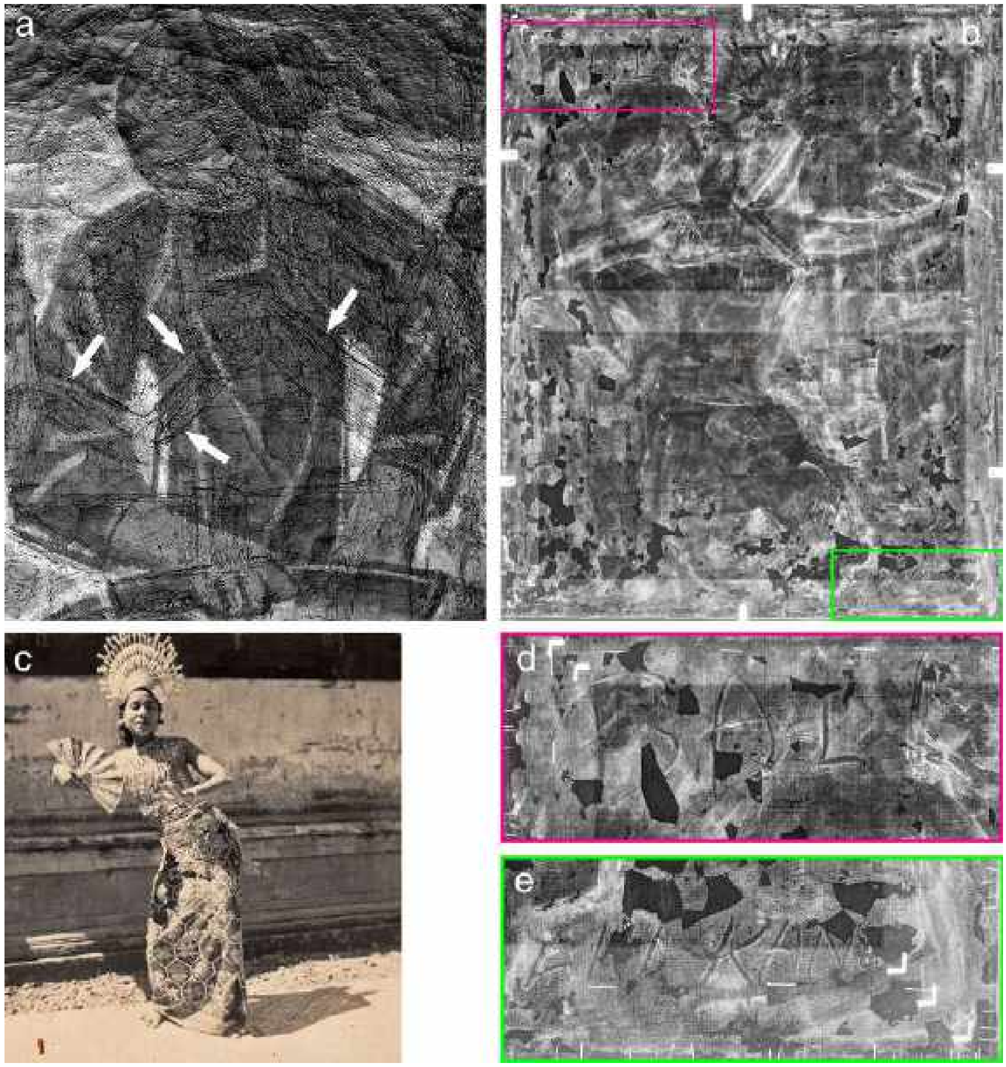


Fig. 21 **a** RTI detail image of *Char Siew seller*, revealing texture details corresponding to the earlier painted composition. **b** XRR image of the painting rotated at 90° clockwise, unveiling a vertical composition of a dancer. **c** Archival photograph of a Balinese dancer taken by the artist. Liu Kang Family Collection. Image courtesy of Liu family. **d**, **e** XRR detail images of the painting showing an inscription (BALI) and a signature (LIU KANG)

composition. The changes are located in the central model's face and hairstyle and in the shape of the distant hilltops and clouds (Fig. 19d, e). As the painting was donated by Liu Kang in 2003, these alterations can be attributed to him. This finding confirms the artist's tendency to rework the paintings after their creation, which can cause art-historical implications [15, 36].

The IR photography of the reverse sides of the paintings was very effective in detecting the concealed compositions. Thus, a composition created in the horizontal orientation resembling the village scene was found underneath *Scene in Bali*. The IR imaging technique allowed us to identify typical Malay timber houses, characterised by verandahs with fretwork railing panels and perforated ventilation panels fitted above the doors or upper sections of the walls (Fig. 20a) [73, 74], similar to those in Liu Kang's *Village* and *Kampong scene* (Fig. 1a, b). Another horizontally oriented composition was found underneath *Boats*. The hidden scene depicts a group of farm animals, including what appears to be cattle, surrounded by chickens and other animals in the foreground (Fig. 20b).

The evidence of an earlier composition underneath *Char Siew seller* was initially discovered with RTI. In several areas, the pronounced underlying brushstrokes do not accord with the current composition (Fig. 21a). The XRR revealed a hidden vertical composition of a Balinese dancer that could have been inspired by one of the photographs taken by the artist (Fig. 21b, c). The discovery of this composition is especially interesting because the artist made an inscription (BALI) in the top-left corner and signature (LIU KANG) in the bottom-right corner of the painting by scratching into wet paint with a sharp tool (Fig. 21d, e). Interestingly, XRR showed extensive losses to the paint layer, which could have encouraged the artist to abandon the composition and reuse the canvas.

Conclusions

The extensive technical study was carried out on ten paintings, which represent Liu Kang's important period of the 1950s when he developed his own style [75]. The study combined non- and micro-invasive analytical methods to characterise the artist's painting materials and technique. The yield results were cross-referenced with the single source indicating Liu Kang's pigment preferences during the investigated period. The limitations of that source were compensated by referencing contemporary advertisements that indicate some artists' colourmen brands available in Singapore around that time. Accessing their catalogues was an important step to better interpret certain data derived from the analyses. The understanding of Liu Kang's working practice was advanced by his archival drawings and old photographs.

The results show continuous use of the majority of the identified painting materials during the periods before the trip to Indonesia (1950–1952) and after (1953–1958). The study revealed that the artist used commercially prepared linen canvases, which he probably purchased in lengths by the metre. Although four canvas densities and five types of ground preparation were distinguished, Liu Kang's preferred type of support was linen canvas with a thread count of 13×15 per cm and a double-layered oil-based ground. Both layers are composed of the same constituents (chalk, lithopone and/or barium white and zinc white, lead white and titanium white), albeit mixed in different concentrations. This type of painting support was identified in the artworks created before and after 1952. Single- and, exceptionally, triple-layered structure of ground as well as semi-absorbent ground on canvases with distinctively low and high densities were used less frequently.

With regard to the palette of colours, all investigated pigment mixtures were bound in oil. Ultramarine appears consistently in the blue passages with occurrences of Prussian, cerulean, cobalt, phthalocyanine and manganese blues. However, cerulean and cobalt blues appear only in *Government office in Johore Bahru* (1953), manganese blue was used only in *Scene in Bali* (1953), and phthalocyanine blue was the sole blue pigment employed in *Painting kampong* (1954). As for green paints, viridian was used predominantly but always in mixes with other pigments. Its frequent presence with cadmium yellow and/or zinc yellow does not rule out the use of commercially prepared cadmium green or permanent green. Other green pigments used intermittently are phthalocyanine green and emerald green. Emerald green was identified in two paintings, *Village* (1950) and *Orchids* (1952), whereas phthalocyanine green appears in *Char Siew seller* (1958). Green colours were also obtained by mixing Prussian blue and/or ultramarine with Cd- and Cr-containing yellows. Regarding the yellow paints, it is clearly evident from the analytical data that cadmium yellow or its variant was prevailing. Other detected yellow pigments are yellow iron oxide, chrome, zinc and cobalt yellows. For obtaining brown paints, Liu Kang used yellow and red iron oxides and umber, and sometimes modified them with Cr-containing yellow(s), cadmium yellow or its variant and bone black. The analyses of the red paints revealed that Liu Kang made an extensive use of organic red pigments. Although identifying the organic reds was challenging, evidence suggests eosin-derived geranium lake, anthraquinone derivative pigment synthetic alizarin lake, and red azo pigment naphthol red AS-D. There is also a notable presence of cadmium red. Regarding white paints, the use of lead white, lithopone and/or barium white and zinc white was confirmed. Black painted areas contain bone black and its occurrences were found in mixtures with other pigments. The obtained results of the pigments' analyses do not fully corroborate Ho Kok Hoe's 1955 account about Liu Kang's paints. Except for viridian, which was confirmed as the artist's favourite green, it is evident that Prussian blue is not the prevailing blue pigment; however, it was extensively used as an admixture for green paints. Vermilion was not identified in the investigated paint samples. Nevertheless, it is conceivable that Liu Kang, while sharing the information with Ho Kok Hoe, referred to a composite pigment sold under a similar name and containing organic and inorganic pigments.

The studies of Liu Kang's painting process revealed a distinctive conceptual phase represented by the consistent use of drawings and photographs, which appear to be a convenient method of capturing interesting subjects and motifs for future reference. This phase helped the artist to grasp a full idea of the intended painting, hence resulting in a minimal need for preparatory drawing on the primed canvas. The analyses of the painting technique allowed us to identify four different approaches, suggesting an evolution of the methods of expression that were finalised in the stylistic innovation seen in *Outdoor painting* and *Painting kampong*. His painting technique, which reveals an effortless manipulation of the paint with a brush and palette knife, benefits from thorough studies of the idea prior to the painting. His repertory of descriptive techniques includes scraping into wet paint, building the impastos, enhancing the shapes with outlines and exposing the white ground of the canvas. An important contribution to the knowledge of Liu Kang's working practice was evidencing the modifications he made during the painting and detecting the rejected compositions he reused for new artworks.

Finally, the low concentrations of the investigated pigments in the heterogeneous structures of the paint layers made the identification process a challenging one. Thus, the findings of the analysis mandate a broader characterisation of Liu Kang's pigments, which require the application of chromatography and a range of vibrational spectroscopic techniques. Besides mapping the distribution of the painting materials, macro X-ray fluorescence (MA-XRF) imaging could also assist in a better visualisation of the concealed compositions.

Appendix 1

Table 2 Overview of canvas and ground characteristic of the investigated paintings

Title & inventory number	Date	Weave	Average thread count/cm	Twist	Fibre	Weave matching group	Sample, layer number	SEM–EDS detected elements*	FTIR identification	Result	Type of ground
Village, 2003-03270	1950	Plain	V14 × H17	Z	Linen	1	9, 2	**Ti**, **O**, **C**, **Pb**, Ba, Zn, (S, Si, Na, Cl, Ca, Al)	Lead white, lithopone and/or barium white and zinc white, oil	Titanium white, lead white, lithopone and/or barium white and zinc white, chalk, oil	1
							9, 1	**Pb**, **C**, **O**, **Ba**, Zn, S, Ti, Na, (Si, Cl, Al)	Lead white, lithopone and/or barium white and zinc white, oil	Lead white, lithopone and/or barium white and zinc white, titanium white, oil	
Kampong scene, 2003-03245	1951	Plain	V13 × H15	Z	Linen	2	3, 2	**C**, **O**, **Pb**, **Zn**, Ba, Na, Si, Ca, (Ti, S, Al, Cl, Mg)	Lithopone and/or barium white and zinc white, chalk, oil	Lead white, lithopone and/or barium white and zinc white, chalk, titanium white, oil	2
							3, 1	**O**, **C**, **Pb**, **Ca**, **Si**, **Al**, **Zn**, Ba, (Na, K, Fe, Sr, Cl)	Lithopone and/or barium white and zinc white, lead white, chalk, oil	Lead white, chalk, lithopone and/or barium white and zinc white, oil	
Orchids, 2003-03379	1952	Plain	V13 × H15	Z	Linen	2	3, 2	**C**, **O**, **Zn**, **Pb**, Na, Si, (Ca, Al, Ti, Ba, P, Cl)	Lead white, chalk, China clay, oil, zinc soap	Zinc white, lead white, chalk, China clay, titanium white, oil, zinc soap	2
							3, 1	**O**, **Pb**, **C**, Zn, Al, Si, Ca, (Na, K, Ti)	China clay, lead white, chalk, oil, zinc soap	Lead white, zinc white, China clay, chalk, titanium white, oil, zinc soap	
Government Office in Johore Bahru, 2003-03300	1953	Plain	V15 × H13	Z	Linen	2	22, 2	**Zn**, **C**, **Pb**, **O**, Na, Ca, (Ba, Ti, Si, Al, Mg)		Zinc white, lead white, chalk, barium white, titanium white	2
							22, 1	**O**, **C**, **Ca**, **Zn**, Pb, Na, (Si, Sn, Al)	Chalk, lead white, oil, zinc soap	Chalk, zinc white, lead white, oil, zinc soap	
Scene in Bali, 2003-03333	1953	Plain	V15 × H13	Z	Linen	2	14, 2	**C**, **Zn**, **Pb**, **O**, Na, Ca, Ba, (Cr, Fe, Al, Si, Ti)	Lead white, chalk, oil, zinc soap	Zinc white, lead white, chalk, barium white, titanium white, oil, zinc soap	2
							14, 1	**C**, **O**, **Ca**, **Zn**, Pb, Na, (Ba, Cr, Si, Al, Fe)	Chalk, lead white, oil	Chalk, zinc white, lead white, barium white, oil	
Offerings, 2003-03269	1953	Plain	V10 × H11	Z	Linen	4	1, 1	P**b**, **C**, **O**, (Ba, Ca, Cl)	Lead white, chalk, oil, proteins	Lead white, barium white, chalk, oil, proteins	4
Outdoor painting, 2003-03290	1954	Plain	V19 × H17	Z	Linen	3	1, 1	**C**, **Zn**, **O**, (S, Si)	Oil, zinc soap	Zinc white, oil, zinc soap	3
Painting kampong, 2003-04149	1954	Plain	V19 × H17	Z	Linen	3	1, 1	**Zn**, **C**, **O**, (S, Si)	Oil, zinc soap	Zinc white, oil, zinc soap	3

Table 2 (continued)

Title & inventory number	Date	Weave	Average thread count/cm	Twist	Fibre	Weave matching group	Sample, layer number	SEM–EDS detected elements*	FTIR identification	Result	Type of ground
Boats, 2003-03275	1956	Plain	V13 × H15	Z	Linen	2	1, 2	**C**, **Zn**, **Pb**, **O**, Na, Ca, Ba, (Si, Ti, Al)		Zinc white, lead white, chalk, barium white, titanium white	2
							1, 1	**O**, **C**, **Ca**, **Zn**, **Pb**, Na, (Si)	Chalk, lead white, oil	Chalk, zinc white, lead white, oil	
Char Siew seller, 2003-03311	1958	Plain	V13 × H15	Z	Linen	2	1, 3	**C**, **O**, **Ti**, **Zn**, Pb, Ca, Na, Si, (Ba, S, Cl, Sr, P)		Titanium white, lithopone and/or barium white and zinc white, lead white, chalk	5
							1, 2	**Zn**, **C**, **Pb**, **O**, Na, Ca, (Si, Cl)	Chalk, lead white, oil, zinc soap	Zinc white, lead white, chalk, oil, zinc soap	
							1, 1	**O**, **C**, **Ca**, **Zn**, **Pb**, Na, (Si)	Chalk, lead white, oil, zinc soap	Chalk, zinc white, lead white, oil, zinc soap	

*Major elements are given in bold, minor elements in plain type and trace elements in brackets

Appendix 2

Table 3 Overview of the materials identified in the paint samples extracted from the investigated paintings

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
Village, 2003-03270	1950	Blue	3	**C**, **Zn**, **O**, Na, Al, Si, S, (Mg, Ba, Ca, K, Sr, Fe)	Lithopone and/or barium white and zinc white, ultramarine, chalk, Prussian blue	
		Green	9	**C**, **O**, **Ba**, Zn, Pb, S, Cl, Fe, Al, Cd, (Cr, Na, Si, Ca, Ti, Cu, Se, As, Sr)	Lithopone and/or barium white and zinc white, Prussian blue, lead white, Cr-containing yellow(s), cadmium yellow and/or cadmium orange or their variants, emerald green	Lithopone and/or barium white and zinc white, Prussian blue, lead white, chrome yellow, zinc yellow, possible cadmium yellow and/or cadmium orange or their variants, oil
		Green	16	**C**, **O**, **Zn**, Ba, Pb, Na, Cr, S, Fe, Al, (Mg, K, Ti, Si, Cd, Cl)	Lithopone and/or barium white and zinc white, lead white, Cr-containing yellow(s), cadmium yellow or its variant, Prussian blue	
		Green	18	**C**, **O**, Ba, Zn, Cr, S, Na, K, Al, (Ti, Si, Sr, Cu, Cl)	Lithopone and/or barium white and zinc white, Cr-containing yellow(s), ultramarine, emerald green contamination	Lithopone and/or barium white and zinc white, Prussian blue, zinc yellow, possible ultramarine, oil
		Green	19	**O**, **C**, **Pb**, **Ba**, S, Cr, Fe, Al, Zn, N, Mg, Na, (Ti, Si, Cl, Sr, Ca, K)	Lead white, lithopone and/or barium white and zinc white, chrome yellow, Prussian blue, ultramarine, viridian	
		Yellow	21	**C**, **O**, **Zn**, Ba, Cd, S, Na, Fe, Ca, Si, Al, Ti, (Pb, Sr, Cl)	Lithopone and/or barium white and zinc white, cadmium yellow or its variant, yellow iron oxide, lead white	
		Red	25	**C**, **O**, **Zn**, Na, Al, Ba, Fe, Ca, (P, S, Si, Ti, K)	Lithopone and/or barium white and zinc white, red iron oxide, organic red(s)	Lithopone and/or barium white and zinc white, synthetic alizarin lake, organic red, oil
		Brown	23	**C**, **Cd**, **O**, S, Ba, Fe, Zn, Se, Al, Si, (Pb, Na, Ti, Ca, Mg, Sr)	Cadmium yellow or its variant, yellow iron oxide, lithopone and/or barium white and zinc white, lead white, titanium white	
		White	4	**Zn**, **C**, **O**, Na, (Ca, Mg, Pb, Al, Si)	Zinc white, chalk, lead white	
Kampong scene, 2003-03245	1951	Blue	3	**C**, **Ba**, **O**, S, Zn, Ca, Na, (Si, Sr, Pb, Al, Ti, Mg)	Lithopone and/or barium white and zinc white, ultramarine, chalk, lead white, titanium white	Lithopone and/or barium white and zinc white, chalk, possible ultramarine overlapped by lithopone bands
		Green	5	**C**, **O**, **Ba**, S, Zn, Pb, Ca, Si, Na, Al, (Fe, Cr, Ti, Sr, Cl)	Lithopone and/or barium white and zinc white, lead white, chalk, ultramarine, yellow iron oxide, Prussian blue, viridian, titanium white	
		Green	8	**O**, **Ba**, **C**, Zn, Cr, S, Al, K, Na, Si, (Cl, Sr, Pb, Ti, Ca)	Lithopone and/or barium white and zinc white, Cr-containing yellow(s), ultramarine, lead white, titanium white, chalk	Lithopone and/or barium white and zinc white, zinc yellow, oil
		Green	11	**C**, **O**, **Ba**, S, Zn, Fe, Al, Na, (Sr, Cd, Pb, Ca, Ti, Cl, Cr, Si, K, Mg)	Lithopone and/or barium white and zinc white, Prussian blue, ultramarine, cadmium yellow or its variant, lead white, Cr-containing yellow(s), titanium white	Lithopone and/or barium white and zinc white, Prussian blue, possible cadmium yellow or its variant, possible zinc yellow, oil
		Yellow	2060	*Ba*, *Cd*, *S*, *Pb*	Cadmopone or cadmium yellow and barium white, lead white	

Table 3 (continued)

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
		Red	10	**C**, **O**, Al, Zn, Ca, Pb, P, Na, (Ba, S, Si, K, Cl)	Lithopone and/or barium white and zinc white, lead white, organic red(s), chalk, bone black	Lithopone and/or barium white and zinc white, lead white, synthetic alizarin lake, oil
		Red	15	**C**, **O**, **Ba**, S, Zn, Ca, (Na, Si, Sr, Al, Pb, P)	Organic red(s), lithopone and/or barium white and zinc white, ultramarine	
		Brown	9	**O**, **C**, **Ca**, Fe, Si, Ba, Zn, S, Al, Pb, (Na, K, Ti, Mg)	Red iron oxide, lithopone and/or barium white and zinc white, lead white, titanium white	
		Black	2063	*Fe*, *Ca*, *Mn*, *Si*	Umber, possible bone black	
Orchids, 2003-03379	1952	Blue	3	**O**, **C**, **Ti**, Ca, Ba, Pb, Zn, Si, S, P, Al, Fe, (Na, K, Sr, Cl)	Titanium white, chalk, lithopone and/or barium white and zinc white, lead white, Prussian blue, ultramarine,	Lithopone and/or barium white and zinc white, chalk, carbon black
		Green	4	**C**, **O**, **Ba**, Pb, Ti, Zn, S, Si, Al, (Na, Ca, Cr, Cd, Cl, Sr)	Lithopone and/or barium white and zinc white, lead white, titanium white, viridian, chalk, cadmium yellow or its variant	
		Green	5	**C**, **O**, **Ba**, **Pb**, S, Cr, As, Zn, (Ti, Cu, Si, Sr, Cl, Na, Ca, Al)	Lithopone and/or barium white and zinc white, chrome yellow, emerald green, viridian, titanium white, ultramarine, chalk	Lithopone and/or barium white and zinc white, chrome yellow, emerald green, oil
		Yellow	8	**C**, **O**, **Ti**, **Ba**, Cd, S, Zn, Al, Si, Na, (Sr, Ca, P)	Titanium white, lithopone and/or barium white and zinc white, cadmium yellow or its variant, bone black	
		Brown	6	**O**, **C**, **Fe**, **Si**, Ti, Ba, Pb, Zn, Al, S, Ca, (Cd, Mn, Na, Sr, K, Cl, P, Mg)	Yellow iron oxide, umber, titanium white, lithopone and/or barium white and zinc white, lead white, cadmium yellow or its variant, bone black	
		Brown	7	**C**, **O**, **Ti**, Ba, Zn, Cd, S, Ca, Pb, Fe, (Na, Al, Si, P, Sr)	Titanium white, lithopone and/or barium white and zinc white, cadmium yellow or its variant, chalk, lead white, yellow iron oxide, bone black	
Government Office in Johore Bahru, 2003-03300	1953	Blue	22	**C**, **O**, **Pb**, Zn, Sn, Al, Mg, Ba, Co, (Na, Cr, Ca, S, Si)	Lead white, lithopone and/or barium white and zinc white, cerulean blue, cobalt blue, ultramarine, viridian, chalk	Lead white, lithopone and/or barium white and zinc white, oil
		Blue	3	**C**, **O**, **Pb**, **Zn**, Mg, Al, Na, (Sn, Si, Co, Ca, Ba, Cl)	Lead white, zinc white, cerulean blue, cobalt blue, chalk, barium white	
		Green	6	**C**, **O**, **Pb**, Zn, Ba, Cr, Fe, S, Sn, Mg, Al, Na, (Co, K, Cd, Cl, Si, Sr)	Prussian blue, lithopone and/or barium white and zinc white, Cr-containing yellow(s), lead white, ultramarine, viridian, cadmium yellow or its variant, cerulean blue, cobalt blue	Prussian blue, lithopone and/or barium white and zinc white, zinc yellow

Table 3 (continued)

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
		Green	7	**O**, **C**, **Cr**, Al, (Zn, Pb, S, Cd, Ca, Ba, Si)	Viridian, lithopone and/or barium white and zinc white, lead white, cadmium yellow or its variant	
		Yellow	12	**C**, **O**, **Pb**, **Fe**, Ba, Al, Zn, S, (Si, Ca, Na, Mg, Cl)	Lead white, yellow iron oxide, lithopone and/or barium white and zinc white, chalk	
		Yellow	16	**O**, **C**, **Pb**, Ba, S, Fe, Al, Zn, Cr, Mg, (Si, Ca, Na, P, Sr, Cl)	Lithopone and/or barium white and zinc white, lead white, Cr-containing yellow(s), yellow iron oxide, bone black	Lithopone and/or barium white and zinc white, lead white, chrome yellow, zinc yellow, oil, zinc soap, possible low intensity bands of iron oxide overlapped by lithopone and zinc yellow bands
		Red	17	**Pb**, **C**, **O**, Zn, (Na, Cl, Si, Fe, N, Al, Cr, K, Co, Ca)	Lead white, organic red(s), zinc white, Fe-, Cr-, Co-containing pigments contamination	Lead white, organic red(s), oil, zinc soap
		Brown	8	**Pb**, **C**, **O**, Fe, Zn, Si, (Cl, Na, Ca, Al, Mg)	Lead white, red iron oxide, zinc white, chalk	
		Brown	18	**O**, **Fe**, **C**, **Pb**, Si, Cl, Zn, Ba, (Mg, Al, Ca, Na, Mn, S, P, Sr, K)	Yellow iron oxide, umber, lead white, lithopone and/or barium white and zinc white, chalk, bone black	
		Black	14	**O**, **C**, **Ca**, P, Pb, Al, As, Zn, (Fe, Ba, S, Si, Na, Mg)	Bone black, lead white, lithopone and/or barium white and zinc white	
Scene in Bali, 2003-03333	1953	Blue	12	**O**, **C**, **Ba**, S, Al, Mg, Zn, (Pb, Mn, Na, Ti, Ca, Si, Cl)	Lithopone and/or barium white and zinc white, ultramarine, traces of lead white, manganese blue, titanium white, chalk	Lithopone and/or barium white and zinc white, manganese blue, oil
		Blue	10	**C**, **O**, **Zn**, Cr, Na, Al, (Ba, Ca, S, Cl, Si)	Lithopone and/or barium white and zinc white, viridian, ultramarine	
		Green	8	**Zn**, **C**, **O**, Na, Ba, N, (S, Cr, Cl, Al, Ca, Mg, Pb, Si, K, Co, Sr)	Lithopone and/or barium white and zinc white, viridian, ultramarine, chalk, lead white, Co-containing pigment contamination	
		Green	7	**Pb**, **O**, **C**, Ba, Zn, Al, (S, Fe, Na, Cl, Cd, Ca, K, Si)	Lead white, lithopone and/or barium white and zinc white, Prussian blue, ultramarine, cadmium yellow or its variant	
		Yellow	9	**Pb**, **O**, **C**, **Fe**, Zn, Na, Si, K, Mg, Co, (Ca, Ba, Al)	Lead white, yellow iron oxide, lithopone and/or barium white and zinc white, cobalt yellow, chalk	
		Red	13	**C**, **O**, **Ba**, S, Cd, Zn, Pb, Al, Se, (Na, Ti, Ca, Fe, Si, P, Sr)	Lithopone and/or barium white and zinc white, cadmium red or its variant, lead white, titanium white, chalk, yellow iron oxide	Lithopone and/or barium white and zinc white, cadmium red or its variant, organic red
		Brown	14	**Pb**, **C**, **O**, **Zn**, Fe, Na, Ca, Si, (Ba, Cl, Al, Cr, Mg, Ti)	Lead white, lithopone and/or barium white and zinc white, yellow iron oxide, Cr-containing yellow	
		White	11	**Pb**, **C**, **O**, Zn, Ba, (Na, Cl, Al)	Lead white, lithopone and/or barium white and zinc white	

Table 3 (continued)

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
Offerings, 2003-03269	1953	Blue	4	**C**, **O**, **Ba**, S, Zn, Ca, Na, (Al, Ti, Si, Sr, Fe	Lithopone and/or barium white and zinc white, ultramarine, titanium white, Prussian blue	
		Blue	3	**C**, **O**, **Zn**, Ti, Al, Na, Ca, Mg, (Si, S, Cl, Ba, Pb)	Lithopone and/or barium white and zinc white, chalk, ultramarine, lead white	
		Green	7	**C**, **Zn**, **O**, Ba, Na, S, Cl, Cr, Al, (Si, Mg, Ti, Sr, Fe, Cd, Ca)	Lithopone and/or barium white and zinc white, Cr-containing yellow, viridian, titanium white, Prussian blue, cadmium yellow or its variant	Lithopone and/or barium white and zinc white, Prussian blue, possible cadmium yellow or its variant, possible zinc yellow, oil
		Yellow	8	**O**, **Ba**, **Cd**, **C**, **S**, Al, Zn, Ti, (Na, Si, Pb, K, Sr, Cl, Ca, Se)	Lithopone and/or barium white and zinc white, cadmium orange or its variant, titanium white, lead white, chalk	
		Red	9	**C**, **Zn**, **O**, Ba, Na, Pb, S, Al, (Br, Si, Ca, Ti)	Lithopone and/or barium white and zinc white, Br-containing organic red on Pb- or Al-based substrate, chalk, titanium white	Lithopone and /or barium white and zinc white, lead white, organic red(s), zinc soap, oil
		Red	10	**Cd**, **O**, **C**, S, Se, Pb, Al, Zn, Ba, (Ca, K, Fe, Na, Cl, Ti)	Cadmium red or its variant, lead white, lithopone and/or barium white and zinc white, chalk, yellow iron oxide	
		White	12	**Ba**, **O**, **C**, **S**, Zn, Ca, Na, (Ti, Sr, Pb, Al, Si, Cl)	Lithopone and/or barium white and zinc white, chalk, traces of titanium white, lead white	
Outdoor painting, 2003-03290	1954	Blue	8	**C**, **Zn**, **O**, Na, Cr, (Pb, Ba, Ca, Al, S, Mg, Fe, Si, Cl, P)	Lithopone and/or barium white and zinc white, viridian, ultramarine, Prussian blue, bone black	
		Blue	12	**O**, **C**, Ca, Si, Na, Al, S, Zn, (Sr, K, Pb, Cl, Fe)	Ultramarine, chalk, zinc white, lead white, Prussian blue	
		Blue	13	**C**, **Zn**, **O**, Na, Ca, (Si, Al, S, Sr, Cl)	Zinc white, chalk, ultramarine	
		Green	3	**O**, **C**, **Cr**, Zn, Al, Cd, Pb, S, Ba, (Na, Ca, Si, Cl, Fe, Mg)	Viridian, lithopone and/or barium white and zinc white, cadmium yellow or its variant, lead white, traces of chalk, Prussian blue	
		Green	5	**C**, **O**, Cl, Ca, Al, Ti, Zn, Cd, S, (Mg, Fe, Cu, Si, Pb, Na, Sr, Ba)	Titanium white, lithopone and/or barium white and zinc white, cadmium yellow or its variant, ultramarine, Prussian blue, lead white, Cu-containing pigment contamination	Phthalocyanine green
		Green	10	**C**, **O**, **Zn**, Cr, Cd, S, Pb, Ba, Na, (Cl, Al, Mg, Si)	Lithopone and/or barium white and zinc white, viridian, cadmium yellow or its variant, lead white	
		Yellow	6	**O**, **C**, **Ba**, S, Cd, Al, Zn, Pb, Cr, (Ti, Si, Na, Ca, Mg)	Lithopone and/or barium white and zinc white, cadmium yellow, Cr-containing yellow(s), titanium white, chalk	Lithopone and/or barium white and zinc white, possible cadmium yellow or its variant, chrome yellow, zinc yellow, oil

Table 3 (continued)

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
		Red	11	**C**, **O**, Ti, Ca, Zn, Mg, Al, Cd, (S, Na, Cl, Fe, Ba, Si)	Titanium white, chalk, lithopone and/or barium white and zinc white, organic red(s), cadmium yellow or its variant, yellow iron oxide	
		Red	7	**O**, **C**, **Al**, S, Zn, (Na, Ca, Cl)	Organic red, zinc white, chalk	Organic red, oil
		Brown	9	**C**, **O**, **Fe**, Zn, Si, (Pb, Mg, Ca, Na, Sr, Al, Cl, S)	Yellow iron oxide, zinc white, lead white, chalk	
Painting kampong, 2003-04149	1954	Blue	3	**C**, **O**, Ba, N, Al, S, Cu, Zn, (Mg, Ti, Cl, Na, Si)	Lithopone and/or barium white and zinc white, phthalocyanine blue, traces of titanium white	Lithopone and/or barium white and zinc white, phthalocyanine blue, oil
		Blue	122	*Zn*, *Ba*, *Cu*, *Al*, *S*	Lithopone and/or barium white and zinc white, phthalocyanine blue	
		Blue	123	*Zn*, *Ba*, *Cu*, *Al*, *S*	Lithopone and/or barium white and zinc white, phthalocyanine blue	
		Blue	125	*Zn*, *Ba*, *Cu*, *Al*, *S*	Lithopone and/or barium white and zinc white, phthalocyanine blue	
		Green	4	**C**, **O**, **Zn**, **Cr**, Na, Al, Cd, (S, Ba, Si, Ca)	Lithopone and/or barium white and zinc white, viridian, cadmium yellow or its variant, chalk	
		Yellow	6	**C**, **Cd**, **O**, **S**, **Ba**, Zn, Al, Na, (Si, Pb, Ca, Ti, Sr)	Cadmium yellow or its variant, lithopone and/or barium white and zinc white, lead white, chalk, titanium white	
		Red	5	**C**, **O**, Pb, Ba, Br, Al, (Zn, S, Na, Si)	Lithopone and/or barium white and zinc white, Br-containing organic red on Pb- or Al-based substrate	Lithopone and/or barium white and zinc white, organic red(s), oil
		Brown	54	*Si*, *Cl*, *Ca*, *Mn*, *Fe*, *Sr*, *Br*, *Ba*, *Pb*	Umber, chalk, lead white, barium white, possible eosin-derived geranium lake	
		Black	53	*P*, *Fe*, *Ca*, *Zn*, *Pb*	Bone black, lead white, zinc white	
Boats, 2003-03275	1956	Blue	4	**C**, **O**, Si, Al, Na, S, Ca, Ti, (Zn, K, Mg, Fe, Sr, P)	Ultramarine, titanium white, zinc white, bone black, Prussian blue	
		Blue	6	**C**, **O**, **Zn**, Ba, S, Na, Ca, (Al, Si, Ti, Fe, Sr, Cu)	Lithopone and/or barium white and zinc white, ultramarine, titanium white, Prussian blue	
		Green	5	**C**, **Zn**, **O**, Ba, Na, S, (Cr, Ti, Cl, Si, Al, Mg, Sr)	Lithopone and/or barium white and zinc white, ultramarine, viridian, titanium white	
		Yellow	8	**C**, **O**, **Ba**, S, Cd, Al, Ti, (Zn, Na, Si, Sr, Ca)	Lithopone and/or barium white and zinc white, cadmium yellow or its variant, titanium white, chalk	

Table 3 (continued)

Title and inventory number	Date	Colour	Sample	SEM–EDS* and XRF** detected elements	PLM, SEM–EDS, XRF assignment	FTIR identification
		Red	3	**C**, **O**, **Ba**, S, Cd, Zn, (Al, Se, Ti, Na, Ca, Si, Fe)	Lithopone and/or barium white and zinc white, organic red(s), cadmium red or its variant, traces of titanium white, chalk, yellow iron oxide,	
		Red	7	**C**, **O**, Ba, Pb, Al, Br, S, (Si, Sr, Ti, Cl, Ca, Na)	Barium white, Br-containing organic red on Pb- or Al-based substrate, titanium white, chalk	Barium white, eosin-derived geranium lake, oil
		Red	11	**O**, **C**, **Ba**, Pb, S, Fe, Al, Zn, Cd, Cr, Ca, Si, (Na, Ti, Se, Cl, Sn, Mg, K, P, Sr, Br)	Lithopone and/or barium white and zinc white, chrome yellow, yellow iron oxide, cadmium red or its variant, titanium white, organic red on Sn-containing substrate, Br-containing organic red on Pb- or Al-based substrate, bone black	
		Brown	13	**O**, **C**, **Ba**, **S**, Cd, Zn, Fe, Ca, Al, Si, Ti, Na, (Sr, Mg, K, Cl, Pb)	Lithopone and/or barium white and zinc white, yellow iron oxide, cadmium yellow or its variant, chalk, titanium white, lead white	
		Brown	14	**C**, **O**, **Ba**, Fe, Zn, S, Ca, Si, (Al, Na, Ti, Mg, K, Cd, Sr, Cr)	Lithopone and/or barium white and zinc white, red iron oxide, chalk, titanium white, cadmium yellow or its variant, Cr-containing yellow	
		White	12	**C**, **Ba**, **O**, **S**, Zn, Ca, Na, (Ti, Sr, Pb, Al, Si, Cl, Fe)	Lithopone and/or barium white and zinc white, chalk, traces of titanium white, lead white, ultramarine, yellow iron oxide	
Char Siew seller, 2003-03311	1958	Blue	5	**O**, **C**, Ca, Si, Na, Al, S, Zn, (Fe, Ba, K, Cl, Pb, Mg, P)	Ultramarine, lithopone and/or barium white and zinc white, Prussian blue, lead white, bone black	
		Green	4	**C**, **O**, **Ba**, Cl, S, Zn, Al, Ca, (Na, Cu, Ti, Sr, Mg, Si)	Lithopone and/or barium white and zinc white, chalk, phthalocyanine green, titanium white	Lithopone and/or barium white and zinc white, chalk, phthalocyanine green, oil
		Yellow	6	**C**, **O**, **K**, Zn, N, Co, Mg, Na, Pb, (Fe, Cr, Al, Ca, Si, Cl)	Cobalt yellow, lead white, Cr-containing yellow(s), chalk, yellow iron oxide	Cobalt yellow, possible lead white, chrome yellow, zinc yellow, organic red, zinc soap, oil
		Red	3	**C**, **O**, Cl, Ba, Ca, Zn, (S, Cd, Na, Al, Mg, Fe, Si)	Lithopone and/or barium white and zinc white, chalk, organic red(s), cadmium yellow or its variant, yellow iron oxide, organic red	Lithopone and/or barium white and zinc white, possible cadmium yellow or its variant, naphthol red AS-D, oil
		Brown	7	**Zn**, **C**, **O**, Fe, Na, Pb, (Al, Si, Cr, Cl, Ca, Ba, Mg, S)	Zinc white, yellow iron oxide, lead white, Cr-containing yellow, barium white, chalk	
		White	8	**C**, **O**, **Ba**, Zn, S, Na, Ca, Ti, (Sr, Al, Pb, Si, Fe, Cl, P, Mg)	Lithopone and/or barium white and zinc white, chalk, titanium white, lead white	

*Major elements are given in bold, minor elements in plain type and trace elements in brackets

**Elements detected with XRF are given in italics

Abbreviations
NGS: National Gallery Singapore; UVF: Ultraviolet fluorescence; UVR: Reflected ultraviolet; IR: Infrared; IRFC: Infrared false-colour; RTI: Reflectance transformation imaging; XRR: X-ray radiography; XRF: X-ray fluorescence; OM: Optical microscopy; PLM: Polarised light microscopy; FE-SEM–EDS: Field emission scanning electron microscope with energy dispersive spectroscopy; BSE: Backscattered electron mode; ATR-FTIR: Attenuated total reflectance-Fourier transform infrared spectroscopy; MA-XRF: Macro X-ray fluorescence; W&N: Winsor & Newton; R&S: Reeves & Sons.

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Authors' contributions
DL carried out the examination of the paintings, technical photography, RTI, sampling, OM, PLM, XRF, SEM–EDS analyses, data interpretation, and wrote the manuscript. TK provided the interpretation of the FTIR data. MM carried out the FTIR analyses. BS carried out the FTIR analyses and provided visualisation of the FTIR data. All authors read and approved the final manuscript.

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The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
Authors declare that have no competing interests.

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Abstract: The comprehensive technical investigation of female nude paintings by the Singapore pioneer artist Liu Kang (1911–2004) provided the evidence for a discussion of the evolution of his palette of colours and his working process for expression in this genre, particularly the execution of female bodies. As the artist's free expression in classical nude paintings was limited by the censorship imposed by the Singapore government, the investigated artworks span two periods, 1927–1954 (early career) and 1992–1999 (the "golden years", during which censorship policies were relaxed). Hence, eight paintings from the Liu family and National Gallery Singapore were selected for non- and micro-invasive analyses of the paint layers. The obtained results were supplemented with archival sources to elucidate certain aspects of Liu Kang's working practice. The investigation revealed the importance of drawing and sketching studies in the development of artistic ideas. The analytical techniques, such as polarised light microscopy (PLM), field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) and attenuated total reflectance–Fourier transform infrared spectroscopy (ATR-FTIR), enabled us to observe a transition from the yellow iron-based tonal ranges of skin colours to complex pigment mixtures composed of additions of cobalt blue, ultramarine, Prussian blue, Cr-containing yellow(s) and green(s), cadmium yellow, orange and/or red and organic reds, revealing the artist's more liberal use of colours and his experimentation with their contrasting and complementary juxtaposes. In terms of painting technique, the artist's comparatively laborious paint application using small brushes quickly gave way to a more effortless manipulation of the paint using bigger brushes and the incorporation of palette knives. Moreover, visible light (VIS), near-infrared (NIR) and X-ray radiography (XRR) imaging techniques led to the discovery of a hidden composition in one investigated artwork, which bears resemblance to the nude painting known only from an archival photograph. Additionally, for the first time, the archival search provided photographic evidence that Liu Kang used oil paint tubes from Royal Talens and Rowney in the 1990s. Overall, this in-depth investigation contributes to the understanding of Liu Kang's approach to the female nude painting and may assist conservators and art historians in studies of twentieth-century commercial paints.

Keywords: Liu Kang; pigment identification; SEM-EDS; FTIR; IRFC; PLM; X-ray; hidden paintings

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1. Introduction

Liu Kang (1911–2004) is considered a major and influential figure of Singapore's visual arts of his time. Born in China, Liu Kang graduated in 1928 from Xinhua Arts Academy in Shanghai and moved to Paris, where he studied at the Académie de la Grande Chaumière in Montparnasse (1929–1932). During that time, he was attracted to Impressionism, Post-Impressionism and Fauvism [1], which influenced many of his artworks. That exposure is particularly evident in his vibrant use of colours and a variety of adopted painting techniques [2]. In 1933, he returned to Shanghai and took charge of the faculty of Western art at the Shanghai Art Academy—China's leading art teaching institution. He continued painting and teaching in Shanghai until the outbreak of the Second Sino-Japanese War (1937–1945). The war drove him to Malaya, where he struggled to develop artistically due to the Japanese Occupation (1941–1945). Liu Kang settled in Singapore permanently in 1945 and pursued the quest of developing his own artistic style. His career became increasingly prominent after 1952 when he visited the Indonesian island of Bali. The trip had a profound effect on Liu Kang and inspired him to contribute to the Nanyang style of painting, which refers to a regional art movement initially practised by a group of migrant Chinese painters in Singapore between the late 1940s and the 1960s. The style reflects Southeast Asian subject matter and involves techniques derived from the School of Paris and traditional Chinese ink painting [3]. However, Liu Kang's artistic development did not end with the established Nanyang style. He often retraced his steps and reworked old themes, such as in the study of nudes.

The theme of nudes accompanied the artist during his student and teaching years in Shanghai, emigration to Malaya and throughout his oeuvre in Singapore, including his "golden years". At the age of 92, he was still attending life drawing sessions at the Lasalle-SIA College of the Arts organised by Group 90, an informal group of Singaporean artists studying and promoting nudity as an art form [4,5]. Liu Kang's predilection for the depiction of nudes can be elucidated by his admiration of the human body as the perfect creation in itself. He expressed his thoughts in a 1953 essay: "The human body, which contains the endowments of nature, is a mould that is the most curvaceous, has the most exquisite and forceful lines, and exudes the most subtle and delightful lustre in the world" [6]. Liu Kang reaffirmed the importance of artistic studies of the human body almost a half-century later, in 2002: "With elements such as proportion, symmetry and texture for the artist to deliberate upon, the human body is truly the most beautiful form in the universe" [7].

Interestingly, despite Liu Kang's mastery of nudity as a form of art in the countless drawings created during his entire career (Figure 1a,b), the theme is underrepresented in his paintings. The artist did not engage in the painting of nude figures due to censorship laws in multi-ethnic Singapore as well as concerns over moral sensitivity. Hence, there is a significant gap spanning nearly 40 years (from around 1954 to 1992) when he abandoned this genre. In a 1993 interview, he recalled: "I never really had the opportunity to paint and show nudes in the past. The climate in the country was conservative and what you could show in an exhibition was controlled. The police would come to an exhibition and ask for the nudes to be removed, or request that not too many are shown" [8]. This account is consistent with a newspaper article reporting the banning by the Singapore Young Men's Christian Association art club of four nude pastel artworks during the annual exhibition in 1952. According to the statement by an official, the decision was made to prevent public moral outrage: "We do not mind art for art's sake but moralists may be shocked when art is superimposed" [9]. In 1970, Liu Kang wrote: "Confucian philosophy [is] not open-minded towards the naked human body. It is nearly impossible for local artists to have an opportunity to draw nudes" [10]. Hence, the artist worked on nude figures mainly in the form of drawings instead. He considered life drawing as essential to mastering fundamental art skills [11] and a relatively convenient form of expression as, compared to paintings, it required less time and storage space. In addition, he probably self-censored by disguising his painting of semi-nudes in Bali as a depiction of the Balinese way of life (Figure 1c). Despite his apparent self-censorship, Liu Kang strongly disagreed with the imposed limitation of the artistic expression of ideas and publicly defended nude painting as an artistic genre. In a 1987 interview, he stated that "[nudity in art] was not entirely a Western concept because it was once popular in China and India" [12].

Figure 1. (**a**) Liu Kang, *Nude*, 1968, pastel on paper, 56 × 38 cm. (**b**) Liu Kang, *Nude*, 1969, pastel on paper, 46 × 65 cm. (**c**) Liu Kang, *Balinese woman and children*, 1962, oil on canvas, 98.5 × 131.5 cm. Gift of the artist's family. Collection of National Gallery Singapore.

In the 1990s, it finally became possible for Liu Kang to return to painting nudes more openly. Although conservative voices fixedly advocated the fully dressed human body in art as being in accordance to Oriental moral concepts [12,13], the 1992 Censorship Review Committee Report recognised the need for balance between artistic creativity and the safeguarding of moral values. Interestingly, the report did not mention nudity in paintings, but its subsection, "nudity in calendars, posters, magazines and newspapers", stated that "nudity itself is not obscene or offensive to many people" [14]. In a 1993 interview, Liu Kang concluded: "Recently, I have a sense that people are more open-minded here and I was fired up again to paint nudes. I guess I am making up for the lost time" [8]. Indeed, Liu Kang's nude paintings from the 1990s represent the culmination of the artist's lifelong exploration of one of his special subjects.

The available information seems to suggest that the artist's exploration of nudity in paintings spans two periods: 1927–1954 (early career) and 1992–1999 (the "golden years"). The theme reveals an evolution of the artist's painting expression from realism to different variants of modernism, including the Nanyang style [15,16]. Although the execution of female nudes from his early career is consistent with the technique known from his other genres of the same period, the nudes from the 1990s represent an unconventional experimentation with colour and brushwork, which can be elucidated from his 1997 essay: "Though my paintings are guided by a central principle in terms of style, there were some short periods when there would be styles or works that took an entirely different direction from my established style. This was due to the fluctuations of my mood" [17].

Hence, this study aims to investigate the development of the artist's approach to nude paintings by focusing on the pigment mixtures and painting techniques for depicting nude female bodies. Factors such as brushwork and colour palette were crucial for the characterisation of the forms of the figures and their skin tones. This research builds upon and expands the scope of the earlier analytical investigations of Liu Kang's paintings [2,18,19], and, for the first time, sheds light on the artist's palette of colours and painting techniques within one genre. The obtained results can provide conservators and art historians with a better understanding of Liu Kang's painting process.

2. Materials and Methods

2.1. Materials

The research in this paper focuses on eight paintings of nudes created during two periods, 1927–1954 and 1992–1999, from the Liu family and National Gallery Singapore collections (Figures 2 and 3). Two paintings represent the pre-war, Shanghai years. One was created during the unplanned emigration to Malaya, and five other paintings represent Liu Kang's career twilight in the 1990s. It should be noted that the final year of the first period (1927–1954) corresponds to the 1954 nude painting on canvas known only from the archival photograph taken by the artist in the 1950s (Figure 4). The painting was executed in a typical Nanyang style by the artist after his trip to Bali in 1952 [19]. Although the information about the artwork remains unknown, its unpublished photograph is presented in this study for documentation purposes.

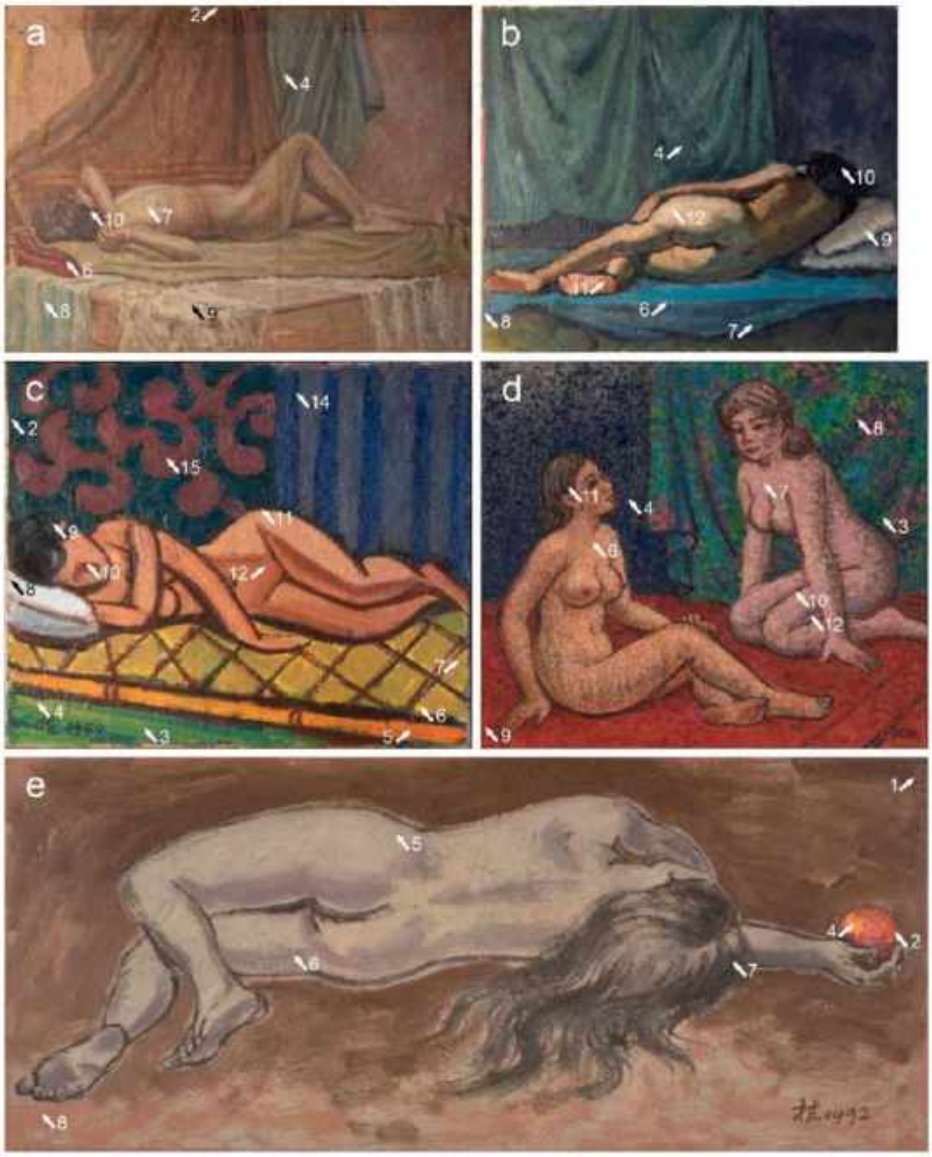

Figure 2. The paintings by Liu Kang: (**a**) *Nude*, 1927, oil on canvas, 45 × 60 cm; (**b**) *Nude*, 1934, oil on canvas, 45.5 × 55 cm; (**c**) *Nude*, 1940, oil on canvas, 38.5 × 46 cm; (**d**) *Nude*, 1995, oil on canvas, 66 × 76 cm; (**e**) *Nude*, 1992, oil on board, 42 × 97 cm. Paintings (**a**–**c**) are from Liu Kang family collection. Images courtesy of Liu family. Paintings (**d**,**e**) are gifts of the artist's family. Collection of National Gallery Singapore. White arrows indicate sampling areas.

In total, 62 paint samples from the artworks were analysed. Where possible, the samples were extracted from the surface paint layers in the areas of the existing losses. Table 1 summarises the inventory and technical data of the paintings, and Figures 2 and 3 indicate sampling areas for the analyses. It should be noted that the progressive numbering of the samples is not consistent due to the poor quality of some material, which was excluded from further analyses.

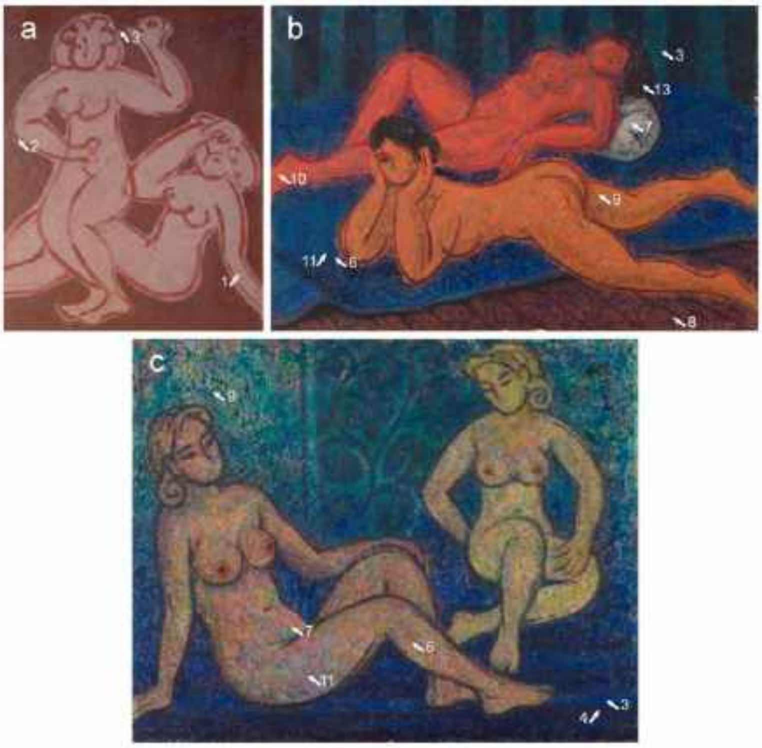

Figure 3. The paintings by Liu Kang: (**a**) *Two nudes*, 1996, oil on board, 43 × 36 cm; (**b**) *Beauties at rest II*, 1998, oil on canvas, 85 × 127 cm; (**c**) *In conversation*, 1999, oil on canvas, 61 × 76 cm. Painting (**a**) is from Liu Kang family collection. Image courtesy of Liu family. Paintings (**b**,**c**) are gifts of the artist's family. Collection of National Gallery Singapore. White arrows indicate sampling areas.

Figure 4. Archival photograph of a nude painting on canvas, 1954. Liu Kang family collection. Image courtesy of Liu family.

Table 1. Inventory and technical information of the paintings by Liu Kang included in this study.

Title and Inventory Number	Owner	Date	Dimensions H × W (cm)	Primary Support
Nude	Liu family	1927	45 × 60	Canvas
Nude	Liu family	1934	45.5 × 55	Canvas
Nude	Liu family	1940	38.5 × 46	Canvas
Nude, 2003-03259	NGS	1992	42 × 97	Board
Nude, 2003-03265	NGS	1995	66 × 76	Canvas
Two nudes	Liu family	1996	43 × 36	Board
Beauties at rest II, 2003-03470	NGS	1998	85 × 127	Canvas
In conversation, 2003-03305	NGS	1999	61 × 76	Canvas

2.2. Methods

This research relied on a multi-analytical approach that prioritises the use of non-invasive imaging techniques to preliminarily characterise the surfaces of paintings and pigment mixtures. These techniques involved visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR) and near-infrared (NIR). Pigment distribution and sampling areas were tentatively determined by combining the aforementioned imaging techniques with infrared false-colour (IRFC) manipulation, which enabled us to discriminate between the areas of same colour that had been achieved with different pigments. NIR and X-ray radiography (XRR) were employed to verify the presence of underlying preparatory drawings and earlier compositions.

The micro-invasive techniques involved extraction of the paint samples and their analyses in cross-sections to obtain vital information concerning their organic and inorganic components. Hence, optical microscopy (OM), polarised light microscopy (PLM), field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) and attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) were employed.

The results of the analytical methods were supplemented with photographs of the artist at work, revealing some interesting details of his painting practice, including painting materials and tools. Liu Kang also made sketches of his models in preparation for painting; therefore, these sketches were included in this study as an integral element, providing a better understanding of the artist's approach to the subject matter. The sketches allowed us to trace the evolution of the ideas, which were finalised in the paintings.

2.2.1. Technical Photography

The images of the paintings were acquired using a modified to full-spectrum (360–1100 nm) Nikon 850 DSLR camera equipped with a Nikon AF Micro NIKKOR 60 mm f/2.8D lens (Tokyo, Japan) and a set of bandpass filters for different spectral ranges [20–22]. For imaging calibration, the X-Rite ColorChecker Passport (Grand Rapids, MI, USA) and American Institute of Conservation Photo Documentation (AIC PhD) target were used [20]. As a source of illumination, two 500 W halogen lamps were used for VIS imaging. The illumination of the UVF and UVR photography was provided by two lamps fitted with eight 40 W 365 nm UV fluorescence tubes. VIS and UVF images were acquired with X-Nite CC1 and B+W 415 filters coupled together. UVR photography was taken with Andrea "U" MK II filter, while NIR was performed with Heliopan RG1000 filter (Gräfelfing, Germany) mounted on the camera lens. The IRFC images were obtained by manipulating VIS and NIR photographs with Adobe Photoshop CC according to American Institute of Conservation protocol [23].

2.2.2. Digital Microscopy

Digital microscopy of the paintings was carried out using Keyence VHX-6000 (Osaka, Japan), with a zoom lens operating at magnifications of 20×–200×. Built-in Keyence software—VHX-H2M2 and VHX-H4M—was used for measurement analyses.

2.2.3. XRR

X-ray radiography of the paintings was conducted with a Siemens Ysio Max digital system (Munich, Germany) with a detector of dimensions 35 × 43 cm and a resolution of 7 million pixels. The radiographic images were captured at 40 kV, 0.5–2 mAs, 4 s acquisition time and 100 cm distance between the X-ray source and detector. The acquired images were processed using iQ-LITE, followed by Adobe Photoshop CC software for final alignment and merging.

2.2.4. Preparation of Samples

Paint samples for the cross-sections analyses were embedded in acrylic resin—ClaroCit from Struers (Cleveland, OH, USA). Samples selected for the PLM analyses were prepared as dispersions on microscope slides in a mounting medium, Meltmount from Cargille (Cedar Grove, NJ, USA), with a refractive index of 1.662, and covered with a cover glass.

2.2.5. OM and PLM

The structures of the paint samples were examined in reflected VIS and UV light on a Leica DMRX polarised microscope (Wetzlar, Germany) providing 100×, 200× and 400× magnifications. PLM of the pigments was carried out in transmitted VIS light at the same range of magnifications following the workflow developed by Peter and Ann Mactaggart [24]. The samples were photographed using a Leica DFC295 digital camera.

2.2.6. FE-SEM-EDS

The paint cross-sections were mounted on conductive carbon tapes and analysed with a Hitachi SU5000 FE-SEM (Tokyo, Japan) coupled with Bruker XFlash® 6/60 EDS (Billerica, MA, USA). The SEM, backscattered electron mode (BSE), was operated at an acceleration voltage of 20 kV, low vacuum mode at 50–60 Pa, 50–60 intensity spot, 180 s acquisition time and 10 mm working distance. The data collection and processing were performed with Bruker ESPIRIT 2.0 software.

2.2.7. ATR-FTIR

ATR-FTIR spectroscopy was performed on paint cross-sections using a Bruker Hyperion 3000 FTIR microscope equipped with a mid-band MCT (Mercury Cadmium Telluride) detector, coupled with a Vertex 80 FTIR spectrometer. The ATR objective (20×) equipped with a germanium crystal was used for the compression of the samples. The background was measured with 64 scans before each acquisition. A total of 64 scans were acquired for each sample at a resolution of 4 cm^{-1} over the spectral range 4000 to 600 cm^{-1}. Data were processed and interpreted using Bruker Opus 7.5 software. The interpretation of data was conducted using the reference spectra in the material collection of the Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, spectral library of the Infrared and Raman Users Group (IRUG) [25], as well as Database of ATR-FTIR spectra of various materials [26].

3. Results and Discussion

3.1. Pigments

The presented results of the pigment analyses and the discussion focus on the mixtures primarily used by Liu Kang for the depiction of nude figures. However, due to sampling limitations, certain tonal ranges of the skin colours were not fully investigated. Hence, the analyses of the paint mixtures from the drapery settings of the compositions supported a tentative assessment of the pigment mixtures used for achieving skin colours and enabled us to confirm the use of certain pigments found at low concentrations in the skin colours.

The painterly settings, although being integral parts of the compositions, were treated by the artist with less attention; therefore, their technical characterisation was simplified to the prevailing pigment constituents. For clarity of the presented results, we organised them in sections corresponding to the paintings, which were arranged in the chronological order of their creation. The overview of the data is presented in Appendix A, Table A1.

3.1.1. Nude (1927)

The flesh colour of the model was probably achieved by interplaying yellow, red, green and blue hues to create highlights, mid-tones and shadows, as can be exemplified by the detail VIS image of the model's calf (Figure 5a). The bluish shadow underline may be associated with ultramarine or cobalt blue, based on its red representation in the IRFC imaging (Figure 5). The greenish mid-tone turns grey-blue in IRFC, suggesting the use of green earth or emerald green (Figure 5). Although the IRFC result is not conclusive, the use of emerald green (PG21) is likely, based on its identification in the green backdrop (sample 4). The elemental analyses of the green backdrop revealed the co-location of As and Cu elements, whereas FTIR measurements exhibited the intensive ester group stretching band at 1554, 817 (As-O stretch), 766 and 634 cm^{-1}, which could be assigned to emerald green (Figure 6) [27]. However, the latter peak is overlapped by the concomitant presence of lithopone in the investigated paint sample. The lithopone was confirmed by IR absorption bands at 1184, 1108, 1072, 983, 634 and 607 cm^{-1} [26]. A pink light reflection along the shadow on the model's calf was imaged orange in the IRFC (Figure 5); thus, it could be linked with an organic red rather than red iron-containing earth as the latter would appear greenish-brown in the IRFC imaging [20,28].

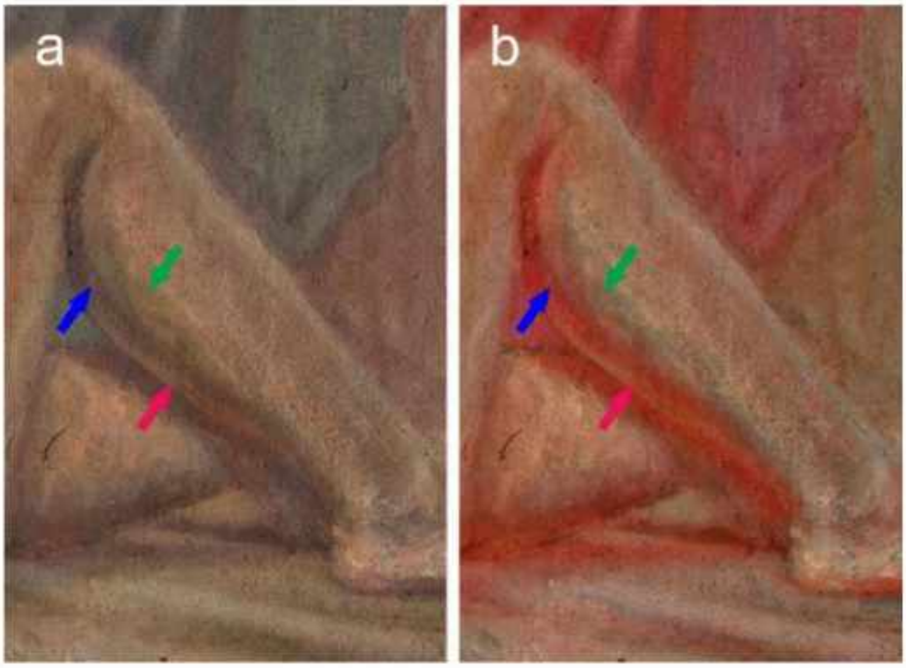

Figure 5. Detail of *Nude* (1927), imaged in VIS (**a**) and IRFC (**b**). The arrows indicate the areas of interest in VIS and their IRFC colour change: blue arrow—bluish shadow turns red; green arrow—greenish mid-tone turns grey-blue; red arrow—pink light reflection turns orange.

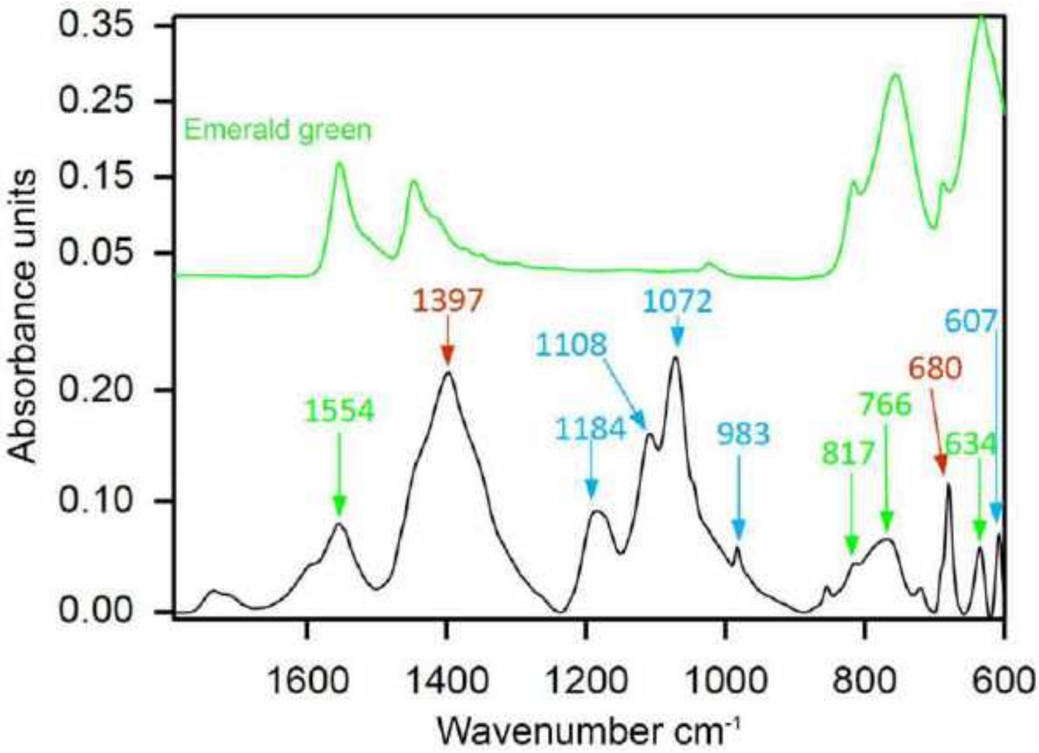

Figure 6. ATR-FTIR spectra of the green paint of sample 4 extracted from *Nude* (1927) with labelled (green) marker peaks of emerald green and reference spectra of the same pigment. Bands labelled in red indicate lead white and bands labelled in blue refer to lithopone. However, band 634 cm^{-1} is indicative of both emerald green and lithopone.

The brighter tints of the model's skin (sample 7) predominantly involved lead white (PW1), based on a strong Pb-signal and FTIR absorption peaks at 3533, 1394 (CO_3^{2-} asymmetric stretching), 1046, (CO_3^{2-} symmetric stretching), 852, 836, (CO_3^{2-} bending), 768 and 680 cm^{-1} (CO_3^{2-} bending) [29]. An admixture of lithopone (PW5) and/or barium white (PW21) and zinc white (PW4) is assumed, based on the FTIR detection of the characteristic peaks in the SO_4^{2-} group at 1186, 1109, 1072, 983 (the symmetric stretching vibration), 636 and 608 cm^{-1} (the out-of-plane bending vibration) and by SEM-EDS recording of Zn- and Ba-signals. It is worth noting that S was not detected in the sample probably due to the strong Pb $M\alpha_1$ signal overlapping the weaker S $K\alpha_1$ signal. A trace presence of Ca may suggest chalk (PW18) contamination. Interestingly, the co-location of As and Cu elements detected with SEM-EDS in the solitary green particles present in sample 7 permitted attribution to emerald green (Figure 7).

The model's dark hair was executed using the wet-on-dry technique with complex pigment mixtures, as illustrated in the VIS microscopic image and SEM-EDS elemental distribution maps of sample 10 (Figure 8). The SEM-EDS analysis of the bottom layer of the paint recorded signals of Fe, Ca, Si, Mn and P. This result combined with the FTIR absorption peak at 1032 cm^{-1} seems to point to either umber (PBr7) (Si-O-Si asymmetric stretching) [30,31] or bone black (PBk9) (PO_4^{3-} stretching) [30,32,33]. The presence of Na, Al, Si and S elements seems to point to an admixture of ultramarine (PB29), also observed with PLM (blue particles with low refractive index appear red with Chelsea filter). Traces of As and Cu elements evidence contamination with emerald green, which was confirmed to have been used more distinctly in other parts of the composition. The reddish upper layer of the same sample is an equally complex pigment mixture. Judging from the PLM observation of a good deal of red particles with a unique low refractive index and SEM-EDS detection of a strong Al-signal, organic red, probably on the Al-based substrate, was assumed. Meanwhile, strong Ba- and S-signals may correspond to barium white, which is a common extender of lake pigments as well as lead white [34], also considered to be present in the investigated pigment mixture. A trace presence of Zn allowed us to consider an admixture of zinc white or lithopone as Ba and S were already detected. The latter was also supposed with FTIR by peaks at 1167, 1104, 1071, 984, 632 and 606 cm^{-1}. The minor and trace presence of Cr, As and Cu elements suggests a contamination of Cr-containing green and/or yellow pigment(s) and emerald green. The detection of Ca, Fe and P elements suggests an admixture of bone black and/or iron-containing earth pigment. A single IR absorption peak at 1021 cm^{-1}, can be identified as an asymmetric Si-O-Si stretching band in iron-rich earth or can represent the $PO4^{3-}$ group in bone black.

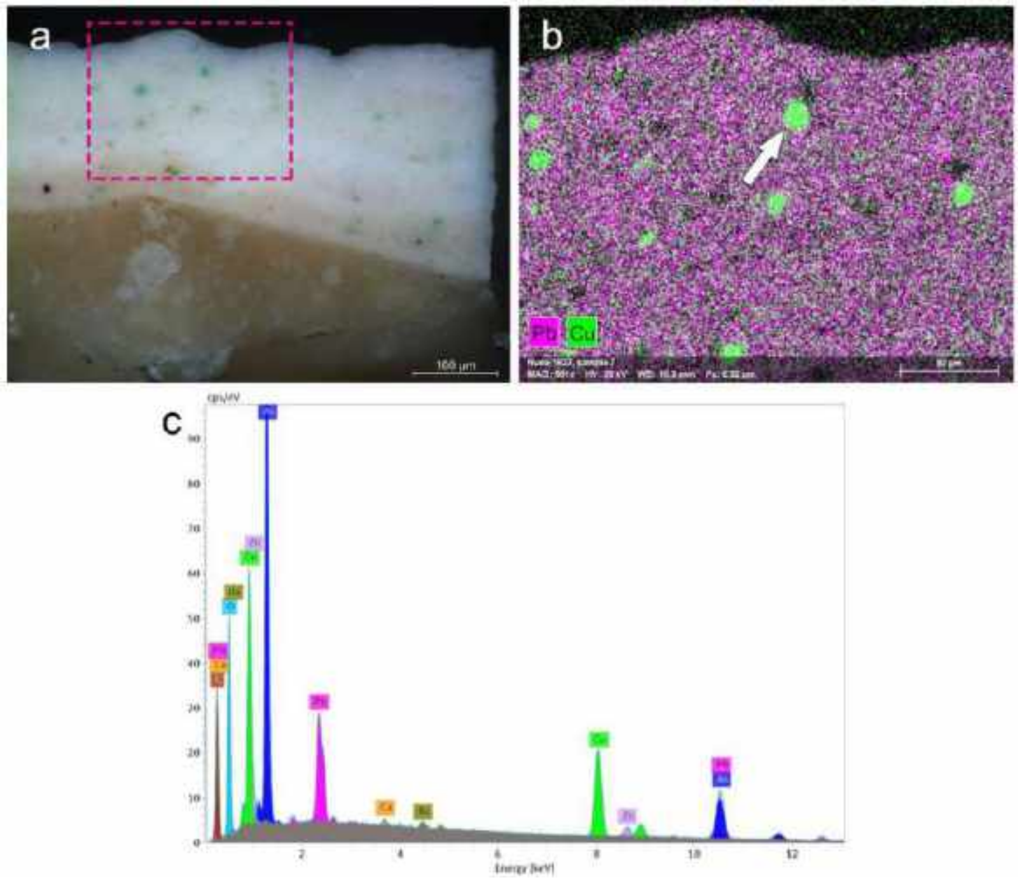

Figure 7. Microscopy image of the cross-section of sample 7 at 200× magnification, extracted from the area of the model's skin from *Nude* (1927) (**a**). The red rectangle indicates the area where the SEM-EDS elemental map was acquired. The corresponding SEM-EDS mapping of the skin colour paint (layer 2) (**b**) shows the distribution of lead (Pb) and copper (Cu) in the paint sample. The corresponding SEM-EDS spectra of the green particle (**c**) indicated with an arrow in SEM-EDS map (**b**) shows strong Cu- and As-signals, suggesting the presence of emerald green pigment particle.

Regarding the model's setting, as well as the emerald green in the green backdrop that was identified earlier (sample 4), the PLM enabled us to observe green particles with optical features typical for viridian (PG 18) (large and rough anisotropic green particles with high refractive index) [24,35] confirmed by the detection of a strong Cr-signal. Unfortunately, the FTIR identification of viridian was challenging due to the fingerprint region of this pigment (600–400 cm^{-1}) being behind the spectral range of the measurement. The analysed green paint was modified with some ultramarine suggested by SEM-EDS and PLM analyses, and white paint that could have a similar composition to that identified in other pigment mixtures of the investigated painting. Viridian, confirmed with PLM and SEM-EDS as the primary green pigment admixed with some ultramarine, was used for painting the light green textile underneath the model (sample 8). Moreover, the FTIR analysis permitted us to detect a low intensity band occurring at 794 cm^{-1} that could be indicative of viridian, matching with the IRUG reference [36], while the other band at 1070 cm^{-1} that could support the characterisation of this green pigment was masked by the broad absorption band of lithopone.

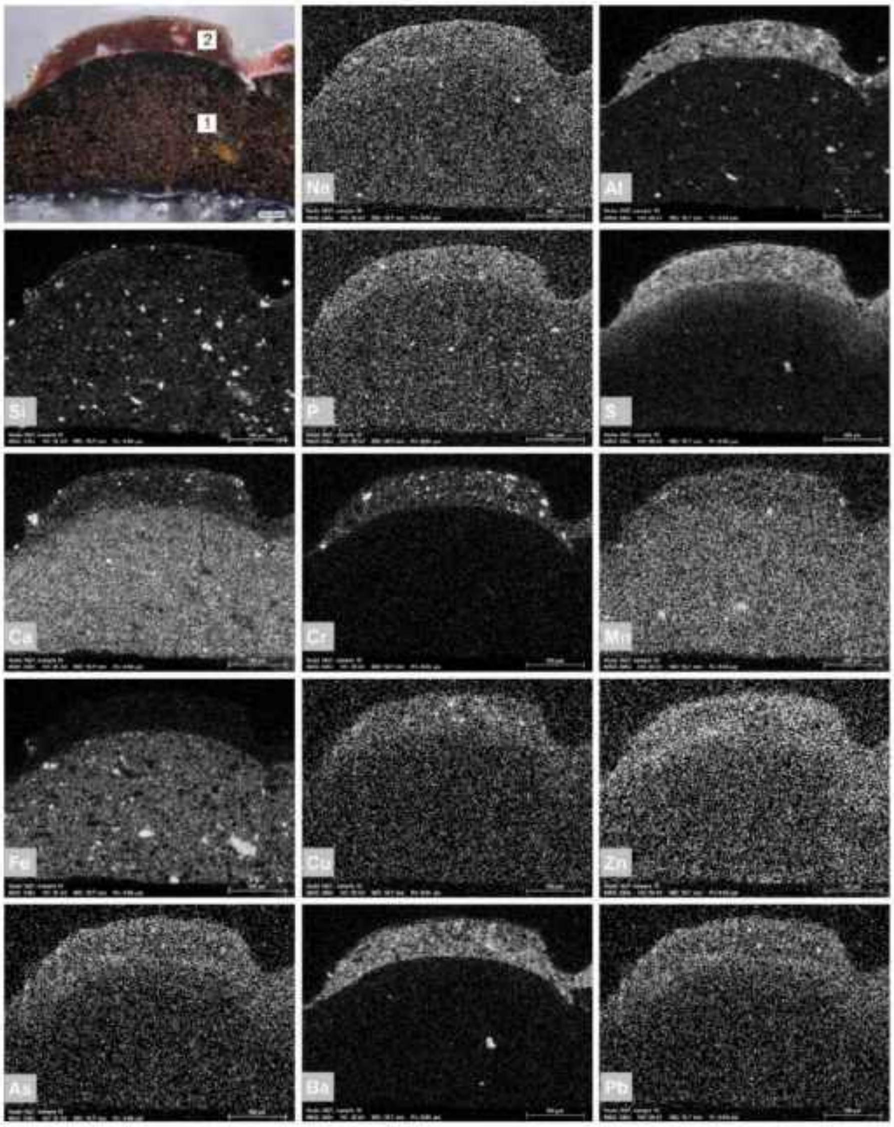

Figure 8. Microscopy image of the cross-section of sample 10 at 200× magnification, extracted from the area of model's hair from *Nude* (1927), photographed in VIS (top-left), followed by SEM-EDS maps showing the distribution of the detected elements. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, black means low intensity. A high intensity of Fe-, Ca-, Mn- and P-signals recorded from the layer 1 can be assigned to umber and bone black. The co-location of Al, P, S, Ca, Cr, Cu, Fe, Zn As, Ba and Pb in layer 2 suggests the presence of organic red, lead white, lithopone and/or barium white and zinc white, probably Cr-containing green(s) and/or yellow(s), emerald green, bone black and/or iron-containing earth pigment.

The analyses of the paint used for the brown backdrop (sample 2) revealed a complex mixture of pigments, probably composed of organic red on Al-containing substrate. PLM combined with SEM-EDS enabled us to identify admixtures of viridian, a trace presence of bone black and yellow iron-containing earth pigment (yellow, anisotropic particles with a high refractive index), and emerald green contamination.

PLM and SEM-EDS analyses of the red paint extracted from the model's pillow (sample 6) suggest the incorporation of organic red on an aluminium-based substrate with some bone black and white paint admixture. The analyses of sample 9 extracted from a white painted area confirmed the use of lead white admixed with lithopone and/or barium white and zinc white, a pigment composition frequently found in other analysed samples of the paint layer.

3.1.2. Nude (1934)

Based on the PLM and SEM-EDS, the highlights and warm mid-tones of the flesh colour (sample 12, 11) involved varied concentrations of yellow iron-containing earth pigments. However, IR absorption peaks of kaolinite at 3696, 3622, ca. 1005, 912, 800 and 779 cm^{-1} enabled us to infer the presence of yellow ochre (PY43) in sample 11 [37,38]. This pigment was mixed with lithopone and/or barium and zinc whites to achieve different yellow tints. Cool greenish mid-tones were assessed based on their purple colour change in the IRFC (Figure 9), allowing us to infer the presence of Cr- or Co-containing green pigment. However, based on the PLM, SEM-EDS and FTIR analyses of the green backdrop (sample 4), a composition made of ultramarine and yellow iron-containing earth pigment could also be involved in the execution of cool mid-tones of the model's body. Her dark hair (sample 10) was achieved by mixing what is probably carbon black with ultramarine, resulting in a red appearance in IRFC. The colour intensity was controlled by adding a white paint resembling that identified in the flesh tone (sample 12) and the white pillow (sample 9).

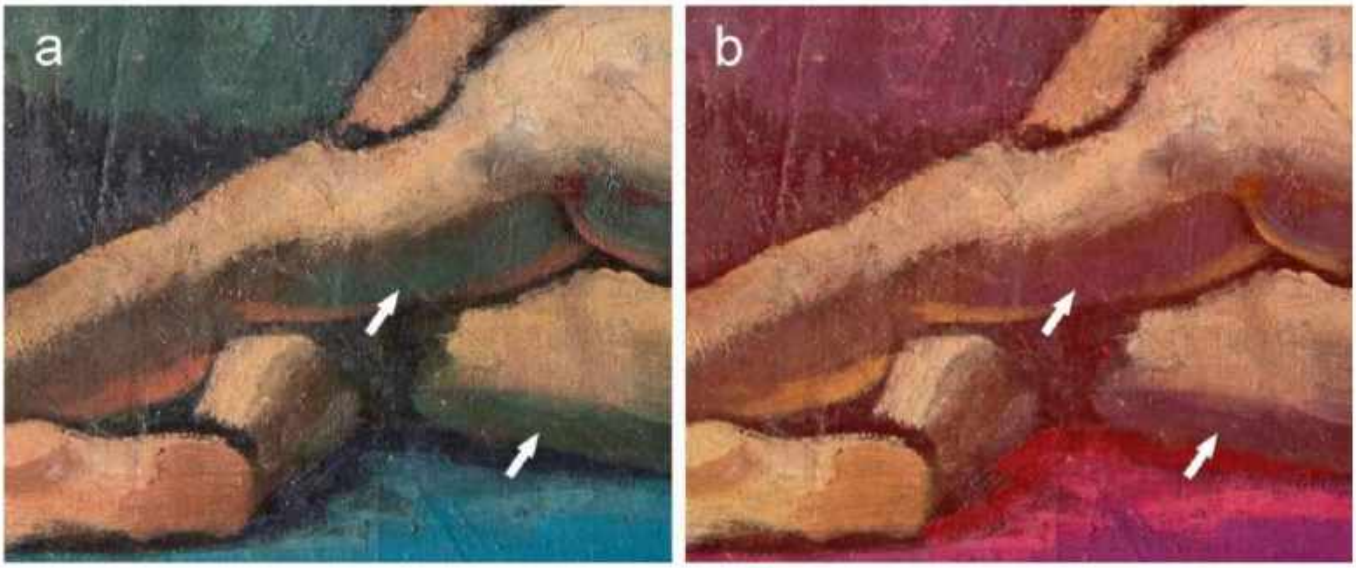

Figure 9. Detail of *Nude* (1934), illustrating the greenish mid-tones imaged in VIS (**a**) and purple IRFC result (**b**).

The palette of colours identified in the drapery setting is limited. Viridian and ultramarine prevail in all three blue tones (sample 6, 7, 8). Although a detection of an intensive IR absorption peak at 797 cm^{-1} (sample 6) was not satisfactory to make an unequivocal attribution to viridian [36], the combined evidence provided by PLM and SEM-EDS was sufficient to confirm the presence of this pigment. Interestingly, for the execution of a green backdrop, the artist incorporated ultramarine and yellow iron-containing earth pigment instead of viridian (sample 4). Elemental analyses of the white paint extracted from a white painted pillow (sample 9) enabled us to infer that the mixture is probably composed of lithopone and/or barium white and zinc white with admixtures of chalk and titanium white (PW6).

3.1.3. Nude (1940)

Here, the model's body was depicted without exploiting the potential of the cool mid-tones, which were successfully used in two earlier artworks. The figure was painted almost monochromatically using tints of yellow iron-containing earth pigment (sample 11, 12) with added white paint, probably comprising lithopone and/or barium white and zinc white, chalk, titanium white and lead white. The composition of the white admixture is converging with the analyses of the white paint extracted from the pillow (sample 8). A dark brown paint (sample 10) used to delineate the model's shape is composed predominantly of umber, bone black, traces of Cr-containing yellow(s) [39] and white paint resembling that identified in sample 8. The black used for the model's hair (sample 9) is a mixture of bone black with yellow iron-containing earth pigment and ultramarine brightened with some white paint of similar composition as that identified in sample 8. Additionally, the paint mixture probably includes cadmium yellow (PY35) contamination based on the trace Cd- and S-signals. However, a coinciding presence of Ba and Zn elements may account for cadmopone (co-precipitated cadmium sulfide and barium sulfate) or zinc-modified light cadmium yellow [40].

The blue vertical strip of the background primarily consists of ultramarine with trace admixtures of bone black and Prussian blue (sample 14). This blue pigment in combination with the yellow iron-containing earth pigment and viridian was used for a green background (sample 2). The PLM and SEM-EDS analyses of the red paint from the ornament (sample 15) suggest the presence of organic red on Al-based substrate. A yellow ochre admixture is assumed based on the occurrence of Fe as well as on PLM observation and IR absorption peaks at 3691, 3619, 1026, 1007 and 913 cm^{-1}. Furthermore, the presence of ultramarine was detected by PLM, SEM-EDS and some FTIR absorption peaks at ca. 1000 (overlapping stretching bands for Si-O-Si and Si-O-Al masked by yellow ochre band), 680 and 660 cm^{-1} [41].

A yellow surface underneath the model was achieved with two types of yellow paint (sample 6, 7). A suite of elements indicative of cadmium yellow or its variant was found in sample 6. FTIR did not enable the precise characterisation of cadmium yellow due to its fundamental bands falling outside of the spectral range of the instrument [40]. A mixture predominantly composed of yellow iron-rich earth pigment was detected in sample 7.

Cadmium orange (PO20) and barium white or cadmium orange lithopone (co-precipitated cadmium sulfoselenide and barium sulfate) are probably the main ingredients of the orange paint extracted from the edge of the resting area (sample 5). The pigments are suggested based on the SEM-EDS detection of Ba, Cd, S and Se. An admixture of some organic red on Al-containing substrate was assumed based on the PLM observation and detection of Al-signal. The green space beneath (sample 3) primarily consists of ultramarine and yellow iron-containing earth pigment. The latter pigment appears as a main component of a few isolated yellow brushstrokes in that area (sample 4).

3.1.4. Nude (1992)

In this painting, the female body was executed almost monochromatically with minimal modelling of the form resembling the painting approach to *Nude* (1940). Two samples extracted from the highlight (sample 5) and mid-tone (sample 6) reveal the use of complex mixtures of pigments. The highlights were achieved by mixing umber with some organic red on Al-containing substrate and bone black brightened with titanium white, zinc white, chalk and lead white. FTIR analyses of the mid-tone paint enabled the identification of synthetic alizarin lake (PR83:1) by some characteristic absorption peaks at 1640, 1592, 1350, 1260, 1043 and 720 cm^{-1} [42]. The mid-tone paint also contains red iron-rich earth pigment and trace admixtures of cadmium yellow or its variant and bone black. The intensity of the paint was probably controlled by adding titanium white extended with chalk, lead white, lithopone and/or barium and zinc whites. The dark hair (sample 7) was achieved by mixing bone black with umber and probably modified with some white paint; however, the complexity of the investigated paint makes it difficult to ascertain the exact ingredients of white admixture.

The analyses of two paint samples (sample 1, 8) from the background confirmed a consistent presence of red iron-rich earth pigment, bone black and white paint composed of titanium, zinc, lead whites and chalk. The red paint from an apple (sample 2) contains a synthetic alizarin lake on aluminium-based substrate confirmed by FTIR absorption peaks at 1636, 1589, 1528, 1464, 1360, 1348, 1287, 1267, ca. 1030, 838, 719, 670 and 655 cm^{-1} and SEM-EDS Al-signal (Figure 10) [42–44]. This pigment was combined with cadmium yellow or its variant, red iron-rich earth pigment, some bone black and white, probably of a similar composition as that identified in sample 6. The highlight brushstroke from the apple (sample 4) contains a mixture of cadmium yellow and/or orange or their variants, yellow iron-containing earth pigment, synthetic alizarin lake and a good deal of commonly used white paint such as that identified in samples 2 and 6.

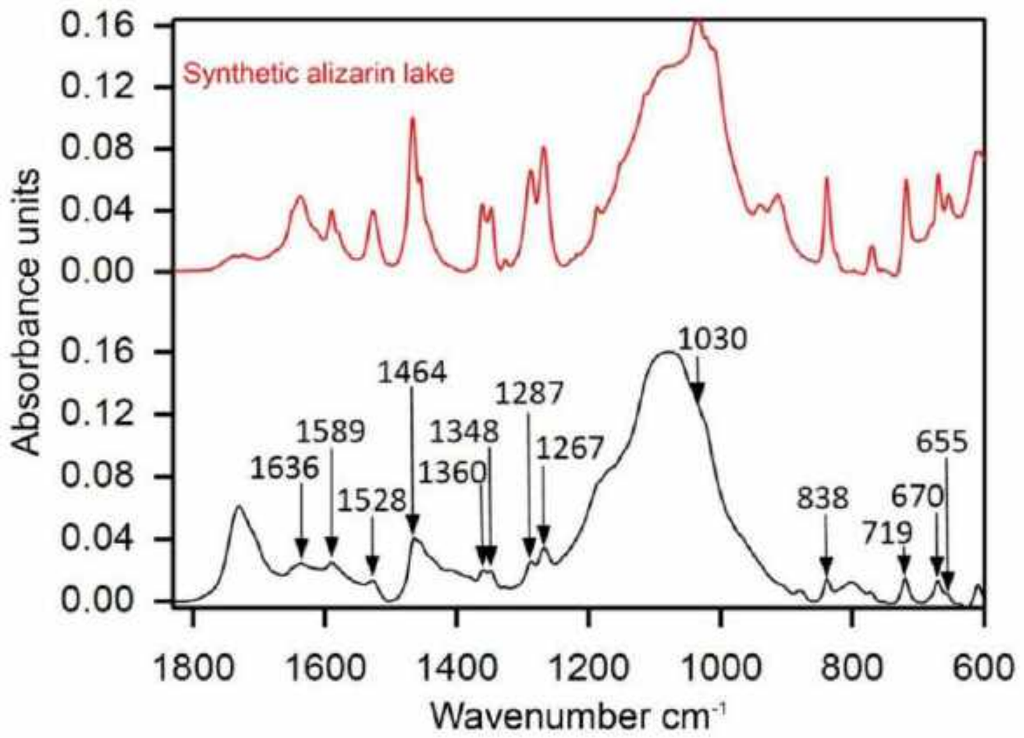

Figure 10. ATR-FTIR spectra of the red paint of sample 2 extracted from *Nude* (1992), with labelled marker peaks of synthetic alizarin lake and reference spectra of the same pigment.

3.1.5. Nude (1995)

The colour of the skin of the model on the left (sample 6) was obtained by mixing yellow and red iron-containing earth pigments with titanium and zinc whites and chalk; however, that paint mixture was modified for the skin colour of the opposite model (sample 7) by adding cobalt blue (PB29), observed with PLM (isotropic particles with a high refractive index that appear red with Chelsea filter) and by detection of concomitant Co and Al elements (Figure 11a,b). Cool mid-tones of the carnations were made with violet paint (sample 12) obtained with ultramarine mixed with red iron-containing earth and synthetic alizarin lake on Al-based substrate. The synthetic alizarin lake was suspected by its characteristic absorption bands at 1465, 1361, 1288, 1266, 1026, 840, 802, 771, 719 and 681 cm^{-1} [42,45]. The intensity of the violet paint was modified with bone black as well as white pigments such as lithopone and/or barium white and zinc white, chalk and some titanium white. Brown outlines were obtained by mixing yellow iron-containing earth pigment with some bone black, titanium and zinc whites (sample 10). For painting strokes of the black hair of the left-hand side model, the artist incorporated bone black, ultramarine, yellow iron-containing earth pigment with white paint made of lithopone and/or barium white and zinc white admixed with titanium white and chalk (sample 11).

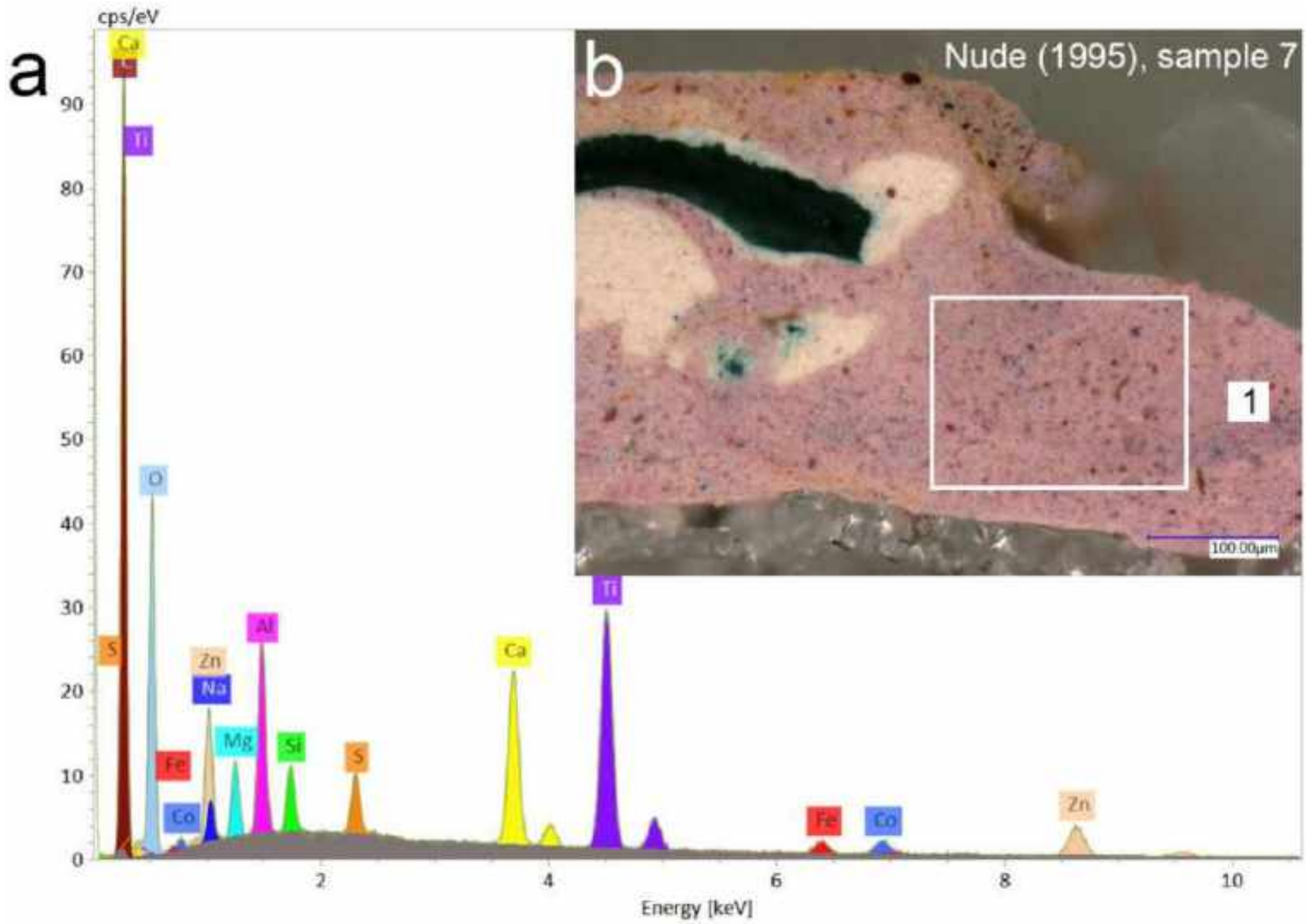

Figure 11. (**a**) SEM-EDS spectra of the pink paint from layer 1 of sample 7 extracted from *Nude* (1995); (**b**) optical microscopy image of the cross-section of the sample at 200× magnification, with marked area of analyses.

The dark blue background (sample 4) is made of cobalt blue with some lithopone and/or barium and zinc whites, chalk and trace presence of titanium white. Although a strong IR absorption band at 643 cm^{-1} was not sufficient to pinpoint cobalt blue, a combined PLM observation and SEM-EDS analysis enabled us to suspect this blue pigment [26]. The FTIR detection of absorption peaks at 1060 and 800 cm^{-1} combined with PLM and SEM-EDS analyses of a green paint from the green backdrop (sample 3) seem to point to viridian as the main component [36]. This pigment was admixed with yellow iron-containing earth pigment, cadmium yellow or its variant, bone black and a common type of white paint already characterised earlier. A concomitant presence of viridian and cadmium yellow may also be attributed to commercially prepared cadmium green. Red paint touches from the green backdrop (sample 8) contain a mixture of red iron-rich earth, organic red on Al-based substrate, bone black and traces of Cr-containing yellow(s) with frequently occurring white paint composition. The other red (sample 9) is a mixture of two different red paints applied wet-on-wet. The upper layer predominantly consists of the red iron-containing earth in combination with synthetic alizarin lake on Al-based substrate. FTIR provided the positive detection of the synthetic alizarin lake by absorption peaks at 1590, 1465, 1362, 1350, 1288, 1187, 1154, 1025, 839, 797, 771, 745, 719 and 671 cm^{-1}, which are consistent with the reference spectra [42,45]. Moreover, the investigated paint contains some admixtures of cadmium yellow or its variant, bone black and frequently occurring white paint composition. The bottom layer is composed mainly of red azo pigment naphthol red AS-D (PR112), identified by the absorption peaks at 3277, 3238, 3189, 3127, 3076, 3028, 1668, 1604, 1593, 1545, 1493, 1478, 1447, 1384, 1363, 1324, 1279, 1257, 1237, 1197, 1154, 1109, 1083, 1037, 1012, 964, 905, 890, 863, 749, 696 and 664 cm^{-1}, and red iron-rich earth. The SEM-EDS detection of strong Cl- and Sn-signals could be linked with another organic red on Sn-substrate [46,47] however, FTIR did not validate this presumption. In addition, the mixture of pigments was brightened with commonly used white paint.

3.1.6. Two Nudes (1996)

The analyses of sample 1 extracted from the pink coloured skin indicate the presence of red iron-rich earth pigment. The principal component of the red painterly contours of the shapes (sample 2) is naphthol red AS-D confirmed based on the absorption peaks in the FTIR spectrum at 3274, 3235, 3186, 3124, 3075, 3027, 1667, 1603, 1594, 1544, 1493, 1478, 1447, 1386, 1364, 1324, 1279, 1258, 1238, 1197, 1154, 1112, 1084, 1046, 1013, 964, 905, 890, 862, 748, 697 and 666 cm^{-1} (Figure 12) [48]. A detection of strong Cl- and Sn-signals may be ascribed to organic red on Sn-containing substrate; however, FTIR measurement did not confirm its presence. Therefore, a precise identification of the constituents of the investigated red paint would require the application of Raman spectroscopy or chromatography. Trace admixtures of red iron oxide, bone black, titanium white, chalk, lithopone and/or barium and zinc whites were also assumed. The paint sample from the uniform brown-red background (sample 3) was found to have the same constituents as sample 2; however, they were mixed in a different ratio, and red iron-containing earth is a prevailing pigment.

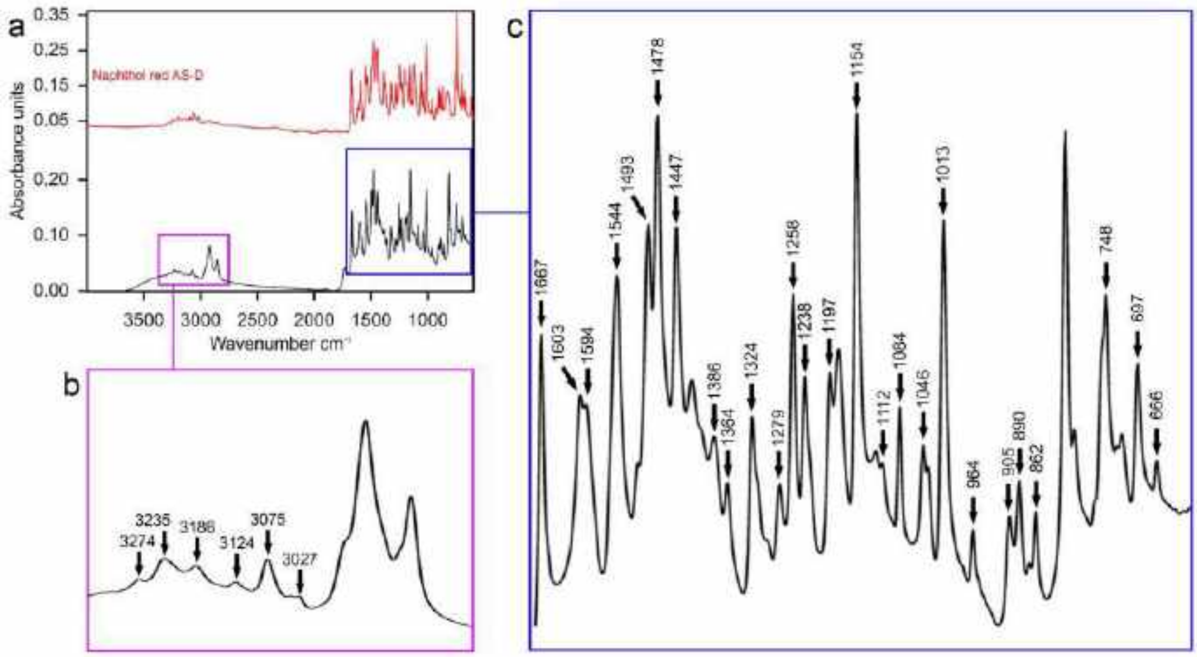

Figure 12. (**a**) ATR-FTIR spectra of the pink paint of sample 2 extracted from *Two nudes* (1996), with labelled marker peaks of naphthol red AS-D and reference spectra of the same pigment; (**b**) a scale expansion of the spectra of the sample from 2700 to 3300 cm^{-1}; (**c**) a scale expansion of the spectra of the sample from 600 to 1700 cm^{-1}.

3.1.7. Beauties at Rest II (1998)

The skin colours of the two models are determined by a predominant use of orange and red paints. The orange paint (sample 9) was found to be primarily made of yellow iron-containing earth pigment and cadmium yellow or its variant light cadmium yellow, based on the detection of Zn, Fe, Cd and S elements (Figure 13a,b). The elemental analyses of the red paint (sample 10) indicated a concomitant presence of Cd, Ba, S and Se, whereas the FTIR measurement exhibited characteristic absorption bands for lithopone or barium sulfate at 1174, 1104, 1065, 983, 635 and 606 cm^{-1}. This outcome seemed to point to cadmium orange and/or cadmium red co-precipitates with barium sulfate (PO20:1 or PR108:1) known as cadmium orange/red lithopones [40,49,50] (Figure 13c,d). Moreover, the PLM and SEM-EDS analyses seem to suggest an admixture of organic red on Al-based substrate and a trace presence of red iron-containing earth pigment, which together contribute to the intense red hue of the investigated pigment mixture. Randomly applied green paint brushstrokes found on the orange model are probably composed of Cr- or Co-containing green based on its purple appearance in IRFC. The black paint used for depicting the models' hair (sample 13) was achieved by mixing bone black with blue pigments such as ultramarine and phthalocyanine blue (PB15). Although, the FTIR measurements provided the peculiar IR absorption peak at 1024 cm^{-1} (overlapping stretching band for Si-O-Si and Si-O-Al), which is insufficient to declare the identification of ultramarine, the additional PLM and SEM-EDS analyses contributed to the detection of this blue pigment. Phthalocyanine blue was detected by peaks at 1605, 1591, 1508, 1419, 1334, 1287, 1166, 1119, 1090, 900, 872, 769, 754 and 720 cm^{-1} as well as SEM-EDS detection of a Cu-signal (Figure 14a) [51–54].

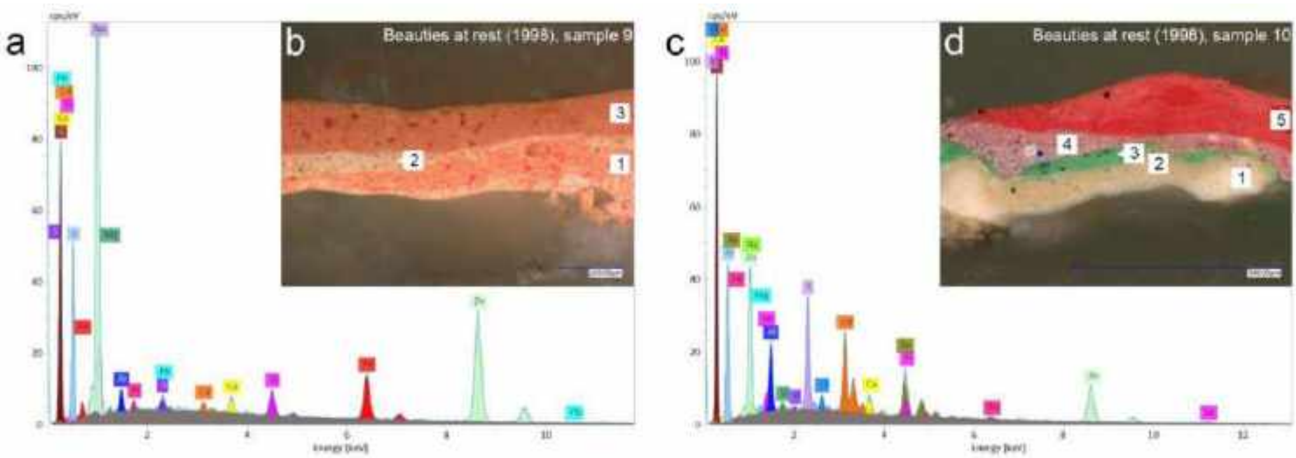

Figure 13. (**a**) SEM-EDS spectra of the orange paint from layer 3 of sample 9 extracted from *Beauties at rest II* (1998); (**b**) corresponding optical microscopy image of the cross-section of the sample at 200× magnification; (**c**) SEM-EDS spectra of the red paint from layer 5 of sample 10 extracted from *Beauties at rest* (1998); (**d**) corresponding optical microscopy image of the cross-section of the sample at 200× magnification.

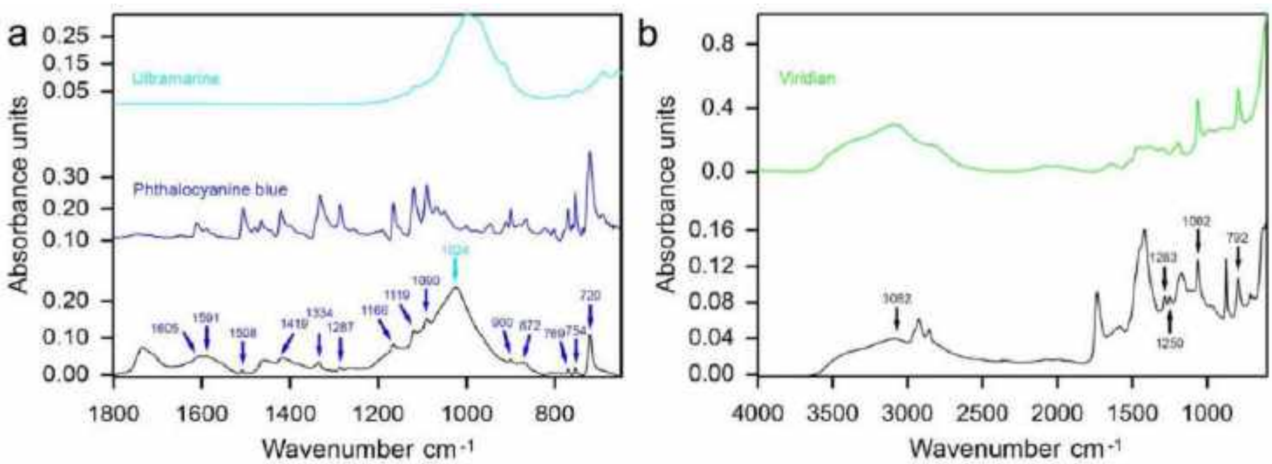

Figure 14. (**a**) ATR-FTIR spectra of the black paint of sample 13 extracted from *Beauties at rest II* (1998), with labelled (dark blue) marker peaks of phthalocyanine blue and ultramarine (light blue) and reference spectra of the same pigments; (**b**) ATR-FTIR spectra of the green paint of sample 3 extracted from *Beauties at rest II* (1998), with labelled marker peaks of viridian and reference spectra of the same pigment.

The principal pigment of the green paint (sample 3) extracted from the vertical stripe of the background is viridian confirmed with FTIR by absorption bands at 3082, 1283, 1250, 1062 and 792 cm^{-1} (Figure 14b) [36]. A blue carpet involved two hues of blue composed of different ingredients as visualised in IRFC imaging (Figure 15). Light blue (sample 11) applied with a palette knife was prepared by mixing ultramarine with Prussian blue (PB27). The latter was identified by PLM observation (dark blue isotropic particles, which appear dark green under a Chelsea filter and have a low refractive index), SEM-EDS detection of an Fe-signal and FTIR absorption peak at 2081 cm^{-1} (C≡N stretching). A trace presence of cadmium yellow or its variant is considered here as contamination. The analyses of the pigment mixture are consistent with dark violet imaging of the sampling area in IRFC, as the resultant colour is determined by the dark blue representation of Prussian blue combined with a purple representation of ultramarine. Dark blue (sample 6) was dabbed with a small brush over the lighter hue. The detection of Cu and IR absorption peaks at 1506, 1420, 1336, 1165, 1118, 1088, 901, 878, 770, 754 and 722 cm^{-1} permitted phthalocyanine blue attribution [51–54]. In addition, the artist added some ultramarine to modify the hue. Ultramarine was confirmed by absorption bands at 1022 and 680 cm^{-1} [41]. This outcome is consistent with the red appearance of the sampling area in IRFC as both phthalocyanine blue and ultramarine turn red. The brown paint used to characterise the floor panels (sample 8) is a mixture of ultramarine, synthetic alizarin lake on Al-containing substrate, red iron-rich earth, bone black, trace presence of cadmium yellow or its variant and Cr-containing yellow or green pigment(s). White paint extracted from the pillow (sample 7) is a combination of titanium white, lithopone and/or barium and zinc whites as well as chalk. Some contamination with red iron-containing earth, viridian and ultramarine were also detected. Nevertheless, the major constituents of the analysed white paint appear consistently in all pigment mixtures discussed here, probably as the artist's addition.

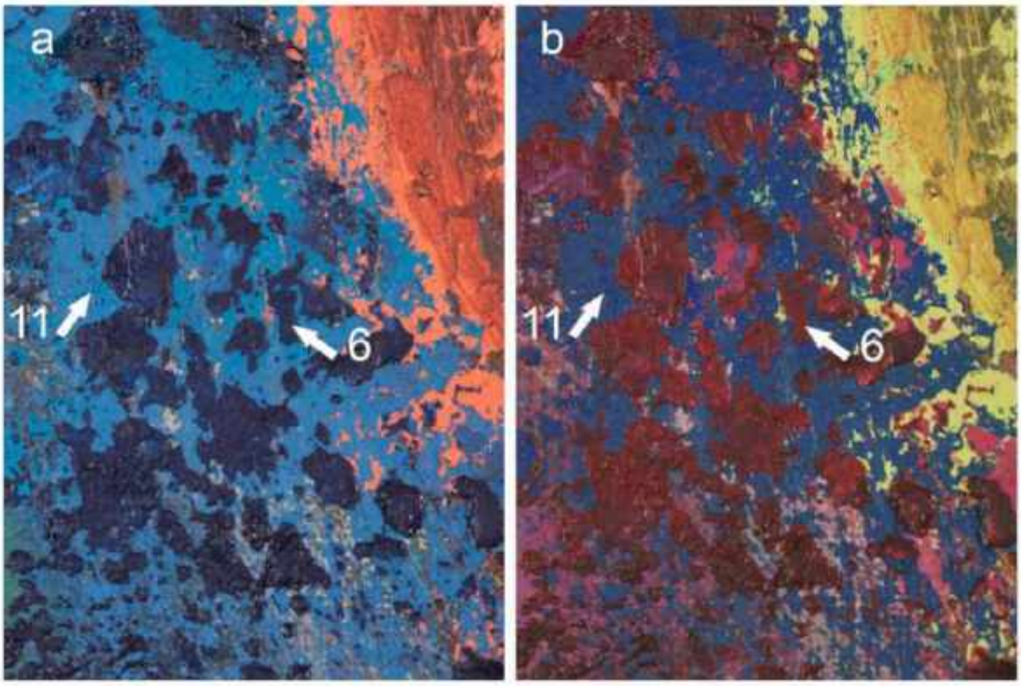

Figure 15. Detail of *Beauties at rest II* (1998), imaged in VIS (**a**) and IRFC (**b**). The arrows indicate the sampling spots of two different blues.

3.1.8. In Conversation (1999)

The female bodies were executed by the pointillist application of complementary colours. Thus, the yellow paint brushstrokes (sample 7) are rich in yellow iron-containing earth. Red (sample 6) contains red iron-containing earth in combination with Cr-based yellow pigment(s) and probably organic red on Al-based substrate. Unfortunately, the overlapping intensive signals for chalk and oil hampered the FTIR identification of the organic red. Blue (sample 11) is composed of ultramarine and some Prussian blue confirmed with FTIR by the absorption peak at 2093 cm^{-1}.

The green background is composed predominantly of viridian (sample 9), while blue paint used for the foreground is composed of ultramarine and phthalocyanine blue (sample 3, 4). However, a small concentration of Fe, Cr, P and Ca elements recorded with SEM-EDS and combined with PLM observation of sample 3 suggest minor admixture or contamination with Prussian blue, viridian and bone black. A light tint of this blue mixture was achieved with the abundance of titanium white, probably admixed with chalk, lithopone and/or barium white and zinc white.

3.1.9. Binders and Other Identified Compounds

The binder for all identified pigment mixtures is drying oil, as confirmed with FTIR analyses and reported in Appendix A, Table A1. This spectroscopic technique enabled the detection of typical IR absorption peaks at 2923, 2853, 1738, 1460, 1375, 1235, 1160, 1098 and 720 cm^{-1} in most of the investigated paint samples [55,56]. Another important result of this study is the detection of zinc soaps in the paint samples extracted from six paintings, by FTIR absorption band at 1540 cm^{-1} [57,58]. They had likely formed as products of the chemical reaction between the saturated fatty acids of the lipid-based binder and the metal ions of the zinc-containing pigments present in the paint layers. The formation of metal soaps appears to be a common feature of Liu Kang's paintings [2,18,19]; however, no deterioration signs linked to the metal soaps have been observed. Nevertheless, special attention should be paid when designing display and storage conditions as well as conservation treatments of Liu Kang's paintings as high humidity promotes the formation of the soaps [59–63].

3.2. Preparatory Underdrawings and Sketching Studies

VIS examination of *Two nudes* (1996) revealed a preparatory drawing executed with thin and fluid red and blue crayon lines over the pink underpaint, then refined with the painterly bold and red contours in the following step (Figure 16). The examination of the remaining seven paintings did not evidence the preparatory underdrawings in VIS or NIR. This observation converges with the authors' research that focused on Liu Kang's earlier artistic periods, where only a few instances of sketches over the prepared ground layer were found in the paintings from the 1950s [19]. Hence, Liu Kang's practice of making preparatory underdrawings remains relatively unknown. The possible explanation could be that the underdrawings must have been very simple and below NIR detection, or the artist laid out the general composition with rough brushstrokes and subsequently blended them into the painted surface. Such an approach to this initial artistic process finds confirmation in a revealing description given by the artist's son, Liu Thai Ker: "After he decides on the subject matter, he studies the various on-location sketches and re-organises the composition of these sketches with more sketch studies to suit his artistic intention. When he gets something he is satisfied with, the image is transferred in broad simple lines on to the canvas" [5]. Hence, more information on the development of the compositions of nudes can be gathered from the artist's sketches on paper.

A signed and dated (1992) pen drawing of two nudes was probably used as a reference for *Nude* (1995) (Figure 17a,b). The drawing reveals that the model on the left was initially semi-reclining, whereas the final painting shows the model in a seated pose. That change enabled the artist to avoid placing any resting structure behind her back, hence resulting in a simpler composition. The pose of the second model from the drawing remains unchanged in the painted version.

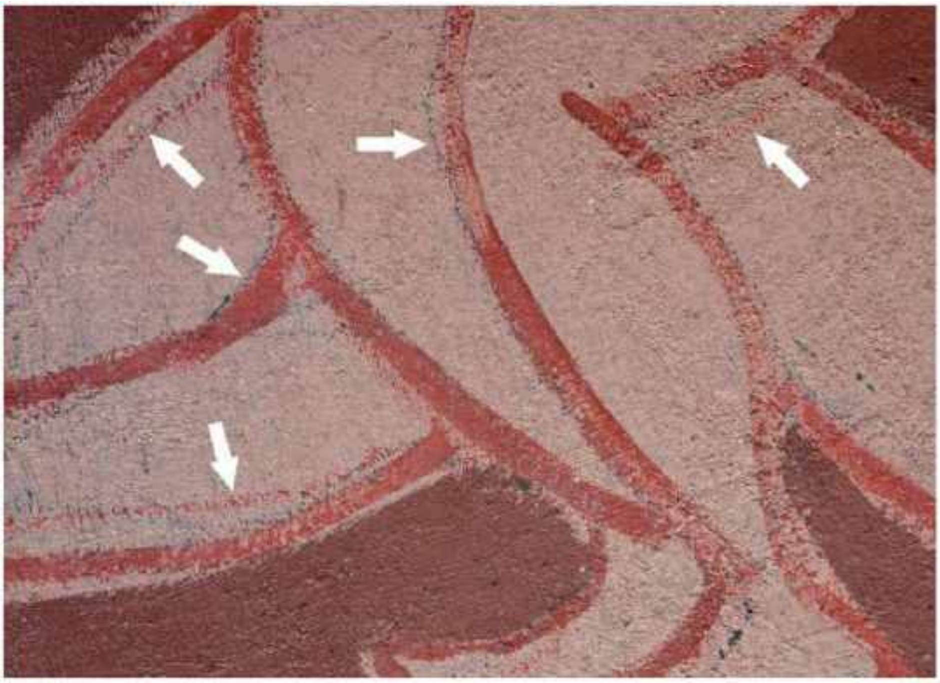

Figure 16. Detail of *Two nudes* (1996) indicating the preparatory drawing executed with red and blue crayon lines over the pink underpaint.

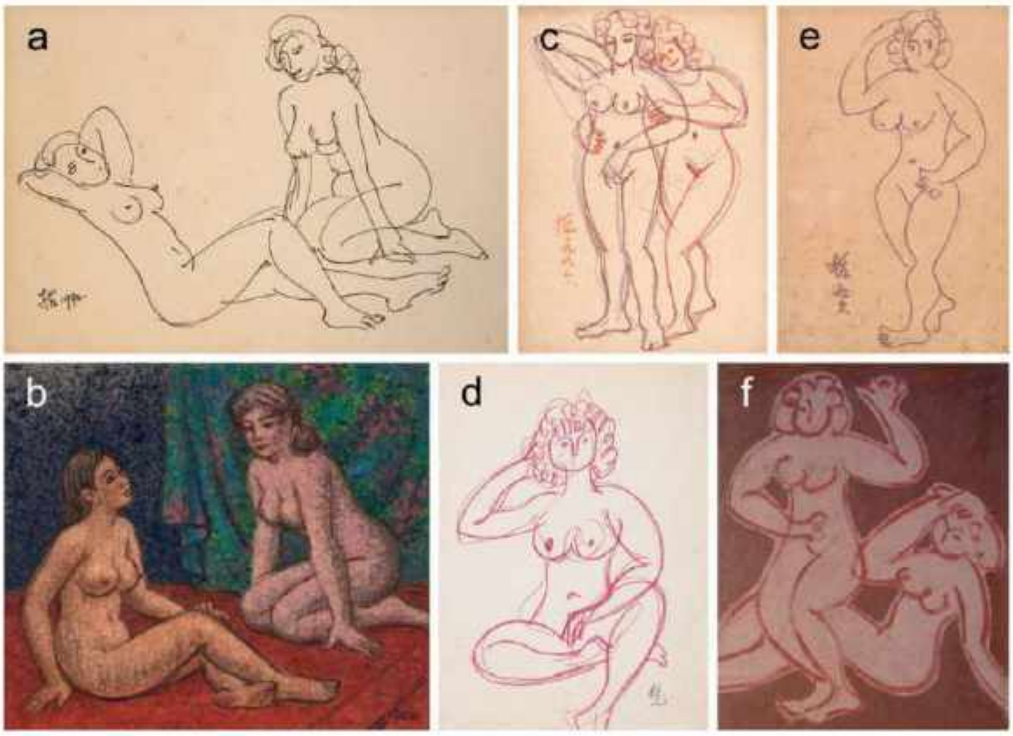

Figure 17. (**a**) Liu Kang, *Nude*, 1992, pen on paper, 26.5 × 38.5 cm. Liu Kang family collection. Image courtesy of Liu family. (**b**) Liu Kang, *Nude*, 1995, oil on canvas, 66 × 76 cm. (**c**) Liu Kang, *Nude*, 1996, crayon on paper, 37 × 27 cm. (**d**) Liu Kang, *Nude*, undated, crayon on paper, 24.5 × 17.5 cm. (**e**) Liu Kang, *Nude*, 1996, pen on paper, 34 × 23.5 cm. (**f**) Liu Kang, *Two nudes*, 1996, oil on board, 43 × 36 cm. Images (**c**–**e**) are gifts of the artist's family. Collection of National Gallery Singapore.

In three crayon sketches from 1996 (Figure 17c–e), the artist explored the theme of nudes in a unique expression characterised by distorted forms, radical reduction of detail and reliance on intricate and fluid lines, which subsequently were adopted for the preparatory underdrawing of *Two nudes* (1996) (Figures 16 and 17f). The style of the sketches suggests that the artist strove to depict the figures in a way that evokes Matisse's drawing series of models from 1941 [64].

A series of four sketches executed with crayon and pencil, exploring reclining models in playful poses, reveals the artist's attempt to establish the general composition of the scene and determine the best poses of figures for the painting *Beauties at rest II* (1998) (Figure 18a–e). A date, 1982, on one of the sketches (Figure 18a) suggests that the initial conceptualisation work was carried out 16 years before the painting was created. Moreover, the archival date-stamped photograph from 1993 shows an unknown but seemingly similar painted version of two female nudes (Figure 18f), allowing us to infer that the artist was very satisfied with the achieved composition, which resulted in different versions of the painted scene.

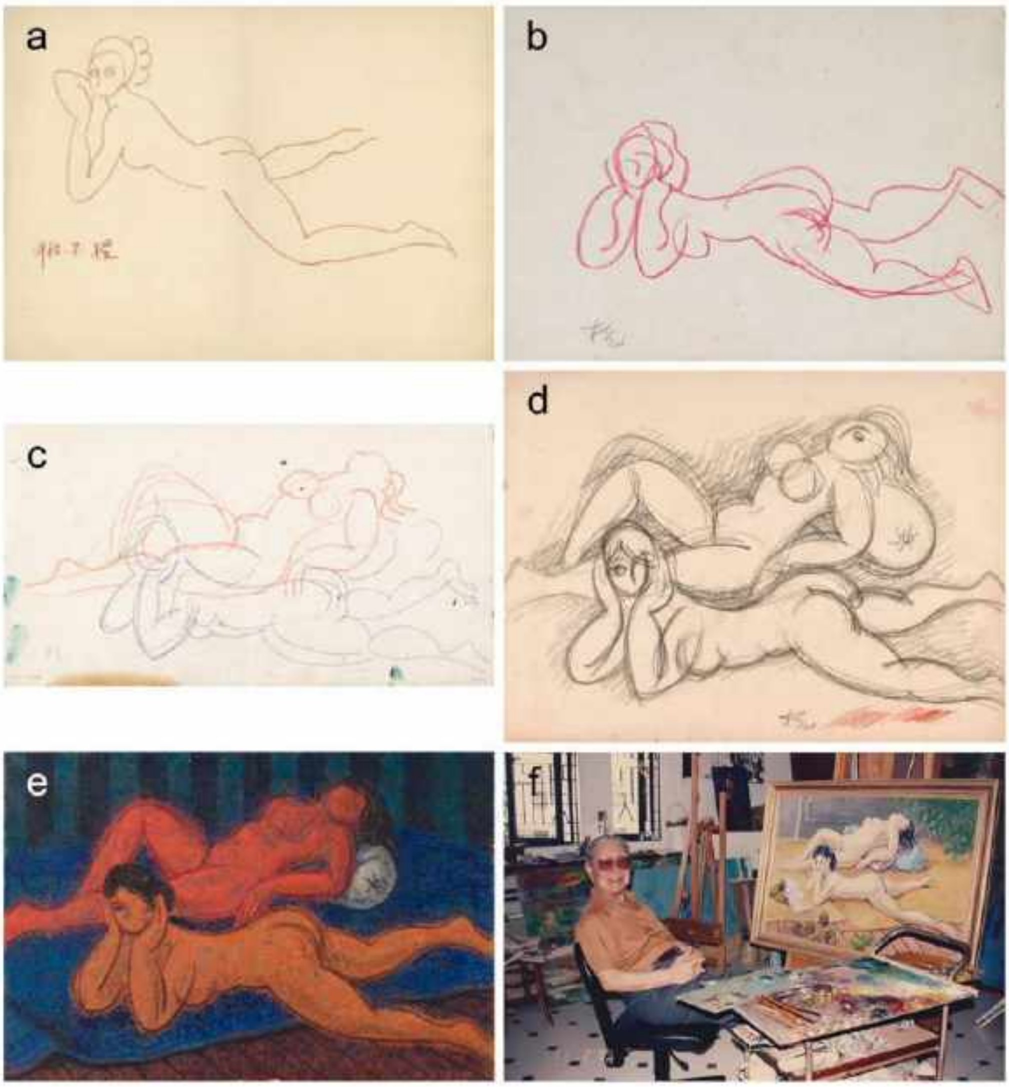

Figure 18. (**a**) Liu Kang, *Nude*, 1982, crayon on paper, 37 × 27.5 cm. Liu Kang family collection. Image courtesy of Liu family. (**b**) Liu Kang, *Nude*, undated, crayon on paper, 15.1 × 21 cm. (**c**) Liu Kang, *Beauties at rest (sketch study)*, undated, crayon on paper, 19 × 34.5 cm. (**d**) Liu Kang, *Beauties at rest III (sketch study)*, undated, crayon on paper, 27 × 36.7 cm. Images (**b**–**d**) are gifts of the artist's family. Collection of National Gallery Singapore. (**e**) Liu Kang, *Beauties at rest II*, 1998, oil on canvas, 85 × 127 cm. (**f**) The 1993 archival photograph of the artist at his earlier version of the nude painting. Liu Kang family collection. Image courtesy of Liu family.

The painting *In conversation* (1999) was inspired by an undated black and red crayon sketch of two female nudes depicted in relaxed sitting positions (Figure 19). A comparison of that initial idea recorded on the paper with the final painting reveals a minor alteration of the distance between the figures and some changes in their gestures. A sense of the depth of the painted composition was enhanced by enlarging the model on the left.

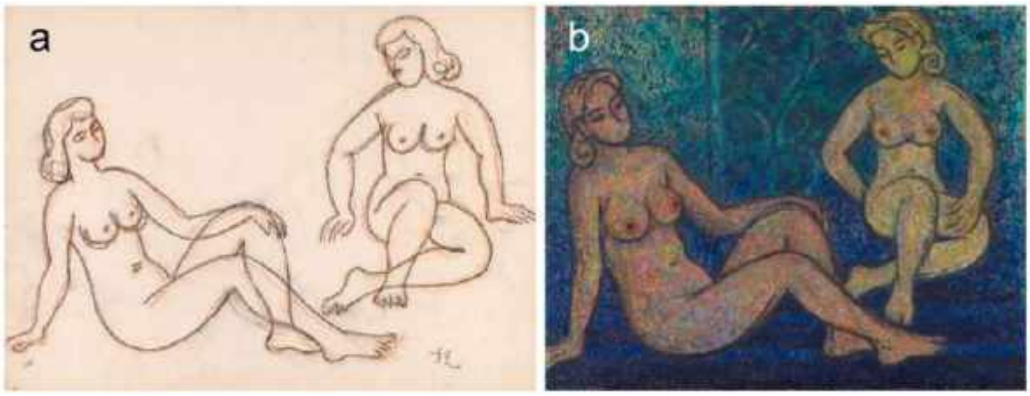

Figure 19. (**a**) Liu Kang, *Nudes*, undated, crayon on paper, 27 × 37 cm. Gift of the artist's family. Collection of National Gallery Singapore. (**b**) *In conversation*, 1999, oil on canvas, 61 × 76 cm.

3.3. Execution of the Paintings

The model in *Nude* (1927) was depicted in a classical way, without any exaggeration of forms or colours. The artist attempted to capture the charm and dimensionality of her body by using suggestive light effects and avoiding strong outlines. Based on the archival photograph taken on the day when the artwork was created, during a live nude painting class at Xinhua Arts Academy in Shanghai, Liu Kang used small and medium-sized brushes that required complex manipulation of the paint, resulting in the creation of the substantial texture (Figure 20a–d). This visible aspect of the painting correlates with the OM of the paint's cross-section (sample 7), exposing a wet-on-wet execution (Figure 7).

A thick and vigorous brushwork of *Nude* (1934) reflects Modernists' influences as it was created after Liu Kang's return from Paris (Figures 2b and 20e). The paint layer was applied with bigger brushes, showing the quality and confidence of the paint strokes that render light effects on the model's body.

That modernist trend can be observed in *Nude* (1940), which is another bold step forward in the evolution of the painterly depiction of the subject (Figure 2c). The composition is characterised by reduced light effects negating the illusion of depth. Hence, the artist rendered the setting with strong colour block division to differentiate the planes of the composition. The incorporation of broad and dark contours to enhance the forms seems justified. However, judging from Liu Kang's strong connection to Chinese tradition, the bold contours can represent inspiration with Chinese ink painting.

Liu Kang's return to the subject of nudity in the 1990s reflects an accomplished artist who enjoyed new painting approaches and tried to make up for lost time. In *Nude* (1992), he departed from the conventional depiction of a model in a realistic setting and adopted an expressionist style, by reducing unnecessary detail to allow the viewer an uninterrupted contemplation of the female's beauty (Figure 2e). Such an idealised approach can be elucidated from his 1989 interview: "The human body is the most beautiful object in nature . . . its form, shape and texture of the skin. It is intricate yet complete and is very difficult to represent" [65]. An apple held by the model creates a strong visual and symbolic accent. The circle or sphere symbolises the perfect form in the art; therefore, the artist might have incorporated the apple to underscore his idea of beauty.

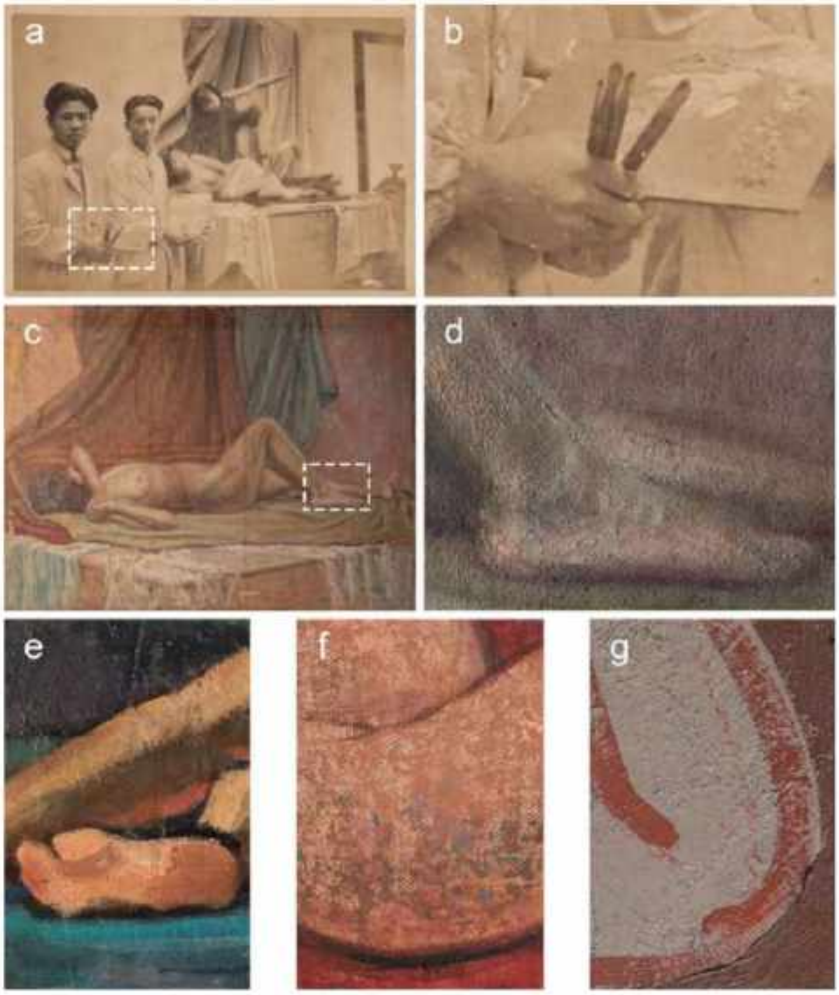

Figure 20. (**a**) The 1927 archival photograph of the artist during a live nude painting class at Xinhua Arts Academy in Shanghai. Liu Kang family collection. Image courtesy of Liu family. (**b**) Detail of the photograph showing the small and medium-sized brushes the artist used probably for the painting of *Nude* (1927) (**c**). (**d**) Corresponding detail of *Nude* (1927), showing the texture of the paint layer. Details of *Nude* (1934) (**e**), *Nude* (1995) (**f**) and *Two Nudes* (1996) (**g**), showing the artist's painting technique for depiction of the models' bodies.

The paint layer in *Nude* (1992) is characterised by broad and decisive brushstrokes that convey a sense of the rapid execution of the composition. However, by the undefined occupation of space by the model and incorporation of fluid contour lines, the style of the painting reflects some influences of Chinese literati painting [66,67], which Liu Kang highly respected as a part of his cultural inheritance [68].

Nude (1995) strikes with a different approach not seen in earlier paintings discussed here (Figure 2d). Instead of one model, the artist depicted two young females sitting and facing each other. The execution of the entire scene was achieved by dragging a thick paint across the textured ground with a stiff brush, thus creating an effect of randomly broken paint flow. This technique is clearly evident in the execution of figures where the skin colour results from layered dashes of tinted paint juxtaposed with the exposed ground layer, assisting in the effect of optical vibration, resembling a pointillist style (Figure 20f). Thus, the artist decisively moved away from the previously employed paint modelling. Bold, sensuous and effortlessly executed strokes of brown paint enhance the shapes of the figures, expressing the artist's notion of beauty. Overall, a new painting approach indicates the artist's willingness to experiment despite his age.

His interest in the form and shape of the female body was translated into the stylised *Two nudes* (1996) (Figure 3a). The colouristic scheme was drastically reduced to three tints of red. The artist employed a palette knife for the flat application of the pink skin colour of the models (Figure 20g). The figures are defined by red fluid brush lines which, together with the intentionally exposed crayon underdrawing contours (Figure 16) and dark background, rapidly executed with brushes, play a significant role in the final aesthetics of the painting.

In conceiving *Beauties at rest II* (1998), Liu Kang followed the original concept reflected in the sketch and depicted the models with limited facial expression (Figure 18a–e). However, most importantly, the artist focused on creating an idealised and eroticised image of the female body by reducing the figures to universal shapes. The realistic skin tones known from the 1993 version of reclining models (Figure 18f) gave way to an expressionistic use of orange and red, which contrasted with the intense green and blue of the setting, revealing a radical interpretation of this composition. Such an approach could have been a result of Liu Kang's deteriorating eyesight. In a 1989 interview, he gave a brief account of his condition after an apparently unsuccessful cornea surgery in 1986: "Of course, there is a difference. The colours are different. I used too much blue and green and my children would point it out to me. I can't paint for periods now. Before, I could paint through the whole day. Now, I get tired. It is a problem" [69]. That unusual painting convention could also have reflected Liu Kang's temperament and susceptibility to varying moods, which dominated his artistic expression [17]. Hence, it is conceivable that this factor could have caused Liu Kang to reject the 1993 version of the composition and reuse it for *Beauties at rest II* (1998). Detailed photography of the latter pointed out that the exposed colour scheme corresponds to the 1993 version of the scene (Figure 21).

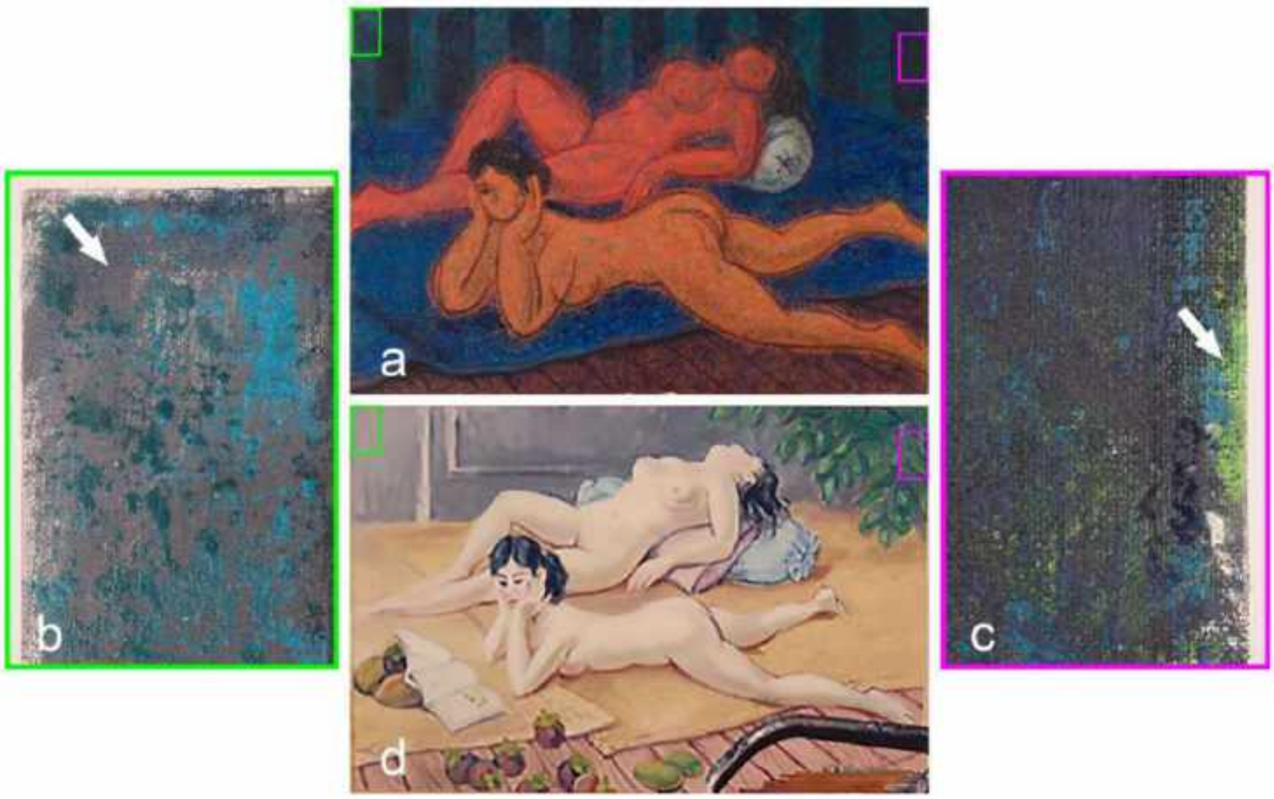

Figure 21. (**a**) *Beauties at rest II* (1998), showing the areas of the exposed colour scheme of the 1993 hidden painted composition (green and pink rectangles). (**b**,**c**) Corresponding details of *Beauties at rest II* (1998) indicating paint of the earlier composition: grey paint (green rectangle) and green paint of (pink rectangle). (**d**) Nude painting from the 1993 archival photograph cropped and transformed with the perspective and distortion control tools of Adobe Photoshop CC. The selected areas show the same colours as found in *Beauties at rest II* (1998) (**b**,**c**).

Subsequent transmitted NIR imaging carried out with the camera facing the front of the painting followed by the XRR, unveiled paint features resembling the leaves of the plant seen in the top-right corner of the 1993 version of the composition (Figure 22a–d). Moreover, the XRR of the bottom-right corner of *Beauties at rest II* (1998) depicted the model in the foreground with an additional pair of legs that could relate to a compositional change made by the artist during the painting process or a hidden nude painting seen in the 1993 photograph. The comparison of the XRR image of *Beauties at rest II* (1998) with VIS of the same painting and the corresponding area of the painting from the 1993 photograph permitted us to distinguish between the legs of the model from both compositions (Figure 22e–g). Thus, the model's right leg from the 1993 photograph depicted with a sense of perspective as much shorter than the left one is clearly seen on the XRR image (Figure 22f).

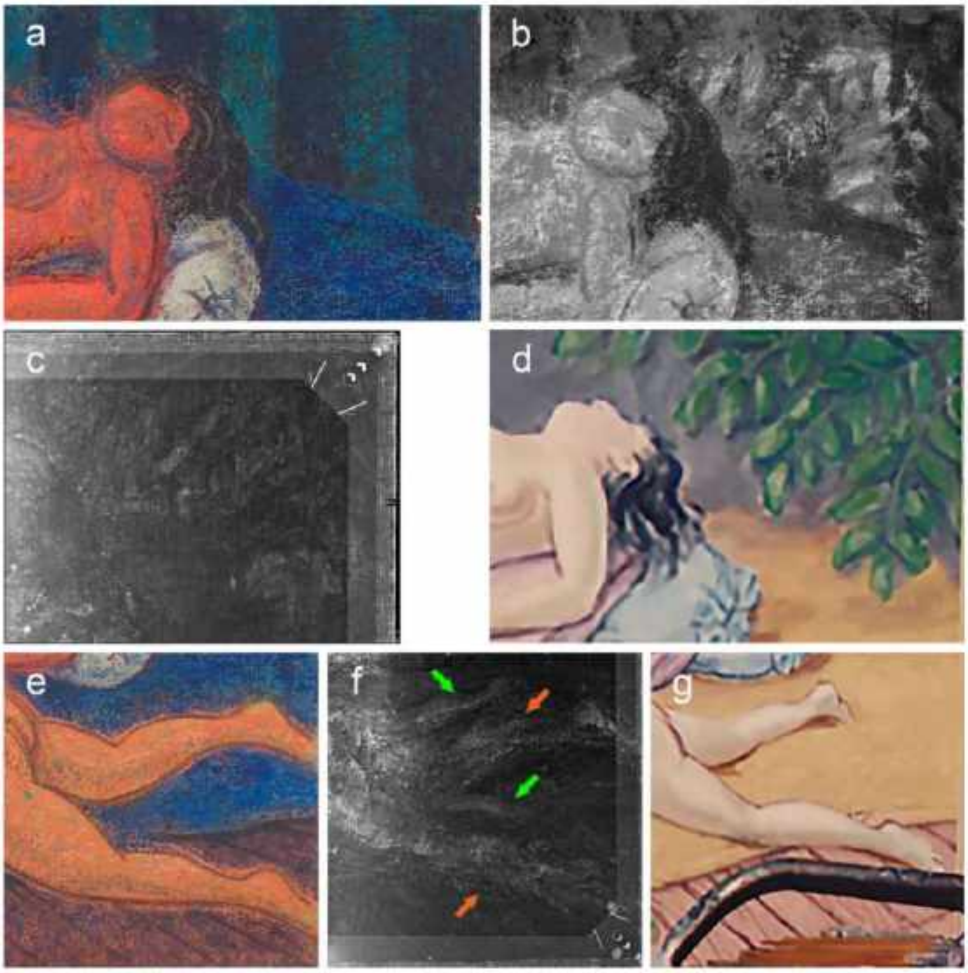

Figure 22. Detail of *Beauties at rest II* (1998) photographed in VIS (**a**) and corresponding transmitted NIR (**b**) and XRR (**c**) images of the same area. The NIR and XRR images reveal the features resembling the leaves of the plant seen in the same area of nude painting from the 1993 archival photograph (**d**). Detail of *Beauties at rest II* (1998) photographed in VIS (**e**) and corresponding XRR image of the same area (**f**). The XRR image reveals the model's legs from *Beauties at rest II* (1998), indicated with the orange arrows, and an additional pair of legs, indicated with green arrows, relating to the figure from the 1993 archival photograph (**g**).

The results of the imaging techniques are additionally supported by the undated archival photograph of the nude painting (Figure 23a), which appears to be an early phase of the overpainting process of the artwork from the 1993. The photograph reveals two features not completely covered with the current painting: vertical divisions of the wall in the top-left corner and obliterated leaves of the plant in the top-right corner. The red colour of the pillow was covered with white paint in the final version from the 1998; however, its traces are still visible through the paint losses (Figure 23b,c).

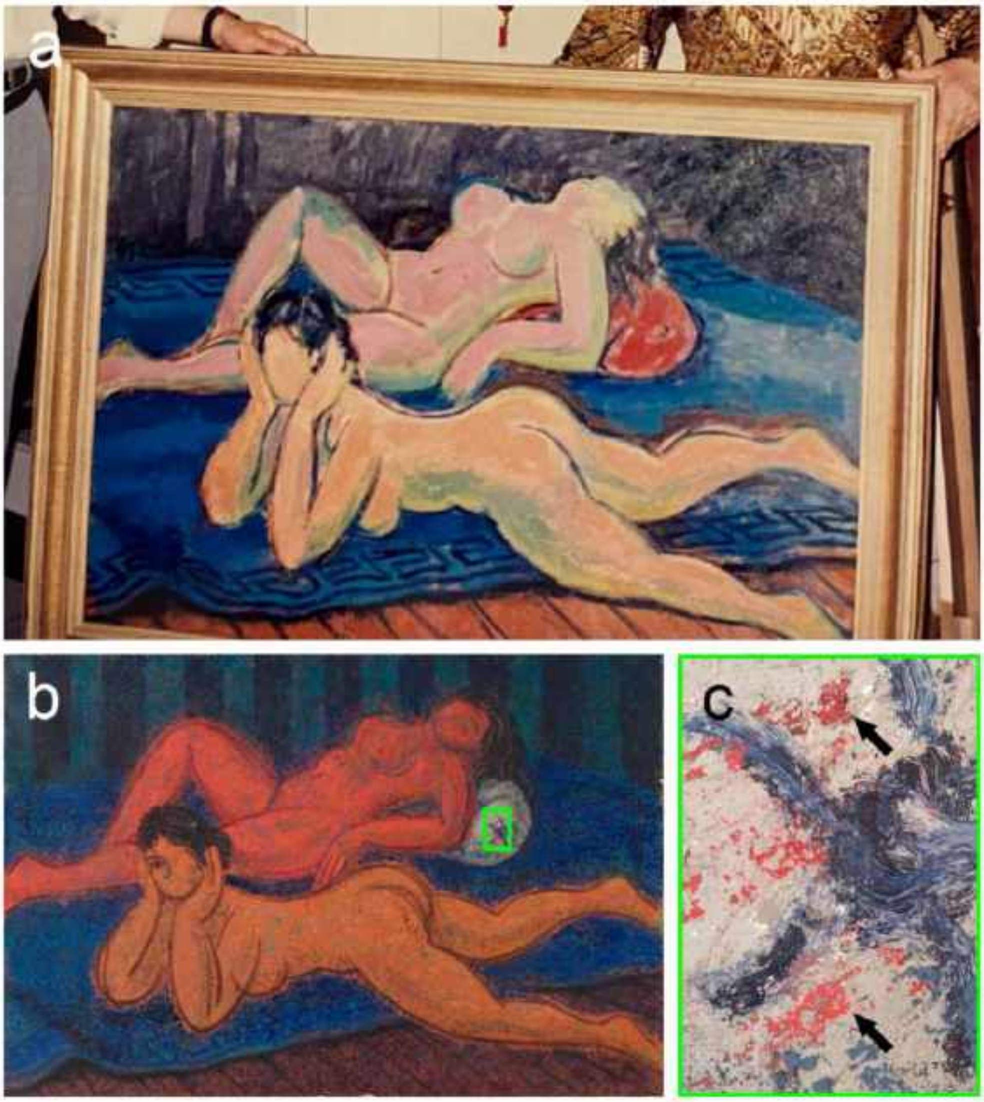

Figure 23. (**a**) Nude painting from the undated archival photograph. Liu Kang Collection, National Library Singapore. (**b**) *Beauties at rest II* (1998), showing the area of the white pillow (green rectangle). (**c**) Corresponding detail of *Beauties at rest II* (1998) showing traces of red paint scheme beneath white finish indicated with the black arrows.

Hence, the obtained findings lead us to believe that the underlying painting could be the one documented in the 1993 casual photograph of the artist in his studio. Although the previous research demonstrated that possible financial constraints [2,18,70] and scarcity of the painting materials [71] motivated Liu Kang's earlier practice of reusing unwanted paintings, these reasons are not convincing in unravelling the case discussed here. Judging from the fact that Liu Kang was already a successful and renowned artist in the 1990s, he did not have to be concerned about access to painting materials and to resort to reusing earlier compositions. Therefore, it is conceivable that rejecting the completed and framed painting from 1993 and reusing it for *Beauties at rest II* (1998), which represents a different style, was a radical move more likely governed by a strong artistic self-criticism or emotions of a great magnitude. At first glance, the paint application technique in *Beauties at rest II* (1998) resembles the approach known from *Nude* (1995). However, contrary to *Nude* (1995), traces of a palette knife application are visible underneath chaotic brushstrokes resulting in the accumulation of thick impastos (Figure 24a).

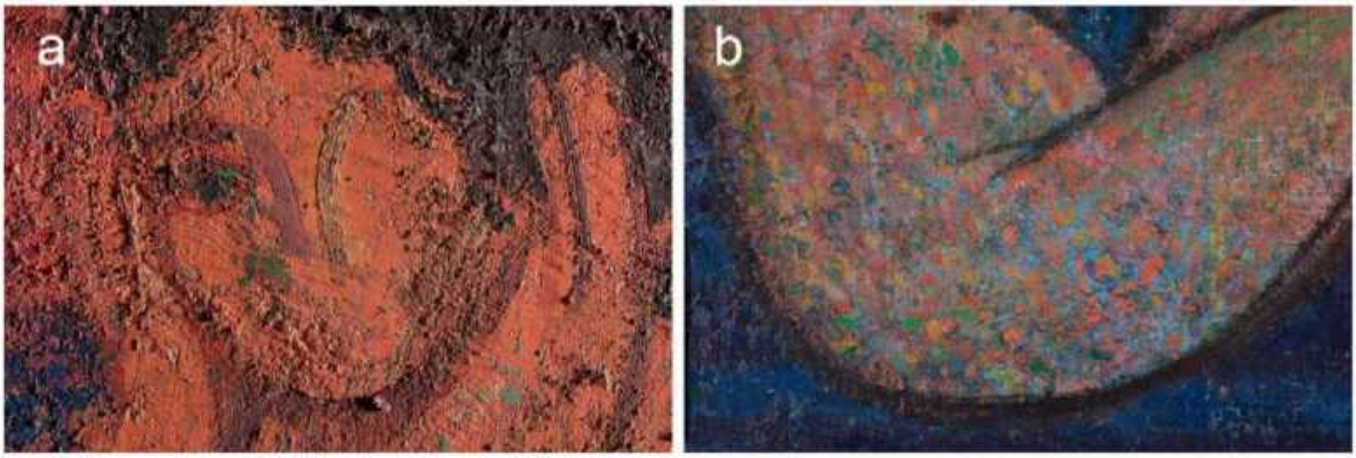

Figure 24. (**a**) Detail of *Beauties at rest II* (1998), indicating traces of a palette knife application underneath thick impastos produced with brush. (**b**) Detail of *In conversation* (1999), showing a pointillist brush application of complementary colours.

In conversation (1999), as one of the latest compositions by Liu Kang in the NGS collection, represents the apogee of his lifelong exploration of the subject of nudes (Figure 3c). It also demonstrates the artist's continuous ability to experiment with new approaches to painting. Although this artwork, alongside *Nude* (1995) and *Beauties at rest II* (1998), reflects a specific painting convention, its execution and optical effects differ from two other examples. Instead of manipulating tinted paint as in *Nude* (1995), the artist made a step forward and incorporated a range of yellow, green, blue and red hues to depict skin colours. His best paint application and interplay of complementary colours can be seen in the mid-tones of the model on the left (Figure 24b). The artist used different size brushes for a pointillist style and the contrasting application of complementary pairs in a near impressionistic fashion.

3.4. Brands of the Painting Materials Used by Liu Kang

In providing technical information about the identified painting materials, the question about the artists' colourmen brand(s) used by Liu Kang is raised. As his final nudes were created in the 1990s, one would expect the existence of visual or written information about Liu Kang's painting materials. Unfortunately, none of Liu Kang's paint tubes were preserved, and the authors did not find any written sources pointing to the brands of the materials he used during his artistic career. However, the archival search allowed the identification of several paint tubes on the photographs of the artist for his 1997 and 1998 exhibition catalogues (Figure 25a,b) [17,72]. The comparison of detailed images of these paint tubes with the authors' reference materials (Figure 25d, e, g) enabled the identification of Royal Talens oil paints (Rembrandt series). Another photograph, which, according to the artist's family, was taken in the 1990s, shows Liu Kang behind a well-stocked painting trolley with the paint tube box sets, which, when compared with the authors' references, appear to be from Royal Talens and Rowney (Georgian series) (Figure 25c,f,h,i). Hence, it could be said that the artist used both brands independently or mixed them during his painting in the 1990s. Moreover, these photographs lead us to believe that the Liu Kang was convinced about using these brands and probably preferred bulk purchase to prevent interruption to the artistic process. This finding is a major step towards expanding the knowledge of Liu Kang's painting materials, as little is known about his art material supplies from earlier artistic periods.

Figure 25. Archival photographs of Liu Kang for his 1997 (**a**) and 1998 exhibition catalogues (**b**) and undated photograph, probably from the 1990s (**c**), showing the artist's paint tubes (blue and red rectangles) and paint tube box sets (green rectangle). Liu Kang family collection. Image courtesy of Liu family. Corresponding details of the photographs showing the: (**d**,**e**) paint tubes from Royal Talens (Rembrandt series); (**f**) the paint tube box sets, from Royal Talens and Rowney (Georgian series). Authors reference paint materials from the 1990s of the: (**g**) Royal Talens (Rembrandt series) oil paint tubes; (**h**) Royal Talens (Rembrandt series) paint tube box set; (**i**) Rowney (Georgian series) paint tube box set.

4. Conclusions

The interdisciplinary study of Liu Kang's female nude paintings is a first attempt to comprehensively analyse and discuss the artist's approach to the theme. The particular aspects of that investigation include the role of the drawing in the final painted composition as well as the evolution of the artist's pigment choices and painting technique for the execution of female bodies.

In terms of the conceptualisation work, Liu Kang relied on drawing and sketching as the primary stage for the development of ideas. However, his further stage of the artistic creation—preparatory underdrawing—was evidenced only in *Two nudes* (1996). Nevertheless, it is conceivable that, once satisfied with the concept, the artist translated his drawing and sketching studies through simple brushstrokes to establish the general composition.

All investigated paint samples contain drying oil as a binder. The characterisation of the pigment mixtures from nude models revealed that the artist consistently employed different tints of yellow iron-rich earth pigments as a principal paint for bright skin tones. Some modifications of that base paint were achieved by replacing yellow iron-containing earths with a mixture of umber, organic red and bone black in *Nude* (1992) or admixing yellow and red iron-containing earth pigments with cobalt blue in *Nude* (1995). In *Two nudes* (1996), the artist moved away from realistic skin tones and depicted figures using a pink colour, achieved with red iron-based earth pigment. This approach continues in *Beauties at rest II* (1998), where alongside the yellow and red iron-based earths, the artist used cadmium yellow, cadmium orange and/or cadmium red or their variants, and organic red on Al-containing substrate. *In conversation* (1999) confirms the experimental nature of the artist by means of the successful use of contrasting and complementary colours. Thus, as well as the yellow and red iron-rich earth pigments and the organic red on Al-based substrate, the artist engaged Cr-containing yellow pigment(s), ultramarine and Prussian blue.

Although the mid-tones were not employed frequently, their tentative VIS and IRFC assessment in *Nude* (1927) and *Nude* (1934) suggested that the artist could have considered emerald green, Cr- or Co-containing green, ultramarine or cobalt blue, organic red and yellow iron-containing earth pigment. In *Nude* (1992), the mid-tone was achieved by mixing synthetic alizarin lake, red iron-containing earth pigment with cadmium yellow or its variant and bone black, while in *Nude* (1995), ultramarine, red iron-containing earth, synthetic alizarin lake on Al-containing substrate and bone black played an important role in obtaining a violet hue of cool mid-tone.

Regarding the dark outlines of the shapes, the analyses of three samples extracted from the paintings created in 1940, 1995 and 1996 revealed a consistent use of yellow or red iron-based earth pigment and bone black. The prevailing use of naphthol red AS-D in combination with red iron oxide and probably an organic red on Sn-containing substrate is suggested in the dark contours in *Two nudes* (1996).

As for the models' black hair, bone black is the prevailing pigment, and it frequently appears with ultramarine. This pair was admixed with a phthalocyanine blue in *Beauties at rest II* (1998). An organic red on Al-containing substrate was added to achieve a warm and deep hue in *Nude* (1927), while the admixture of umber appears in *Nude* (1992). The intensity of black was modified primarily with white paints; however, yellow iron-rich earth pigment and cadmium yellow or its variant were used in *Nude* (1940).

Although 62 paint samples were analysed, the areas of nude figures are not sufficiently represented in the research materials due to sampling limitations. Hence, the analyses of the paint samples from the drapery settings of the compositions supported a tentative assessment of the pigment mixtures used for achieving the skin colours of nude figures.

VIS and digital microscopy played a crucial role in studying the evolution of the painting technique for the execution of nude figures. The earliest *Nude* (1927) represents a realistic style and strong attention to detail, the latter achieved with small brushes. This approach was replaced with a subjective observation resembling Modernist influences, seen in *Nude* from 1934 and 1940. Both paintings demonstrate confident and rapid execution and a gradual reduction in detail and light effects. Liu Kang's return to the theme of nudes in the 1990s is accompanied by an eruption of new concepts and techniques. The repertoire of different sized brushes was extended by the use of palette knifes. The theme of nudity was employed as a platform for the unconventional artist's expression. In *Nude* (1992) and *Two nudes* (1996), he reduced the figures to lines and universal shapes using a limited palette of colours. In *Nude* (1995) and *Beauties at rest II* (1998), he underscored the role of colour and experimented with the optical vibration of different colour values by adopting an almost pointillist paint application technique. This unique technique evolved into an intuitive use of contrasting and complementary colours in *In conversation* (1999).

As well as the technical aspects, the study revealed an earlier painted version of two reclining nudes underneath *Beauties at rest II* (1998). The visual evidence supports the notion that the hidden composition could be the painting documented in the 1993 photograph taken in the artist's studio. This information contributes to our knowledge of Liu Kang's working practice by evidencing a strong sense of artistic self-criticism that governed his decision about rejecting and repainting a former artwork. Moreover, the photograph enabled us to see that the reused painting, which was framed, was completed and satisfactory.

With regard to painting materials, this study provides, for the first time, photographic evidence of Liu Kang using Royal Talens and Rowney (Georgian series) oil paint tubes in the 1990s. This important information may assist researchers and conservators in future monitoring of the deterioration processes of the paint layers from the 1990s. To conclude, the yield data can be used as a reference for any future investigation of Liu Kang's working process. Moreover, the investigation of the commercial oil paints used by Singapore and Western artists in the 1990s can also benefit from the characterisation of pigment mixtures in this study.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of the materials detected in the paint samples obtained from the examined paintings.

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Nude	1927	Green	4	**C**, **O**, **Pb**, Ba, Zn, As, Cr, Cu, Al, Ca, (S, Na, Si, Fe)	Lead white, lithopone and/or barium white and zinc white, emerald green, viridian, ultramarine	Lead white, lithopone and/or barium white and zinc white, emerald green, oil
			8	**O**, **C**, **Cr**, **Ba**, Pb, Ca, S, Zn, (Ti, Na, Si, Al, Cl)	Viridian, lithopone and/or barium white and zinc white, lead white, chalk, titanium white, ultramarine	Lead white, lithopone and/or barium white and zinc white, chalk, viridian, oil
		Yellow	7	**Pb**, **C**, **O**, Zn, Ba, Na, (As, Ti, Ca, Al, Cl)	Lead white, lithopone and/or barium white and zinc white, emerald green, titanium white, chalk	Lead white, lithopone and or/barium white and zinc white, oil
		Red	6	**C**, **O**, Al, Pb, Zn, P, S, Ba, (Ca, Si, Br, Cr, Mg, Ti, Cl)	Organic red on Al-containing substrate, lead white, lithopone and/or barium white and zinc white, bone black, chalk, Cr-containing green and/or yellow(s)	Lead white, lithopone and/or barium white and zinc white, oil
		Brown	2	**C**, **O**, **Pb**, Ba, Al, Zn, Cr, Ca, S, (As, Si, Ti, Fe, Cu, P)	Lead white, lithopone and/or barium white and zinc white, organic red, viridian, emerald green, titanium white, yellow iron-containing earth pigment, bone black	
		Black	10, upper layer	**O**, **C**, Ba, Al, Pb, S, Si, Cr, As, Ca, (Cu, Zn, Fe, P)	Lithopone and/or barium white and zinc white, lead white, organic red on Al-containing substrate, Cr-containing green(s) and/or yellow(s), emerald green, bone black, iron-containing earth pigment	Lithopone and/or barium white and zinc white, bone black and/or iron-containing earth pigment, oil
		Black	10, bottom layer	**O**, **C**, Fe, Ca, Si, Pb, Mn, Al, (Na, As, Mg, S, P, K, Cu)	Umber, bone black, lead white, ultramarine, emerald green	Bone black, iron-containing earth pigment, oil
		White	9	**Pb**, **O**, **C**, Zn, Ba, As, Na, (Cu)	Lead white, lithopone and/or barium white and zinc white, emerald green	Lead white, lithopone and/or barium white and zinc white, oil
Nude	1934	Blue	6	**C**, **O**, **Ba**, S, Zn, Cr, Ca, Na, Ti, (Si, Al, Pb, Sr)	Lithopone and/or barium white and zinc white, viridian, ultramarine, titanium white, lead white	Lithopone and/or barium white and zinc white, chalk, ultramarine, viridian, oil
			7	**C**, **O**, **Ba**, Cr, S, Ca, Zn, Na, Si, Al, Ti, (Pb, Sr, Cl, K)	Lithopone and/or barium white and zinc white, viridian, ultramarine, titanium white, lead white	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
			8	**O**, **C**, **Ba**, S, Cr, Zn, Ca, Na, Si, Al, (Ti, Pb, K, Cl, Fe)	Lithopone and/or barium white and zinc white, viridian, ultramarine, titanium white, lead white	
		Green	4	**C**, **O**, Zn, Fe, Si, Na, Ba, Ca, Al, S, (Mg, Ti, Cl, Pb, Sr)	Lithopone, and/or barium white and zinc white, yellow iron-containing earth pigment, chalk, ultramarine, titanium white	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, oil, zinc soap
		Yellow	12	**C**, **Ba**, **O**, S, Zn, Ca, Ti, Na, (Sr, Fe, Si, Pb, Al, Cl)	Lithopone and/or barium white and zinc white, chalk, titanium white, yellow iron-containing earth pigment	
		Brown	11	**C**, **O**, **Ba**, S, Zn, Ca, Fe, Si, Ti, (Na, Al, Sr, Pb)	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, titanium white,	Lithopone and/or barium white and zinc white, chalk, yellow ochre, oil
		Black	10	**C**, **O**, Ba, Ca, S, (Fe, Zn, Si, Al, Ti, Na, Mg, Pb)	Lithopone and/or barium white and zinc white, carbon black, ultramarine, titanium white	
		White	9	**C**, **O**, **Ba**, S, Zn, Ca, Ti, Na, (Si, Sr, Pb, Fe, Cr, Al, P)	Lithopone and/or barium white and zinc white, chalk, titanium white, yellow iron oxide, viridian, ultramarine	
Nude	1940	Blue	14	**O**, **C**, **Zn**, **Na**, Al, Si, S, (Sr, Mg, K, Ca, Pb, Fe, P, Cl)	Zinc white, ultramarine, bone black, Prussian blue, lead white	
		Green	2	**O**, **C**, Zn, Al, Na, Ca, Cl, Ti, S, Si, Pb, Fe, (Ba, Mg, Sr, K, P, Cr)	Lithopone and/or barium white and zinc white, ultramarine, titanium white, lead white, yellow iron-containing earth pigment, bone black, viridian	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, oil
			3	**C**, **O**, Zn, Ca, Fe, Ti, Mg, Al, Na, Cl, (Si, S)	Zinc white, chalk, yellow iron-containing earth pigment, ultramarine	Lithopone and/or barium white and zinc white, chalk, yellow iron-containing earth pigment, oil
		Yellow	4	**C**, **O**, Fe Ca, Zn, Mg, Ti, (Na, Al, Si, Pb, S)	Yellow iron-containing earth pigment, chalk, zinc white, titanium white, lead white	
			6	**C**, **O**, **Ba**, **Cd**, S, Al, Ti, Zn, (Na, Si, Pb, Ca, Cl, Sr)	Lithopone and/or barium white and zinc white, cadmium yellow or its variant, titanium white, lead white, chalk	Lithopone and/or barium white and zinc white, oil

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
			7	**C**, **O**, Ca, Fe, Zn, Mg, Ti, Al, Na, (Si, S)	Chalk, yellow iron-containing earth pigment, zinc white, titanium white	
		Orange	5	**O**, **C**, **Ba**, Cd, S, Al, Ti, (Zn, Na, Sr, Se, Cl, Si)	Lithopone and/or barium white and zinc white, cadmium orange or its variant, organic red on Al-containing substrate	Lithopone and/or barium white and zinc white, oil
		Red	15	**C**, **Zn**, **O**, Na, Al, Fe, Ti, (Si, Ca, S, Mg)	Zinc white, ultramarine, yellow iron-containing earth pigment, organic red on Al-containing substrate, titanium white	Ultramarine, yellow ochre, oil, zinc soap
		Brown	10	**C**, **O**, **Fe**, **Ba**, S, Zn, Al, Ca, (Ti, Si, P, Pb, Mn, Cr, Cl)	Umber, lithopone and/or barium white and zinc white, bone black, titanium white, lead white, Cr-containing yellow(s)	
			11	**C**, **O**, **Ba**, **Zn**, S, Ca, Na, Ti, (Fe, Sr, Pb, Al, Si, Cl)	Lithopone and/or barium white and zinc white, chalk, titanium white, yellow iron-containing earth pigment, lead white	
			12	**C**, **O**, **Ba**, S, Zn, Fe, Ca, Ti, Na, (Al, Sr, Si)	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, chalk, titanium white	Lithopone and/or barium white and zinc white, yellow iron-containing earth pigment. oil
		Black	9	**C**, **O**, **Ca**, P, Ba, Fe, (S, Zn, Si, Al, Na, Cd, Mg, Ti, Sr)	Bone black, lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, ultramarine, cadmium yellow or its variant, titanium white	
		White	8	**C**, **O**, **Ba**, S, Zn, Ca, Ti, Na, (Sr, Pb, Al, Si, Cl)	Lithopone and/or barium white and zinc white, chalk, titanium white, lead white	
Nude, 2003-03259	1992	Yellow	4	**Cd**, **C**, **O**, **S**, Ti, Zn, Ba, Si, (Ca, Na, Fe, Al, Se, P, Mg)	Cadmium yellow and/or orange or their variants, titanium white, lithopone and/or barium white and zinc white, chalk, yellow iron-containing earth pigment, bone black	Lithopone and/or barium white and zinc white, synthetic alizarin lake, oil
			5	**C**, **O**, Ti, Zn, Fe, Ca, Al, Mg, Na, (S, Si, Pb, Sr, Mn, P)	Titanium white, zinc white, chalk, umber, organic red on Al-containing substrate, lead white, bone black	Iron-containing earth, oil, zinc soap

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Red	2	**C**, **O**, **Cd**, S, Ca, Ba, Zn, Ti, Al, (Fe, Na, P, Mg, Pb, Cl)	Cadmium yellow or its variant, lithopone and/or barium white and zinc white, titanium white, chalk, red iron-rich earth pigment, bone black, lead white, organic red on Al-containing substrate	Lithopone and/or barium white and zinc white, synthetic alizarin lake, bone black, red iron-rich earth pigment, chalk, oil, zinc soap
			6	**C**, **O**, Ti, Zn, Fe, Ca, Al, Na, Mg, (Si, S, Pb, Ba, Cl, P, Cd, Sr)	Titanium white, lithopone and/or barium white and zinc white, chalk, organic red on Al-containing substrate, red iron-containing earth pigment, chalk, lead white, bone black, cadmium yellow or its variant	Synthetic alizarin lake, oil, zinc soap
		Brown	1	**C**, **O**, **Fe**, Ti, Ca, Zn, Si, Al, Na, (Mg, S, K, P, Sr, Pb, Cl)	Red iron-rich earth pigment, titanium white, chalk, zinc white, lead white, bone black	
			8	**C**, **O**, Ti, Ca, Fe, Zn, (Na, Al, Si, P, Mg, S)	Titanium white, chalk, red iron-rich earth pigment, zinc white, bone black	
		Black	7	**C**, **O**, Ca, Fe, Zn, Ti, Mg, Si, (S, Ba, Al, Na, Pb, Mn, Sr, P)	Bone black, umber, titanium white, lithopone, and/or barium white and zinc white	
Nude, 2003-03265	1995	Blue	4	**C**, **O**, Al, Co, Ca, Zn, Si, Ba, (S, Mg, Na, Ti)	Cobalt blue, chalk, lithopone and/or barium white and zinc white, titanium white	Chalk, lithopone and/or barium white and zinc white, cobalt blue, oil
		Violet	12	**C**, **Zn**, **O**, Na, (Al, Ca, Ba, Fe, Ti, S, Mg, P, Si)	Lithopone and/or barium white and zinc white, chalk, organic red on Al-containing substrate, red iron-containing earth pigment, ultramarine, titanium white, bone black	Lithopone and/or barium white and zinc white, synthetic alizarin lake, oil
		Green	3	**C**, **O**, Ca, Zn, Al, Ti, Cr, Na, (Ba, S, Fe, Cl, Cd, Si, Mg, P)	Chalk, lithopone and/or barium white and zinc white, titanium white, viridian, yellow iron-containing earth pigment, cadmium yellow or its variant, bone black	Chalk, lithopone and/or barium white and zinc white, yellow iron-containing earth pigment, viridian, oil, zinc soap
		Yellow	6	**C**, **O**, Ti, Zn, Fe, Ca, Al, Na, Mg, Si, (S, Sr, K)	Titanium white, zinc white, yellow and red iron-containing earth pigments, chalk	
		Pink	7	**C**, **O**, Ti, Zn, Ca, Al, Mg, (Na, Co, Si, Fe, S)	Titanium white, zinc white, chalk, cobalt blue, yellow and red iron oxide	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Red	8	**C**, **Zn**, **O**, Na, Fe, (Al, Ba, Ca, S, Pb, P, Si, Cl, Cr, Ti)	Lithopone and/or barium white and zinc white, red iron-containing earth, organic red, lead white, bone black, Cr-containing yellow(s), titanium white	
			9, upper cluster	**C**, **O**, **Zn**, Fe, Na, Ba, Ca, Al, (S, Cl, P, Ti, Si, Pb, Mg, Cd)	Lithopone and/or barium white and zinc white, red iron-containing earth, chalk, organic red on Al-containing substrate, bone black, titanium white, lead white, cadmium yellow or its variant	Lithopone and/or barium white and zinc white, iron oxide, synthetic alizarin lake, oil
			9, bottom cluster	**C**, **O**, Fe, Cl, Al, Ti, Zn, Ca, Si, (S, Sn, Mg, Ba, Na, Sr, Pb, K)	Red iron-containing earth, organic red on Sn-containing substrate, titanium white, lithopone and/or barium white and zinc white, chalk, lead white	Naphthol red AS-D, lithopone and/or barium white and zinc white, oil
		Brown	10	**C**, **O**, Fe, Zn, Ca, Na, (P, Ti, Al, Si, S, Mg, Cl)	Yellow iron-containing earth pigment, zinc white, bone black, titanium white	
		Black	11	**C**, **O**, Zn, Fe, Ca, Na, (Si, Al, P, Ti, S, Mg, Ba, Sr)	Lithopone and/or barium white and zinc white, chalk, yellow iron-containing earth pigment, ultramarine, bone black, titanium white	
Two nudes	1996	Red	1	**C**, **O**, *Ti*, Zn, Ca, Fe, Al, Mg, (Na, Si, S, Pb, K)	Titanium white, zinc white, chalk, red iron-containing earth pigment, lead white	Chalk, red iron-containing earth pigment, oil
			2	**C**, **O**, **Cl**, Sn, Ca, Mg, Si, (S, Fe, Ti, Zn, Al, Ba, P, Pb)	Organic red on Sn-containing substrate, lithopone and/or barium white and zinc white, chalk, red iron-containing earth pigment, titanium white, bone black, lead white	Naphthol red AS-D, oil
		Brown	3	**C**, **O**, **Ti**, Fe, Cl, Zn, Sn, Ca, (Ba, Mg, Al, S, Si, Na, P, Pb)	Titanium white, red iron-containing earth pigment, organic red on Sn-containing substrate, lithopone and/or barium white and zinc white, lead white, bone black	Naphthol red AS-D, oil
Beauties at rest II, 2003-03470	1998	Blue	6	**C**, **O**, **Zn**, Si, Ti, Al, Na, (Ca, Ba, Mg, Cu, Cl, S, Fe, P)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, phthalocyanine blue, Prussian blue, bone black	Ultramarine, phthalocyanine blue, oil, zinc soap

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
			11	**C**, **O**, **Zn**, Ti, Ca, Na, Fe, Al, Mg, (Cl, S, Cd, Si)	Zinc white, titanium white, chalk, Prussian blue, ultramarine, cadmium yellow	Prussian blue
		Green	3	**C**, **O**, **Cr**, Ca, Ba, (Ti, Mg, S, Zn, Si, Cl, Al, Sr)	Viridian, chalk, lithopone and/or barium white and zinc white, titanium white	Lithopone and/or barium white and zinc white, chalk, viridian, oil
		Orange	9	**C**, **Zn**, **O**, Fe, Na, Ti, (Al, Cd, Ca, Mg, S, Si, Pb)	Zinc white, yellow iron-containing earth pigment, titanium white, cadmium yellow or its variant, chalk, lead white	
		Red	10	**C**, **O**, Zn, Cd, Ba, S, Al, Ti, (Na, Se, Ca, Cl, Mg, Fe, Si, P)	Lithopone and/or barium white and zinc white, cadmium orange and/or red lithopone, organic red on Al-containing substrate, titanium white, chalk, red iron-containing earth pigment, bone black	Cadmium orange and/or red lithopone, red iron-containing earth pigment, oil
		Brown	8	**C**, **O**, Zn, Al, Ca, Ti, S, Na, Si, (Fe, Mg, P, Ba, Cr, Cd)	Lithopone and/or barium white and zinc white, chalk, titanium white, organic red on Al-containing substrate, red iron-containing earth pigment oxide, bone black, Cr-containing yellow and/or green, cadmium yellow or its variant	Lithopone and/or barium white and zinc white, chalk, synthetic alizarin lake, oil
		Black	13	**C**, **O**, Zn, Ca, Si, Na, Al, P, (Cu, Sr, S, Mg, Fe, Ba, Cr, Cl)	Lithopone and/or barium white and zinc white, bone black, ultramarine, phthalocyanine blue	Ultramarine, phthalocyanine blue, chalk, oil
		White	7	**C**, **O**, Ti, Zn, Ba, Ca, Mg, Al, Fe, (Cr, Na, Si, S)	Titanium white, lithopone and/or barium white and zinc white, chalk, red iron-containing earth pigment, viridian, ultramarine	
In conversation, 2003-03305	1999	Blue	3	**C**, **O**, Ti, Si, Ca, Zn, Al, Ba, (Na, Cu, Cl, Fe, Cr, Mg, P, Pb, S)	Titanium white, ultramarine, chalk, lithopone and/or barium white and zinc white, phthalocyanine blue, Prussian blue, viridian, lead white, bone black	
			4	**C**, **O**, Si, Ca, Al, (Cu, Na, P, Zn, Ti, Ba, S, Cl)	Ultramarine, chalk, phthalocyanine blue, titanium white, lithopone and/or barium white and zinc white	Ultramarine, phthalocyanine blue, oil
			11	**C**, **O**, **Ti**, Zn, Ca, Na, (Al, Fe, Mg, Si, S, Pb, Cl, K)	Titanium white, zinc white, chalk, ultramarine, Prussian blue, lead white	Prussian blue

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Green	9	**C**, **O**, **Cr**, Ca, Ba, Mg, (S, Zn, Cl, Ti, Al, Na, Si)	Viridian, chalk, lithopone and/or barium white and zinc white, titanium white, ultramarine	
		Yellow	7	**C**, **O**, **Fe**, Ca, Ti, Zn, (Al, Ba, S, Si, Na, Mg, Cl)	Yellow iron-containing earth pigment, chalk, titanium white, lithopone and/or barium white and zinc white	
		Red	6	**C**, **O**, **Ca**, Zn, Ti, (Ba, Mg, Cl, Pb, Al, Fe, Na, Si, Cr, S)	Chalk, lithopone and/or barium white and zinc white, titanium white, lead white, red iron-containing earth pigment, Cr-containing yellow(s), organic red on Al-containing substrate	Chalk, zinc soap, oil

* Major elements are given in bold, minor elements in plain type and trace elements in brackets.

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Painting Materials and Technique for the Expression of Chinese Inheritance in Liu Kang's Huangshan and Guilin Landscapes (1977–1996)

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Abstract: Liu Kang (1911–2004) was a Chinese artist who settled in Singapore in 1945 and eventually became a leading modern artist in Singapore. He received academic training in Shanghai (1926–1928) and Paris (1929–1932). Liu Kang's frequent visits to China from the 1970s to the 1990s contributed to a special artistic subject—the Huangshan and Guilin mountains. This subject matter triggered an uncommon painting approach for his oeuvre. In this context, this study elucidates the artist's choice of materials and methods for the execution of 11 paintings, dating between 1977 and 1996, depicting Huangshan and Guilin landscapes. The paintings belong to the collection of the National Gallery Singapore. They were investigated with a combination of non- and micro-invasive techniques, supplemented by a wealth of documentary sources and art history research. The obtained results highlight the predominant use of hardboards resembling Masonite® Presdwood® without the application of an intermediate ground layer. Commercially prepared cotton and linen painting supports were used less frequently, and their structure and ground composition were variable. This study revealed the use of a conventional colour base for the execution of the paintings—a consistent colour scheme favouring ultramarine, yellow and red iron-containing earths, viridian and titanium white. Less commonly used pigments include Prussian blue, cobalt blue, phthalocyanine blue, phthalocyanine green, naphthol red AS-D, umber, Cr-containing yellow(s), cadmium yellow or its variant(s), Hansa yellow G, lithopone and/or barium white and zinc white and bone black. The documentary sources indirectly pointed to the use of Royal Talens, Rowney and Winsor & Newton, brands of oil paints. Moreover, technical and archival findings indicated the artist's tendency to recycle rejected compositions, thereby strongly suggesting that the paintings were executed in the studio. Although this study focuses on the Singapore artist and his series of paintings relating to China, it contributes to existing international studies of modern artists' materials.

Keywords: Liu Kang; pigment identification; SEM-EDS; FTIR; IRFC; PLM; X-ray; hidden paintings

1. Introduction

Born in China, Liu Kang (1911–2004) is considered one of Singapore's leading modern artists. His stylistic preferences were initially shaped by the art training obtained from Xinhua Arts Academy in Shanghai, followed by studies at the Académie de la Grande Chaumière in Montparnasse, which exposed him to the Impressionism and Post-Impressionism art movements [1]. However, Liu Kang's personal and mature approach to painting was strongly influenced by his regional travels [2]. The most remarkable was a trip to the Indonesian island of Bali in 1952, which inspired him to contribute to the formulation of a new painting concept known as the Nanyang style. The style depicted aspects of the Southeast Asian way of life, integrated Western and Chinese means of artistic expression and incorporated stylistic elements of the batik technique [3–6]. Due to growing nostalgia for the motherland, China was Liu Kang's most often visited country since the communist state opened up to the world in the 1970s [2,7]. Trips to China resulted in countless drawing and painting studies of the majestic landscapes of Huangshan and Guilin mountains [1]—places he remembered from his stay in Shanghai [8]. In a 1955 interview, he recalled: "Every artist should some day visit those mountains. They have been painted by the most famous Chinese masters and have exerted a great influence on the style of Chinese painting. We can learn a great deal from Nature—forms, colours, compositions and moods—and the Yellow Mountains [Huangshan] are inspiring" [9]. Liu Kang's memories of Chinese nature were still vivid in 1969 when he wrote in his essay: "Mount Huang can be considered an exemplification of all the best elements of Chinese landscape. However, the most important thing is that once a person falls into its embrace, he naturally feels that everything is spacious and grand, lofty and vigorous, and his mind is infinitely expanded" [10].

The subsequent visits to China from the 1970s onwards revealed Liu Kang's continued fascination with the country's nature, which remained the source of his artistic vision for many years [11]. Moreover, these visits reinforced the artist's sense of Chinese identity, which he expressed in 1993: "Legally, I am a Singapore citizen, but I am Chinese by birth. The Chinese have a long history of several thousand years with deep and firm cultural roots and a distinctive artistic achievement. Besides, she has a vast territory with a magnificent landscape. That is why I have tried to reveal the robust spirit, profound contents and refined taste of her culture in my paintings" [12]. Hence, the adopted painting style and technique for depicting the mountainous Chinese landscapes radically differ from those seen in his early artistic phases associated with practices in Paris [13] and Shanghai [14], post-war Singapore [15], Nanyang style artworks [6] as well as his special theme of Nudes [16]. The ethereal style [1] of the investigated paintings conveys a unique atmosphere of the mountainous landscapes, characterised by the rough structure of the majestic rocks and heavy clouds, which contrasted with delicate vegetation and moisture that obliterates the shapes of the mountains. These effects were achieved with a rich texture and exceptionally heavy impastos, which were uncommon in Liu Kang's general painting technique. Moreover, the artworks strike the viewer with a restricted palette of colours—an unusual choice for the artist known as a skilful colourist [17,18]. These new visual effects undoubtedly reveal the strong impact that the harsh but captivating natural scene made on Liu Kang. The adopted artistic expression seems to reflect an Eastern approach to painting as described by Liu Kang in his 1969 essay: "Eastern artists treat natural scenery as the starting point for depicting their emotions" [19]. The intentional abandonment of the human element in the entire series of paintings additionally enhances the sense of isolation. Another distinguishing feature of the artist's technique is a frequent use of hardboards, which seem to play an important role in facilitating his robust painting technique and the inconvenience of possible outdoor painting sessions. Hence, these peculiarities explain the authors' interest in conducting a comprehensive analyses of Liu Kang's landscapes of Huangshan and Guilin.

This investigation aims to characterize, for the first time, Liu Kang's working process and materials employed for the painterly documentation of the mountainous Chinese landscapes, which he intensively studied from 1977 to 1996. Therefore, the development of artistic ideas, the role of the primary painting supports in the creative process, the pigments selection and the handling of the paint are thoroughly investigated. Moreover, this study expands the knowledge of Liu Kang's style and painting practice beyond the common public perception of his close affiliation with the entire development of the Nanyang style [20,21]. Although the artist is mainly recognised in Singapore and Southeast Asia, and the studied genre relates to China, this research reaches beyond these regions by contributing to the growing knowledge of twentieth-century painting materials and their availability in Singapore.

2. Materials and Methods

2.1. Materials

The discussion of Liu Kang's painting materials and the execution of the Mount Huangshan and Guilin landscapes is based on a technical study of 11 artworks (Figures 1 and 2), spanning the period 1977–1996, from the National Gallery Singapore. It should be noted that the title of the four paintings, *Mountain(s)*, is generic and does not refer to any specific location. However, a Liu family member familiar with the artist's trips suggested that the characteristic views of *Mountains* (1991) and *Mountain* (1995) relate to the Guilin mountains. Therefore, the remaining two paintings bearing the same title likely depict Mount Huangshan.

Figure 1. Paintings by Liu Kang: (**a**) *Mountain*, 1977, oil on board, 38 × 45.5 cm; (**b**) *Mountain*, 1981, oil on canvas, 36 × 29.5 cm; (**c**) *Mount Huangshan*, 1983, oil on board, 84.6 × 64.5 cm; (**d**) *Mount Huangshan*, 1986, oil on board, 74 × 48.5 cm; (**e**) *Mount Huangshan*, 1987, oil on board, 71 × 55.6 cm; (**f**) *Mountains*, 1991, oil on canvas, 76.5 × 61 cm. Gifts of the artist's family. Collection of National Gallery Singapore. Arrows and numbers indicate sampling areas.

The research materials also included 77 paint and ground microsamples extracted from the paintings (Figures 1 and 2). As seven paintings were made on hardboard and four on the canvas, only eight textile fibre samples were collected. The fibres were extracted from the threads of weft and warp of each textile. The inventory data of the paintings are summarised in Table 1.

Figure 2. Paintings by Liu Kang: (**a**) *Mount Huangshan*, 1993, oil on board, 40.5 × 31.7 cm; (**b**) *Mount Huangshan*, 1994, oil on board, 78.5 × 58.3 cm; (**c**) *Mount Huangshan*, 1995, oil on board, 30.5 × 40.5 cm; (**d**) *Mountain*, 1995, oil on canvas, 84.7 × 118.5 cm. (**e**) *Mount Huangshan*, 1996, oil on canvas, 64 × 49 cm. Gifts of the artist's family. Collection of National Gallery Singapore. Arrows and numbers indicate sampling areas.

Table 1. Inventory and technical information of the paintings by Liu Kang included in this study.

Title and Inventory Number	Date	Dimensions H × W (cm)	Primary Support	Auxiliary Support
Mountain, 2003-03246	1977	38 × 45.5	Board	
Mountain, 2003-03313	1981	36 × 29.5	Canvas	Strainer
Mount Huangshan, 2003-03304	1983	84.6 × 64.5	Board	
Mount Huangshan, 2003-03327	1986	74 × 48.5	Board	
Mount Huangshan, 2003-03251	1987	71 × 55.6	Board	
Mountains, 2003-03306	1991	76.5 × 61	Canvas	Strainer
Mount Huangshan, 2003-03376	1993	40.5 × 31.7	Board	
Mount Huangshan, 2003-03307	1994	78.5 × 58.3	Board	
Mount Huangshan, 2003-03378	1995	30.5 × 40.5	Board	
Mountain, 2003-03293	1995	84.7 × 118.5	Canvas	Strainer
Mount Huangshan, 2003-03257	1996	64 × 49	Canvas	Board

2.2. Methods

The adopted research strategy relied on the methods used by the authors in the previous investigation campaigns of Liu Kang's paintings [6,13,16]. Such an approach ensured the consistency of the acquired data and their interpretation. Firstly, non-invasive investigation techniques were carried out to collect technical data, characterise the structure of the primary supports, tentatively identify the pigments, determine the sampling areas and collect the visual evidence of the underlying compositions. These techniques involved the photography of the paintings in visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR), near-infrared (NIR), X-ray radiography (XRR) and surface digital microscopy. Secondly, a small number of paint fragments from each painting was extracted and prepared for the examination by several analytical techniques with the aim of determining the constituent materials of the ground and surface paint layers. These techniques comprised optical microscopy (OM), polarised light microscopy (PLM), field emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) and attenuated total reflectance-Fourier transform infrared spectroscopy (ATR–FTIR). The identified pigments were described by their common name and colour index generic name. The identification of fibres was undertaken by studies of their morphology and chemical staining tests using OM.

The interpretation of the obtained analytical data was supported by the archival sources. The artist's studio photographs, combined with his drawings and photographs of Huangshan and Guilin landscapes from the 1970s and 1980s contribute to tracing his working process from the conception of the ideas to finalised artworks. Moreover, a few still images from the 1982 TV documentary and colourmen catalogues expanded our knowledge of the artist's choice of painting materials and technique.

2.2.1. Technical Photography

Imaging was carried out using a modified to full spectrum (360–1100 nm) Nikon 850 DSLR camera with a Nikon AF Micro NIKKOR 60 mm f/2.8D lens (Tokyo, Japan). Mounting different bandpass filters on the camera lens enabled VIS and UVF (X-Nite CC1 and B + W 415), NIR (Heliopan RG1000) and UVR photography (Andrea "U" MK II) [22–24]. The lighting conditions for VIS and NIR photography involved two 500 W halogen lamps, while the UVF and UVR used two lamps equipped with eight 40 W 365 nm UV fluorescence tubes. The X-Rite ColorChecker Passport (Grand Rapids, MI, USA) was used for the camera calibration and profiling in Adobe Photoshop CC. The images were taken with American Institute of Conservation Photo Documentation (AIC PhD) target to facilitate further processing of RAW files [22]. The infrared false-colour (IRFC) images were obtained by combining VIS and NIR photographs with Adobe Photoshop CC, following the protocol of the American Institute of Conservation [25].

2.2.2. Digital Microscopy

Keyence VHX-6000 (Osaka, Japan) was used for the digital microscopy of the paintings. The instrument was equipped with a zoom lens operating at magnifications of 20×–200×. The images were processed using an integrated Keyence software—VHX-H2M2 and VHX-H4M.

2.2.3. XRR

Radiographic imaging of the paintings was conducted using a Siemens Ysio Max digital X-ray system (Munich, Germany) with a 7 Mpx detector of dimensions 35 × 43 cm. The images were captured at 40 kV, 0.5–2 mAs, 4 s acquisition time and 100 cm distance between the X-ray source and detector. Post-processing work was performed using iQ-LITE and Adobe Photoshop CC 2017 software (San Jose, CA, USA).

2.2.4. Preparation of Samples

The pigments scrapings for the PLM analyses were dispersed on glass microscope slides, mounted with Meltmount (n_D = 1.662) from Cargille (Cedar Grove, NJ, USA), which was introduced under the cover glass. Samples intended for the cross-section analyses were embedded within acrylic resin—ClaroCit from Struers (Cleveland, OH, USA). The resin-cast cross sections were ground and polished wet on SiC Foils from Struers down to grade 4000 using grinder-polisher MetaServ 250 from Buehler (Lake Bluff, IL, USA). The samples of fibres were boiled in water and then mounted on glass microscope slides with a drop of water introduced under the cover glass.

2.2.5. OM and PLM

The samples were examined through a Leica DMRX polarised microscope (Wetzlar, Germany) at magnifications of 100×–400×. Transmitted VIS light was used for the PLM observations and fibres morphology, whereas reflected VIS and UV lights were used for the studies of the cross-sections. The samples were photographed using a Leica DFC295 digital camera and further processed with a dedicated software—Leica Application Suite 4.8. The PLM was carried out using the workflow developed by Peter and Ann Mactaggart [26].

2.2.6. Staining Tests

The phloroglucinol stain determined the presence and concentration of lignin in the natural fibres [27,28]. The principle of the test is based on the agent sorbed only by the lignin part of the fibre. Colour reactions were observed in reflected light at magnification of 100×.

2.2.7. FE-SEM-EDS

The paint cross-sections were affixed to the stubs with carbon tapes and examined with FE-SEM Hitachi SU5000 (Tokyo, Japan) coupled with Bruker XFlash® 6/60 EDS (Billerica, MA, USA). The SEM, backscattered electron (BSE) imaging and EDS analyses were carried out using an acceleration voltage of 20 kV, 60 Pa chamber pressure, 50–60 intensity spot, 180 s acquisition time and at 10 mm working distance. The data were acquired and processed using Bruker ESPIRIT 2.0 software.

2.2.8. ATR-FTIR

Analyses were conducted on paint cross-sections with a Bruker Hyperion 3000 FTIR microscope equipped with a mid-band mercury cadmium telluride (MCT) detector coupled with a Vertex 80 FTIR spectrometer. The ATR objective (20×) equipped with a germanium crystal was used for the compression of the samples. The background was measured with 64 scans before each acquisition. Spectra of each sample were recorded over the spectral range 4000 to 600 cm^{-1}, with a resolution of 4 cm^{-1}, and obtained as a sum of 64 scans. Data were processed and interpreted using Bruker Opus 7.5 software. Additionally, the spectra were interpreted by comparison with references in the material collection of the Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, a spectral library of the Infrared and Raman Users Group (IRUG) [29], as well as Database of ATR-FT-IR spectra of various materials [30].

3. Results and Discussion

3.1. Characteristics of the Painting Supports

Of the 11 Huangshan and Guilin landscapes, 4 were painted on the unbranded textiles. Based on their structure analyses they are distinguished into three matching types.

Type 1 was identified in *Mountain* (1981) and *Mount Huangshan* (1996). This type relates to the plain-weave canvases made of S-twisted warp threads and Z-twisted weft threads. Cotton was confirmed by flattened and twisted fibres. The canvases have high density, characterised by a thread count of 17 × 12 per cm (Figure 3a). The intriguing use of these two textiles by Liu Kang, 15 years apart, could be explained by bringing into play his old stock in 1996. However, the initial discovery of another paint scheme underneath *Mount Huangshan* (1996) and the local framer's date stamp on the back of the plywood auxiliary support strongly suggest that the earlier composition was mounted on the plywood board and framed on 22 September 1981. Then, in 1996 as indicated by the painted date, the artist reused that earlier painting for a new composition (Figure 4).

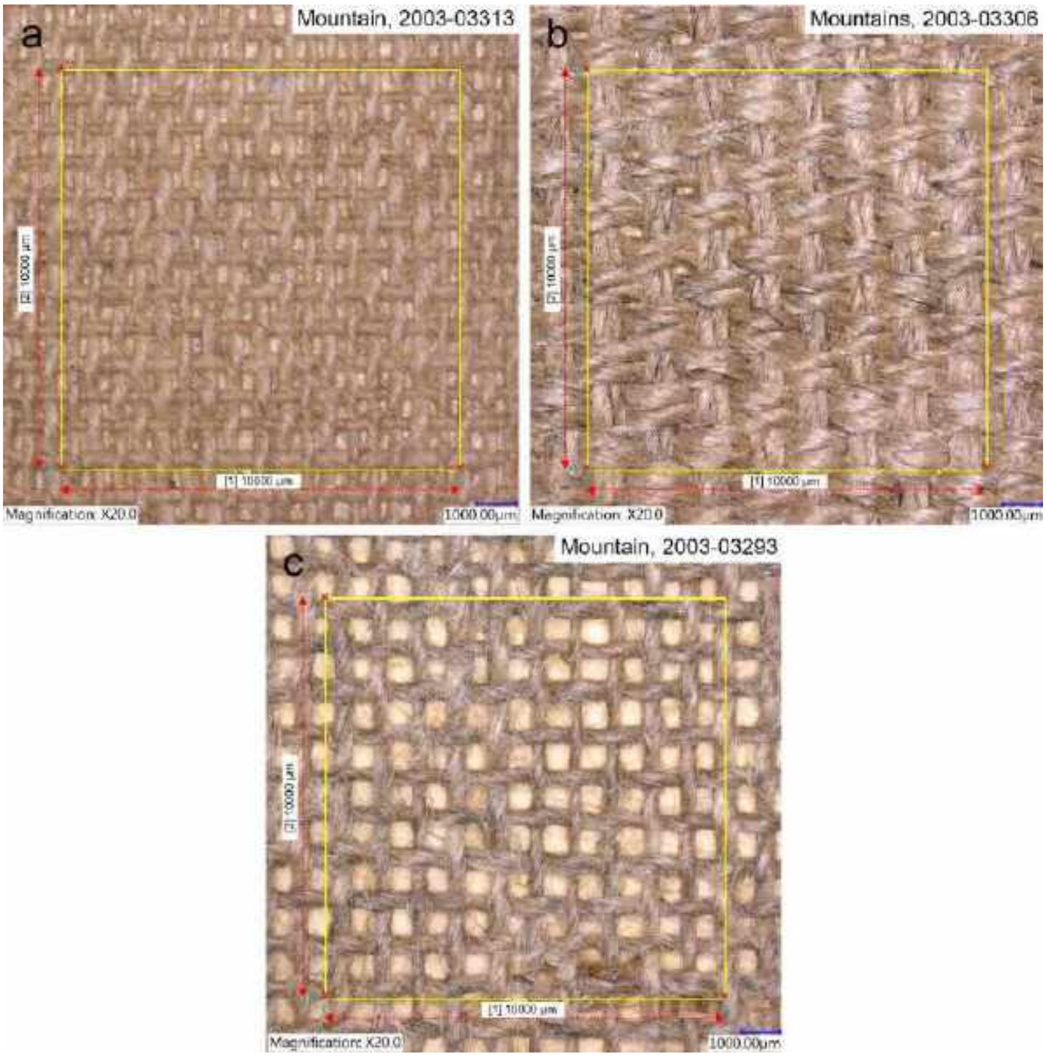

Figure 3. Details of the photomicrographs of three types of canvases identified in the investigated paintings: (**a**) type 1; (**b**) type 2; (**c**) type 3.

Figure 4. Details of *Mount Huangshan*, 1996, showing the: (**a**) underlying paint scheme indicated by the arrows; (**b**) date stamp on the back of the plywood auxiliary support; (**c**) artist's signature "Kang" and date "1996" on the painting.

Types 2 and 3 comprise linen canvases made of Z-twisted weft and warp threads. Linen fibres were identified by their morphological features, such as pronounced dislocations, transverse markings and uneven pink stains, obtained by the phloroglucinol test [27]. However, the discriminating feature of these canvases is the type of weave and density. Hence, the canvas of type 2 is characterised by a basket-weave structure with a thread count of 8 × 10 per cm. It was determined in *Mountains* (1991) (Figure 3b). Type 3 relates to a plain-weave canvas with a thread count of 10 × 10 per cm, and it was identified in *Mountain* (1995) (Figure 3c).

Three investigated paintings are stretched over the unbranded strainers, whereas *Mount Huangshan* (1996) is mounted on the plywood. The visual analyses of the paintings enabled us to distinguish between three types of fastening of the canvas to the auxiliary supports. Regularly distributed nails were observed in the tacking margins of *Mountain* (1981), suggesting commercial stretching of the painting support. However, unevenly spaced staples used for fastening *Mountains* (1991) and *Mountain* (1995), followed by crudely cut edges of the tacking margins, seem to point to the artist's stretching practice.

A sparing utilisation of the canvas supports suggests the artist's awareness of their limitations in that they would not endure his new way of handling of the paint with heavy impastos and robust scraping. Therefore, the preferential use of 4 mm thick hardboards resembling Masonite® (pressure-moulded wood fibres) is evident in seven paintings. A partially preserved stamp on the reverse side of *Mount Huangshan* (1983) conforms with the Masonite® Presdwood® trade name featuring the "Masonite Man", which was regularly marketed in the company's advertisements (Figure 5) [31]. Presdwood® is a hardboard that is smooth on one side and textured on the other due to the screen used to form the fibres in the manufacturing process [32,33]. The hardboards were convenient to use as they did not require a lengthy preparation, compared to the raw canvas. They were light and easy to carry around—an important advantage when painting outdoors. The artist used the smooth side of the boards for painting.

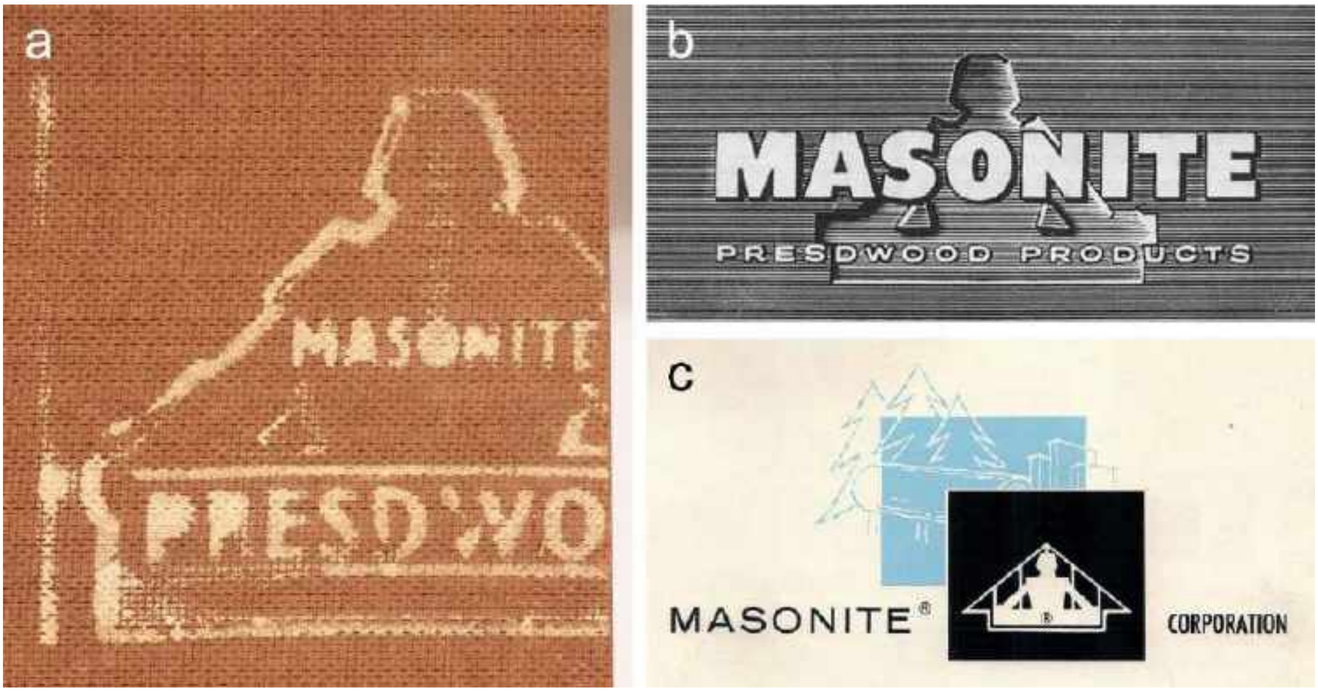

Figure 5. Detail showing the Masonite® Presdwood® stamp on the reverse side of *Mount Huangshan*, 1983 (**a**). Masonite® Presdwood® brand sign featuring the "Masonite Man" from the (**b**) 1950 and (**c**) 1960 Masonite Corporation advertisements.

Regarding the source of supply of the painting supports, it remains uncertain whether the artist acquired them in Singapore or in China. The technical data of the painting supports are presented in Table 2.

Table 2. Overview of the canvas characteristics of the investigated paintings.

Title and Inventory Number	Date	Average Thread Count/cm	Weave	Direction of Warp	Twist	Fibre	Weave Matching Group
Mountain, 2003-03313	1981	17 × 12	Plain	Vertical	S (warp) Z (weft)	Cotton	1
Mountains, 2003-03306	1991	8 × 10	Basket	Horizontal	Z	Linen	2
Mountain, 2003-03293	1995	10 × 10	Plain	Vertical	Z	Linen	3
Mount Huangshan, 2003-03257	1996	17 × 12	Plain	Vertical	S (warp) Z (weft)	Cotton	1

3.2. Characteristics of the Grounds

The microscopic analyses revealed that seven paintings on the hardboards were executed without priming. This observation accords with two archival photographs from the 1990s, providing a rare glimpse into the artist's approach to painting on the hardboard. They document the artist's initial painting process over a recycled composition on the hardboard without the application of an intermediate ground layer (Figure 6). Nevertheless, the features of the grounds are discussed based on the remaining four canvas paintings.

Figure 6. Archival photographs of Liu Kang from the 1990s showing the artist at work. The photographs show the initial underpaint of the sky area conducted over an earlier composition (**a**) and subsequent application of colour for the depiction of vegetation or distant hilltops (**b**). Liu Kang family collection. Images courtesy of the Liu family.

Two types of ground preparation were determined. The ground of type 1 relates to the cotton canvas paintings *Mountain* (1981) and *Mount Huangshan* (1996). The microscopic observation revealed that it is a white and single-layered ground. A concomitant presence of Ba, S and Zn elements combined with IR absorption bands at 1066, 983, 630 and 605 cm^{-1} suggested that the ground is primarily composed of lithopone (PW5) and/or barium white (PW21) and zinc white (PW4) [30] with the addition of lead white (PW1) identified by Pb signal and characteristic IR absorption bands at 3528, 1398 and 681 cm^{-1} [30,34]. Interestingly, the SEM-BSE images showed that barium white compound particles are coarsely ground in *Mountain* (1981), while in *Mount Huangshan* (1996), they are in the form of fine grains (Figure 7a–d). Hence, these variations could relate to marginal changes in formulation of the ground or different batches of the ingredients. The presence of drying oil was detected by IR absorption peaks at 2918, 2849, 1736, 1456, 1161 and 721 cm^{-1} [30]. The commercial preparation of the canvas for *Mountain* (1981) is assumed based on the presence of the ground layer on its tacking margins. The evident correlation of commercial preparation and commercial stretching of the canvas indicates that the painting support was bought ready primed on the strainer. Regarding the *Mount Huangshan* (1996), which has tacking margins cut off, the canvas structure and ground preparation share distinctive features with *Mountain* (1981), pointing to the same manufacturer.

Double grounds of the same structure were identified on linen canvases of *Mountains* (1991) and *Mountain* (1995) (Figure 7e–h). Thick bottom layers are composed predominantly of roughly ground chalk particles (PW18) identified by strong C- and Ca-elements and FTIR peaks at, respectively, 1397, 871 and 712 cm^{-1} [30]. Chalk was admixed with lithopone and/or barium white and zinc white, lead white and titanium white (PW6). The latter was assumed by the presence of Ti. The upper layers are thinner than the bottom layers. They were made of the same constituents but mixed in different concentration. Lead white features as the main compound. A drying oil as a binder was confirmed in both layers. An overview of the ground characteristics of the paintings is presented in Table 3.

Both *Mountains* (1991) and *Mountain* (1995) show an uneven ground coverage of the tacking margins along one edge (Figure 8). Although considered commercial, this kind of preparation probably resulted from the mounting of long and wide canvas by the unprimed edges on a frame before ground application. This leads to the conclusion that the artist bought such prepared canvases from the roll or by the metre and mounted them over the bare strainers.

3.3. Liu Kang's Paint Brands and Palette of Colours

To the best of the authors' knowledge, information about the brand(s) of the paints or pigments used by Liu Kang for the execution of the investigated landscapes is non-existent. As Liu Kang frequently travelled to China, the use of the local Chinese brands can be considered. However, some clues were provided in the TV documentary, *Portrait of an artist: Liu Kang*, presented on 26 February 1982, which featured the artist in his studio using painting materials [35]; when compared against the authors' references and colourmen catalogues, these materials can be identified as oil paint tubes from Royal Talens (Van Gogh series), Rowney (Georgian series) and Winsor & Newton (W&N) (Figure 9a,b). Although the design and labelling of the Royal Talens and Rowney tubes seen in the documentary relates to those manufactured at the time the documentary was made (Figure 9b), the W&N tube appears to be much older. Based on information available from the W&N catalogues, such as the characteristics of tube design and tube labelling, the authors inferred that similar tubes were in use until at least 1957 (Figure 9c,d). A major change in the design of the tubes was observed in the next available catalogue from 1963 (Figure 9e). The W&N tubes from 1979 also showed a different design (Figure 9f). Nevertheless, as Liu Kang displayed a preference for a bulk purchase of the paint colours [16], the use of the old stock paints like those from W&N is not surprising.

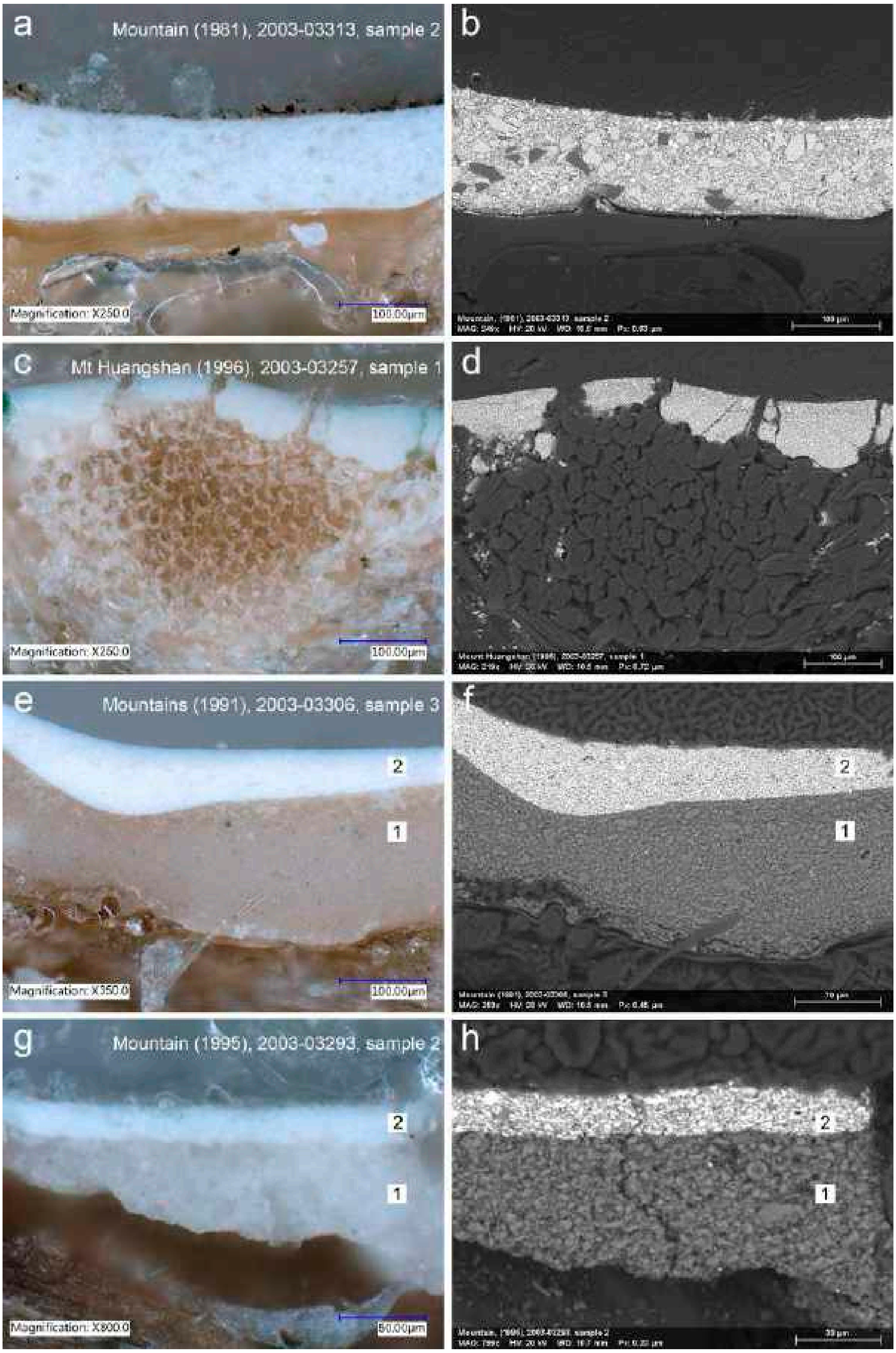

Figure 7. Optical microscopy and corresponding backscattered electron (BSE) images of cross-sections representing two types of identified grounds: (**a**–**d**) single-layered ground of type 1 with coarsely (**b**) and finely (**d**) ground barium white compound particles; (**e**,**g**) double-layered ground of type 2 characterised by a high concentration of chalk in the bottom layer (dark grey) and predominant presence of lead white in the top layer (white) (**f**,**h**). Numbers differentiate between layers of the ground.

Table 3. Overview of the ground characteristics of the investigated paintings.

Title and Inventory Number	Date	Sample, Layer Number	SEM-EDS Detected Elements *	FTIR Identification	Result	Type of Ground
Mountain, 2003-03313	1981	2, 1	**Ba, O, C**, Zn, Pb, S, Si, (Na, Sr, Al)	Lithopone and/or barium white and zinc white, lead white, zinc soap, oil	Lithopone and/or barium white and zinc white, lead white	1
Mountains, 2003-03306	1991	3, 2	**C, O, Pb, Ba**, Ti, Zn, S, Ca, (Na, Si, Al)	Chalk, lithopone and/or barium white and zinc white, oil	Lead white, lithopone and/or barium white and zinc white, titanium white, chalk	2
		3, 1	**O, C, Ca**, Zn, (Pb, Na, Si, Ba, Ti, S, Al)	Chalk, zinc soap, oil	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	
Mountain, 2003-03293	1995	2, 2	**C, O, Ti, Pb, Ba**, Zn, S, Ca, Na, (Al, Si, Cl)	Lithopone and/or barium white and zinc white, lead white, oil	Titanium white, lead white, lithopone and/or barium white and zinc white, chalk	2
		2, 1	**O, Ca, C**, Zn, Pb, (Ba, Na, Ti, Si, Al, S, Cl)	Chalk, lithopone and/or barium white and zinc white, oil	Chalk, lithopone and/or barium white and zinc white, lead white, titanium white	
Mount Huangshan, 2003-03257	1996	1, 1	**C, O, Zn, Ba**, S, Na, (Si, Cl, Al, P, Pb)	Lithopone and/or barium white and zinc white, zinc soap, oil	Lithopone and/or barium white and zinc white, lead white	1

* Major elements are provided in bold type, minor elements in plain type and trace elements in brackets.

Figure 8. Close-up showing the uneven ground coverage found on the tacking margin of *Mountains*, 1991.

Regarding the artists' colourmen brand(s) employed by Liu Kang in the 1990s, Royal Talens (Rembrandt series) and Rowney (Georgian series) oil paints were evidenced in the previous research by the authors [16]. Following on this lead, it can be speculated that the investigated landscapes from that period were painted using the same brands of paints. In addition, it is conceivable that, during the painting sessions, the artist mixed the paints of at least three different brands. Hence, the attribution of the identified pigment mixtures to the specific colourmen brand(s) should be made very carefully.

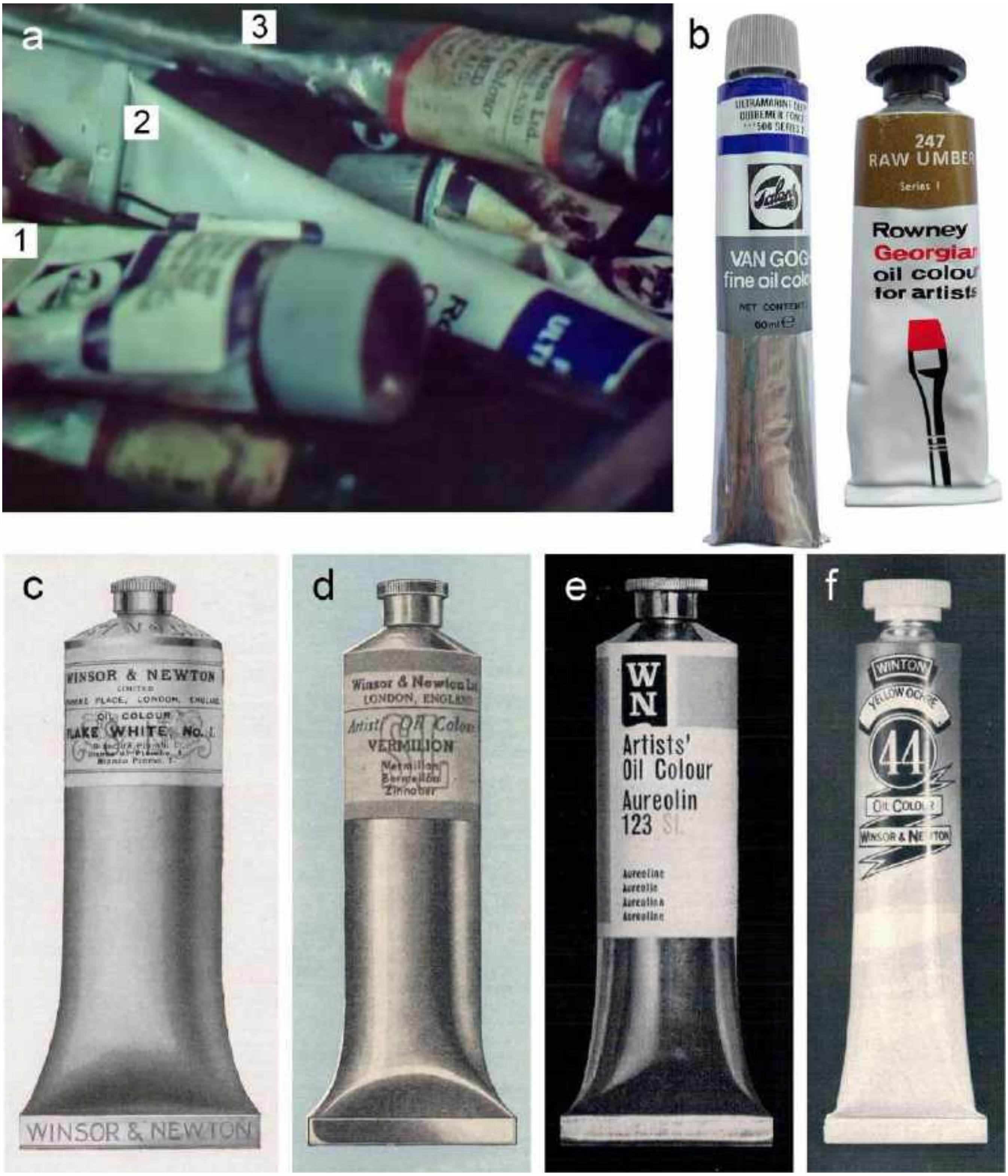

Figure 9. (**a**) Still image from the 1982 TV documentary showing the artist's paint tubes from Royal Talens (1), Rowney (2) and W&N (3). Copyrights of Mediacorp TV Singapore Pte Ltd. (**b**) Authors reference Royal Talens (Van Gogh series) and Rowney (Georgian series) oil paint tubes from the 1980s. W&N oil paint tubes advertised in the company's catalogue from: (**c**) 1934, (**d**) 1957, (**e**) 1963 and (**f**) 1979.

As the subject matter was strongly influenced by fluctuating weather conditions, the painted scenes do not strike the viewer with vivid hues typical for Liu Kang. Instead, the adopted palette of colours is limited; however, the obtained colour mixes prove the artist's colour sensitivity. The colouristic scheme of the investigated paintings relies on the contrasting juxtaposition of brown hues, mainly characterising the raw rock structures of the foreground and middleground, and blue hues representing distant mountain ranges, sky and water. Green hues of scanty vegetation were the less utilised; however, they play an important role in a visual counterbalancing of the optically heavy foreground mountains. The overview of the pigment analyses is presented in Appendix A, Table A1.

3.3.1. Brown

The analyses indicate that the brown hues are primarily composed of yellow and red iron-containing earths. They were suspected based on the PLM observation of a considerable amount of yellow and red particles with high refractive indexes, followed by SEM-EDS recording of distinct Fe signals and FTIR detection of additive minerals such as kaolinite (absorption peaks at 1030, 1000, 915 and 798 cm^{-1}) and gypsum (absorption peaks at 3533, 3401, 1094, 669 and 605 cm^{-1}) [30,36]. However, the FTIR confirmation of iron-containing earths was hindered by the overlapping signals of other compounds present in the paint mixtures, whereas the iron oxide IR absorption bands at 530 and 450 cm^{-1} were beyond the spectral range of the instrument. A concomitant presence of Ca and P elements and IR absorption peak at 1023 cm^{-1} were associated with bone black admixture (PBk9) (PO_4^{3-} stretching) (Figure 10) [37]. The addition of umber (PBr7) was assumed in five brown paint samples based on the concomitant presence of Fe and Mn elements and absorption peaks at 1590, 1001, 797 and 778 cm^{-1} as sample 4 extracted from *Mount Huangshan* (1987) (Figure 11) [30]. The PLM observation of some organic red particles with a unique low refractive index suggested minor admixtures of organic red(s). However, their unequivocal identification was complicated due to a low concentration of the pigment in the investigated brown mixtures. Nevertheless, SEM-EDS of sample 4 from *Mountain* (1977) enabled the detection of trace Cl, Sn and Al signals, suggesting an organic red on Sn- or Al-based substrate (Figure 10) [38–40]. Further FTIR analyses of the sample recorded IR absorption peaks at 3063, 3028, 1666, 1592, 1547, 1380, 1286, 955, 915, 866, 753, 693 and 672 cm^{-1}, indicative of red azo pigment naphthol red AS-D (PR112). Its admixture was also detected in sample 3 from *Mount Huangshan* (1983) based on the IR absorption peaks matching the reference sample at 1591, 1495, 1316, 1262, 1241, 1118, 1026, 881 and 700 cm^{-1}, and the IRUG reference [41]. Moreover, a concomitant presence of Cr, Zn, Ba and Pb allowed us to consider a Cr-containing yellow(s) (Figure 10). However, further PLM and FTIR analyses could not provide a precise identification, except sample 8 from *Mount Huangshan* (1996). IR absorption peaks at 1081, 1028, 853 and 843 cm^{-1} evidenced the presence of chrome yellow (PY34) [30].

A trace presence of other organic reds, probably on an Al-containing substrate, was suspected in two more brown paint samples.

Interestingly, the PLM observation of blue isotropic particles, which turn red with a Chelsea filter and have a low refractive index, suggested the use of ultramarine (PB29) in four analysed brown paints. This outcome corroborated the SEM-EDS detection of Na, Al, Si and S elements. However, FTIR analyses did not permit a conclusive attribution due to the signal interferences of different compounds within similar spectral ranges. Nevertheless, ultramarine could be considered as contamination or a deliberate admixture by the artist to enhance a depth of dark brown brushstrokes. However, according to the 1982 Royal Talens catalogue, this blue was combined with some earth pigment and an unspecified organic pigment, obtaining Talens brown paint (Appendix A, Figure A1). Interestingly, the brown hue of the sample 8 from *Mount Huangshan* (1996) was additionally modified with Prussian blue (PB27). This blue pigment was identified by PLM (observation of dark blue isotropic and low refractive index particles, which turn dark green under a Chelsea filter), SEM-EDS detection of Fe and FTIR absorption peak at 2089 cm^{-1} [30].

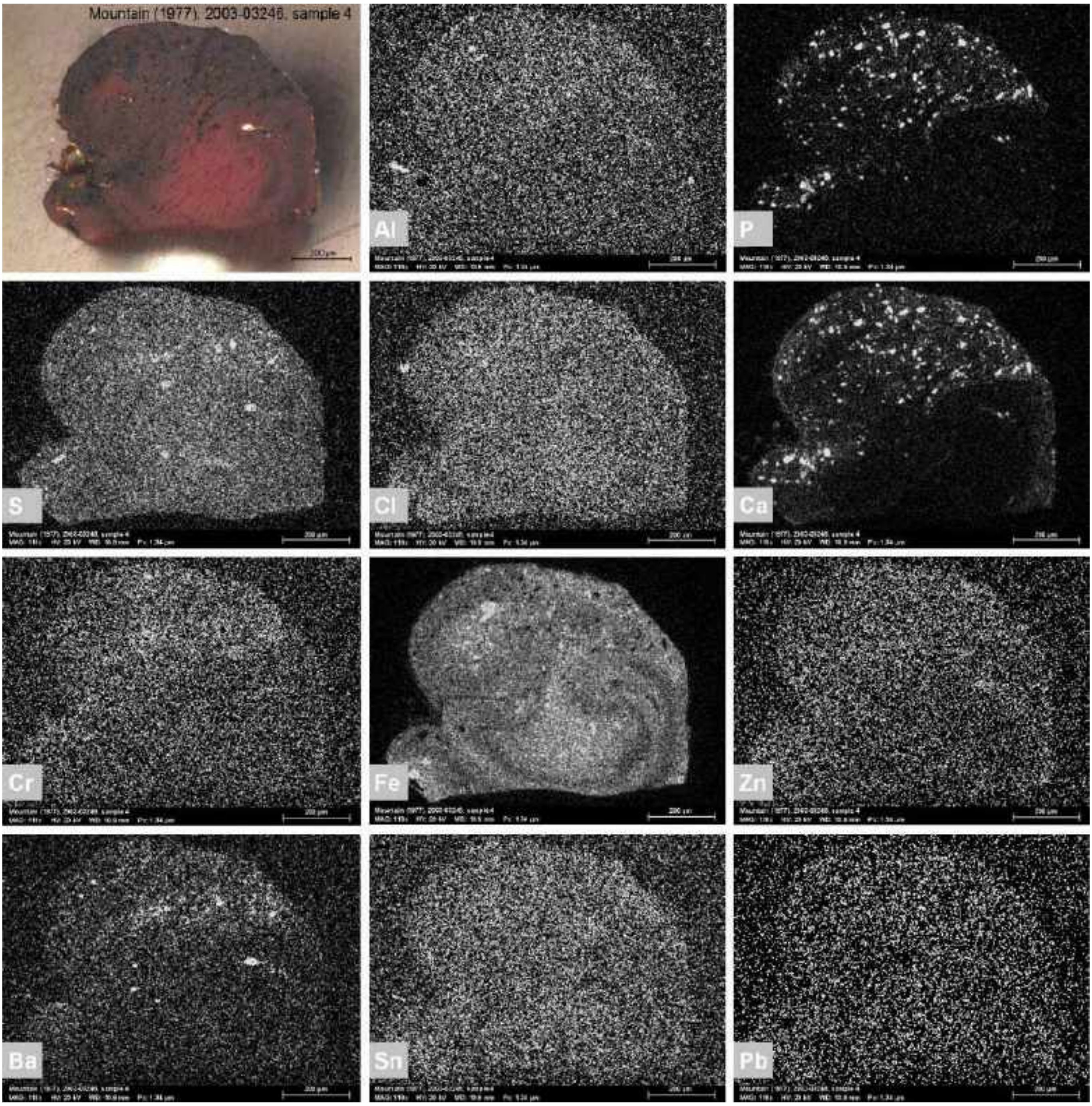

Figure 10. Optical microscopy image of the cross-section of sample 4 at 100× magnification, extracted from *Mountain*, 1977, photographed in VIS (**top-left**), followed by SEM-EDS elemental distribution maps. The greyscale corresponds to the intensity of the signal of each element: white equals high intensity, and black means low intensity. A high intensity of the Fe signal suggests the use of red iron-containing earth. The concomitant presence of Ca and P signals highlights the use of bone black, whereas the co-location of the Al, Cl and Sn elements suggests the presence of organic red on Sn- or Al-based substrate. The concomitant presence of Cr, Zn, Ba and Pb may indicate the use of Cr-containing yellow(s).

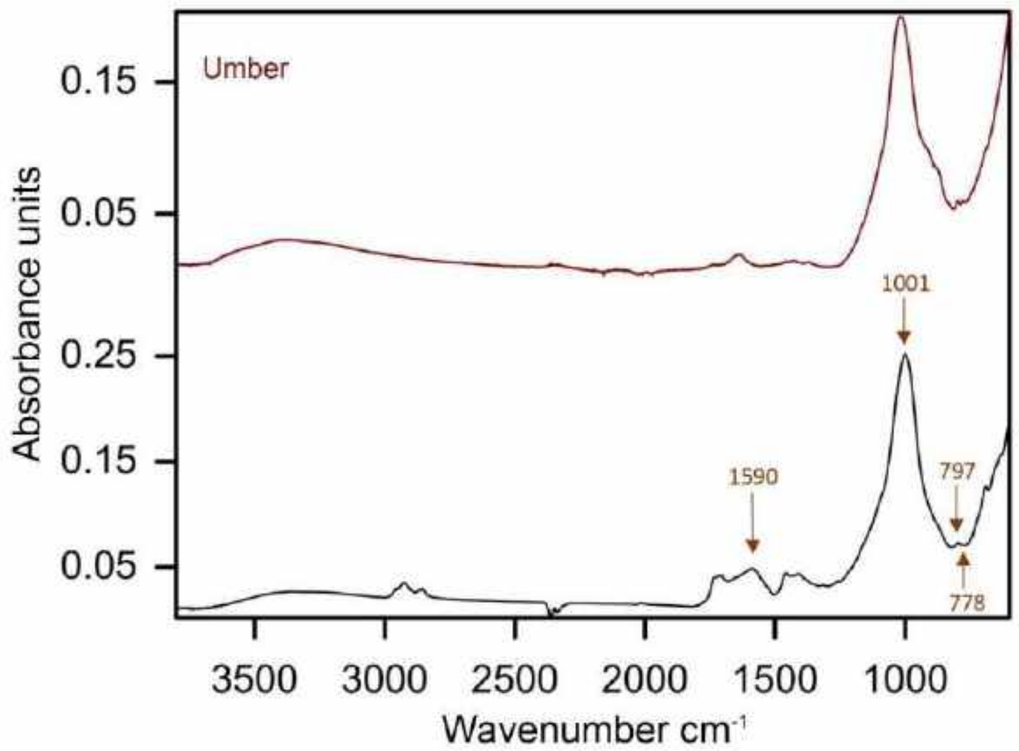

Figure 11. ATR–FTIR spectra of the brown paint of sample 4 extracted from *Mount Huangshan* (1987), with labelled marker peaks of umber and reference spectra of the same pigment.

3.3.2. Yellow and Orange

The analyses of the yellow and orange hues indicated a consistent use of yellow iron-containing earths at variable concentrations in combination with different pigments. For instance, the PLM observation of large and rough anisotropic green particles with a high refractive index tentatively suggested the admixture of viridian (PG18) in the paint sample 7 from *Mountain* (1981) [26,42]. The FTIR spectroscopy of the sample confirmed viridian only by 1068 and 801 cm^{-1} absorption bands as the fingerprint region of this pigment (600–400 cm^{-1}) is behind the spectral range of the measurement. Moreover, an admixture of yellow organic pigment Hansa yellow G (PY1) was confirmed by IR absorption bands at 1666, 1599, 1561, 1508, 1491, 1344, 1294, 1270, 1236, 1175, 952, 911, 801, 771 and 756 cm^{-1} in the same sample [43,44]. Royal Talens listed four variants of organic azo yellow pigments in the 1982 catalogue; however, the company did not specify their variants. Hansa yellow G was available from W&N under the name Winsor yellow, according to their 1982 catalogue (Appendix A, Figures A1 and A2).

Admixtures of cadmium-containing yellow were initially determined based on the characteristic red UV fluorescence of the yellow particles in sample 4 from *Mount Huangshan* (1993) and sample 7 from *Mount Huangshan* (1996) [22]. This observation was further confirmed by coinciding Cd, S, Ba and Zn signals, suggesting the presence of cadmium yellow (PY35) or cadmopone (co-precipitated cadmium sulfide and barium sulfate) or zinc-modified light cadmium yellow (Figure 12). FTIR did not permit an unequivocal identification of cadmium yellow due to its characteristic bands occurring outside of the spectral range of the instrument [45]. Nevertheless, the obtained data correlate with the materials available from Royal Talens and W&N in 1982. Royal Talens listed four shades of cadmium yellow paint composed of cadmium sulfide and two variants of Naples yellow as well as two variants of bright yellow both composed of cadmium sulfide and zinc oxide. W&N listed four shades of cadmium yellow and their Naples yellow was a mixture of cadmium yellow with other pigments (Appendix A, Figures A1 and A2). FTIR analyses of sample 7 from *Mount Huangshan* (1996) identified naphthol red AS-D validated by the absorption peaks at 3274, 3234, 3185, 3123, 3075, 1667, 1603, 1594, 1545, 1478, 1447, 1365, 1324, 1278, 1257, 1203, 1153, 1120, 1071, 1046, 1012, 964, 901, 891, 872, 748, 697 and 665 cm^{-1}. The additional presence of the Sn and Cl elements in sample 7 from *Mount Huangshan* (1996) could point to another organic red on Sn-containing substrate added to the paint mixture to obtain an orange hue. Yellow-green colour brush dabs found in *Mount Huangshan* (1994) are composed of partially mixed yellow iron-rich earth, ultramarine and probably some Co-containing pigment (sample 7), which could be cobalt blue or green; however, its low concentration did not permit PLM observation.

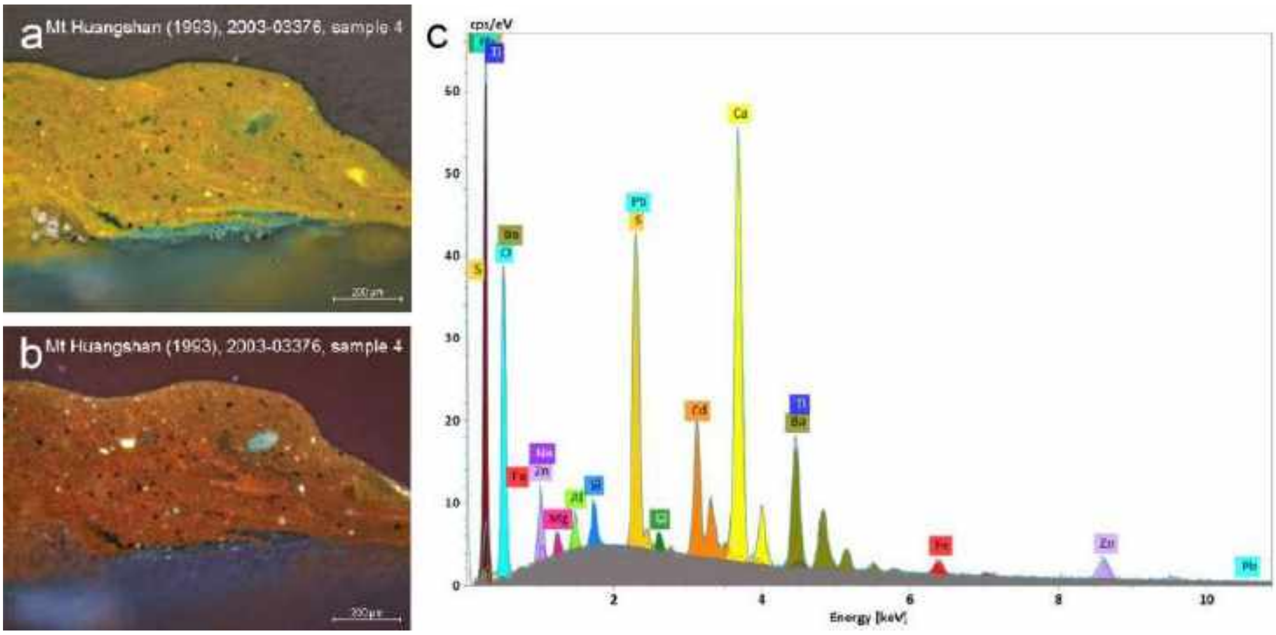

Figure 12. Optical microscopy images of the paint cross-section of sample 4, extracted from *Mount Huangshan*, 1993, photographed in: (**a**) VIS and (**b**) UV. The corresponding SEM-EDS spectra of the yellow paint (**c**). Red fluorescence of yellow paint and strong Cd and S signals combined with Ba and Zn suggests the use of cadmium yellow or cadmopone or zinc-modified light cadmium yellow.

3.3.3. Blue

The analytical results indicate that blue painted areas were achieved through an extensive use of ultramarine admixed frequently with other pigments to obtain the desired hue. Hence, the addition of cobalt blue (PB29) was suspected based on the co-location of Co and Al elements and PLM observation of isotropic particles with a high refractive index that appear red with a Chelsea filter [26,42]. Another blue pigment tentatively identified in the mixtures with ultramarine is Prussian blue. It was assumed based on the Fe signal and PLM observation. [26,42]. Interestingly, a trace Cu signal was recorded in sample 7 from *Mount Huangshan* (1986), suggesting an admixture or contamination with phthalocyanine blue (PB15). This result was further confirmed with FTIR by a complex array of the absorption peaks at 1506, 1416, 1335,1287, 1164, 1118, 1089, 900, 769, 754 and 729 cm^{-1} [46,47]. The analyses of the blue paint samples suggested some admixtures of viridian, yellow or red iron-rich earths, cadmium yellow or its variant and bone black assumed based upon the PLM and SEM-EDS analyses.

Viridian was assumed based on the PLM observation and detection of Cr signal. It was further confirmed by absorbances at 1063 and 796 cm^{-1} as in sample 8 from *Mount Huangshan* (1993) [30]. Phthalocyanine blue was available from Royal Talens in two shades—Rembrandt blue, composed solely of copper phthalocyanine, and Sèvres blue, containing copper phthalocyanine and zinc oxide. This blue pigment was also listed by W&N as Winsor blue (Appendix A, Figures A1 and A2).

3.3.4. Green

The evidence collected from the analysed samples showed some diversity of the selected pigments in obtaining green hues by the artist. By far, viridian is the most frequently occurring green pigment in green paint samples. However, it was used mainly in combination with yellow iron-rich earths, some ultramarine, Prussian blue, cobalt blue, cadmium yellow or its variant or zinc yellow. Although the mixture of viridian with yellow iron-rich earths or ultramarine is considered as artist-made, the combination of viridian and cadmium yellow or its variant detected in sample 5 from *Mount Huangshan* (1993) might be related to commercially prepared cadmium green light, cadmium green dark or cinnabar green dark available from Royal Talens (Appendix A, Figure A1). However, a trace Cd signal in the investigated sample may also suggest contamination as cadmium yellow or its variant was the principal component of the yellow brushstroke in the same artwork (sample 4). SEM-EDS detection of Cu and Cl elements in conjunction with FTIR measurements may account for phthalocyanine green (PG7) in green paints from three investigated green paint samples. The most representative spectra of this green pigment with IR signature peaks at 1498, 1391, 1320, 1305, 1276, 1209, 1152, 1094, 949, 777, 770 and 747 cm^{-1} were recorded from sample 4 extracted from *Mount Huangshan* (1983) (Figure 13a) [48]. Phthalocyanine green was available from W&N as a Winsor Green and from Royal Talens as Rembrandt green and was sold in seven variants as a combination with zinc white and/or organic pigments (Appendix A, Figures A1 and A2). Artist made admixture of yellow ochre (PY43) to phthalocyanine green was detected in sample 4 from *Mount Huangshan* (1986). Yellow ochre was confirmed based on the PLM, high concentration of Fe and IR absorption peaks at 3696, 3651, 3621, 1030, 1008, 906, 796 and 672 cm^{-1} (Figure 13b) [30].

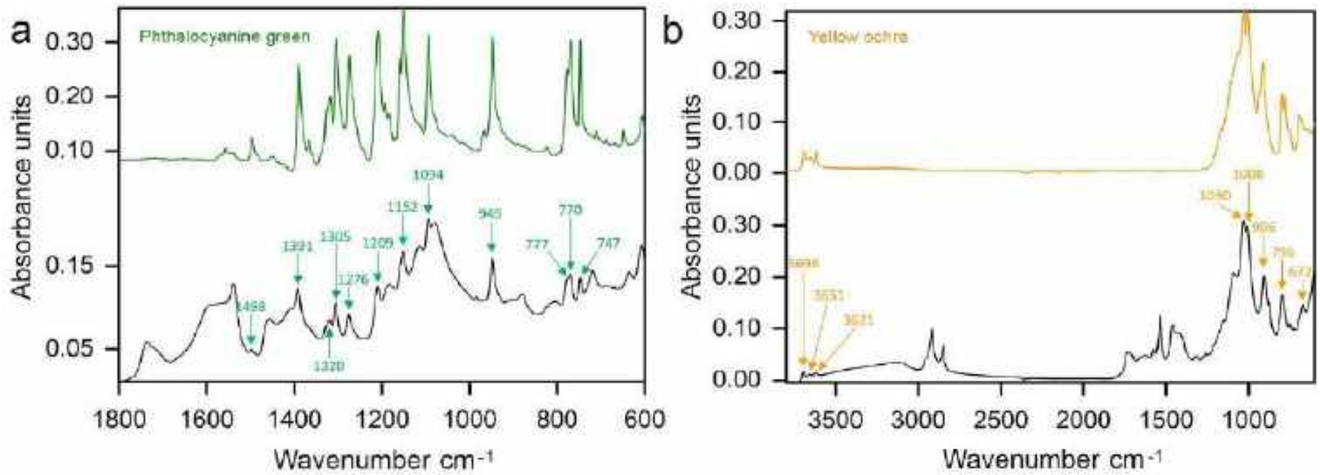

Figure 13. (**a**) ATR–FTIR spectra of the green paint of sample 4 extracted from *Mount Huangshan* (1983), with labelled marker peaks of phthalocyanine green and reference spectra of the same pigment. (**b**) ATR–FTIR spectra of the green paint of sample 4 extracted from *Mount Huangshan* (1986), with labelled marker peaks of yellow ochre admixture and reference spectra of the same pigment.

In addition to viridian and phthalocyanine green, the artist frequently combined ultramarine with yellow iron-rich earths and Hansa yellow G. FTIR analyses of the sample 3 from *Mount Huangshan* (1995) revealed the most representative peaks of Hansa yellow G at 1667, 1598, 1560, 1510, 1493, 1449, 1359, 1342, 1309, 1294, 1271, 1256, 1236, 1176, 1139, 951, 771, 758, 720 and 691 cm^{-1} (Figure 14) [43]. A mixture of ultramarine with cadmium yellow or its variant was assumed in the sample 3 from *Mountain* (1981). A homogenous structure of the paint layer observed on the cross-section may be associated with a commercial mixture, and such was listed in the 1982 Royal Talens catalogue under the name of cinnabar green light (Appendix A, Figure A1).

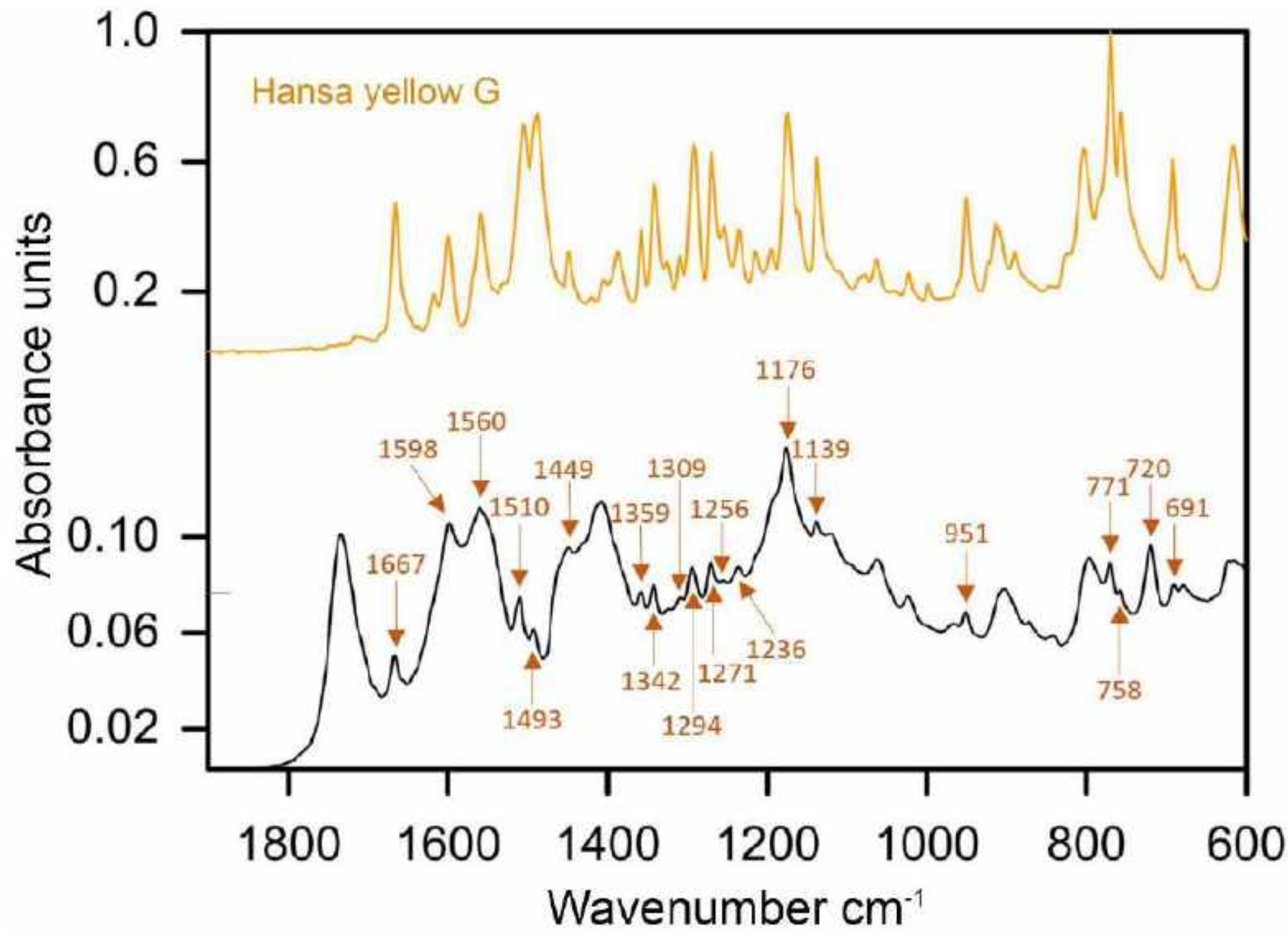

Figure 14. ATR–FTIR spectra of the green paint of sample 3 extracted from *Mount Huangshan* (1995), with labelled marker peaks of Hansa yellow G and reference spectra of the same pigment.

The role of Prussian blue in the development of green hues was generally considered marginal, as it was detected only in three green paint samples. For instance, it was used as a minute admixture to viridian and zinc yellow as in sample 1 from *Mountain* (1977). Although the FTIR measurement did not permit the detection of this blue pigment due to its low concentration, some characteristic blue particles were observed in PLM and SEM-EDS detected trace Fe signal. This result is compliant with the IRFC imaging of the sampling area, as the dark-violet colour is determined by the purple representation of viridian, combined with a dark-blue representation of Prussian blue. Although very little of Prussian blue was added to the paint, this outcome is possible due to a high tinting strength achieved with at low concentration of the pigment [49]. The zinc yellow (PY36) admixture was confirmed with FTIR by absorption peaks at 948, 877, 794 and 719 cm^{-1} (Figure 15) [50].

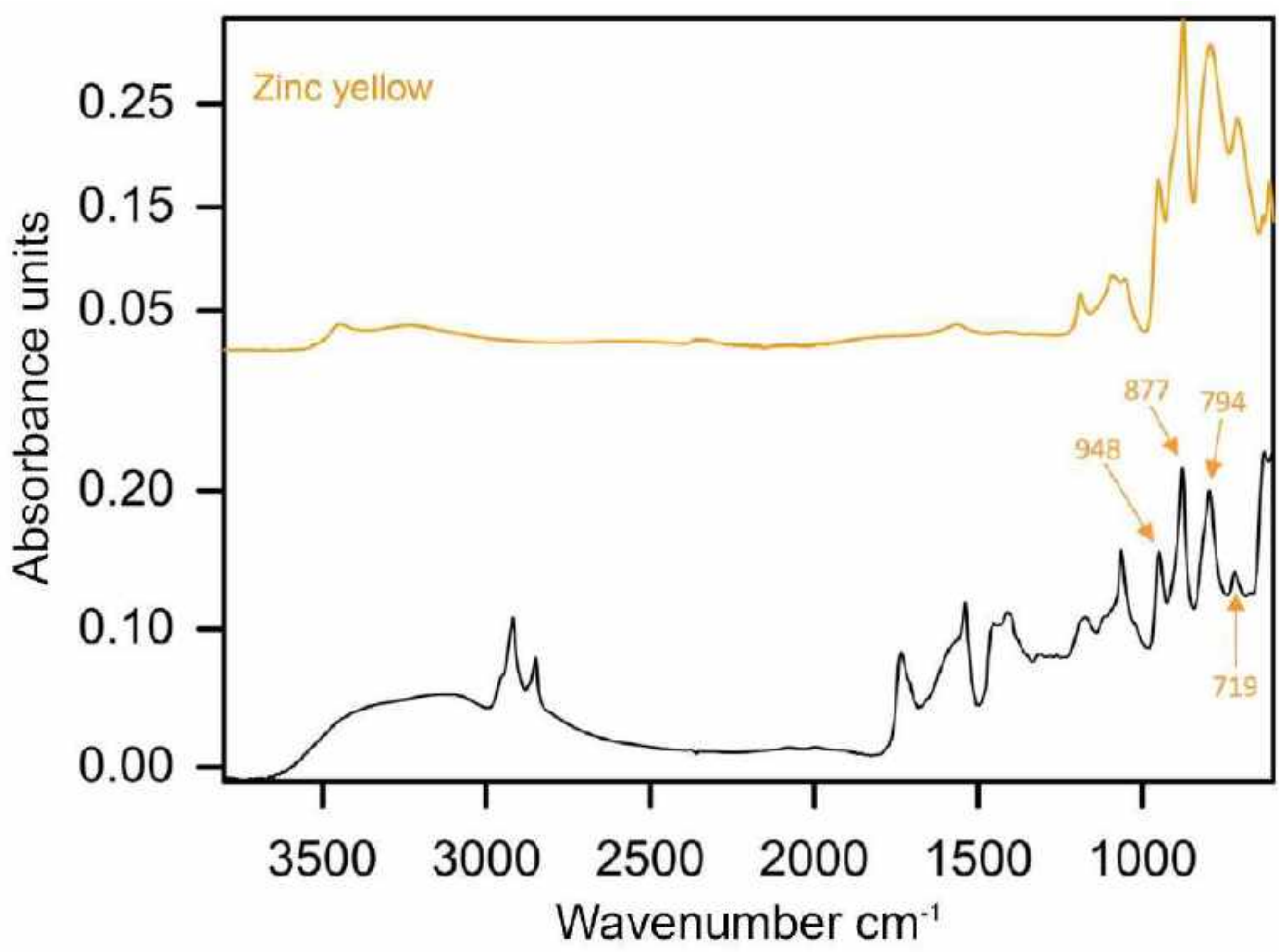

Figure 15. ATR–FTIR spectra of the green paint of sample 1 extracted from *Mountain* (1977), with labelled marker peaks of zinc yellow admixture and reference spectra of the same pigment.

The analyses of sample 4 from *Mount Huangshan* (1983) revealed that Prussian blue combined with phthalocyanine green was the main constituent of some brushstrokes employed for the depiction of the foreground greenery. Prussian blue was assumed by PLM, SEM-EDS and FTIR by the peak at 2091 cm^{-1}, relating to C≡N stretching [51]. This outcome is consistent with the IRFC imaging, as blue representation of Prussian blue combined with purple representation of phthalocyanine green can produce violet.

The admixture of Prussian blue was also confirmed by IR absorption peak at 2088 cm^{-1} in sample 6 from *Mount Huangshan* (1996). The pigment was combined with chrome yellow. Chrome yellow was positively identified by combining strong Cr and Pb signals and some characteristic FTIR bands at 1049, 855, 831 and 626 cm^{-1} [30]. A high concentration of Zn, Ba and S may indicate a barium white extender of chrome yellow and the admixture of zinc white or lithopone [52] (Figure 16).

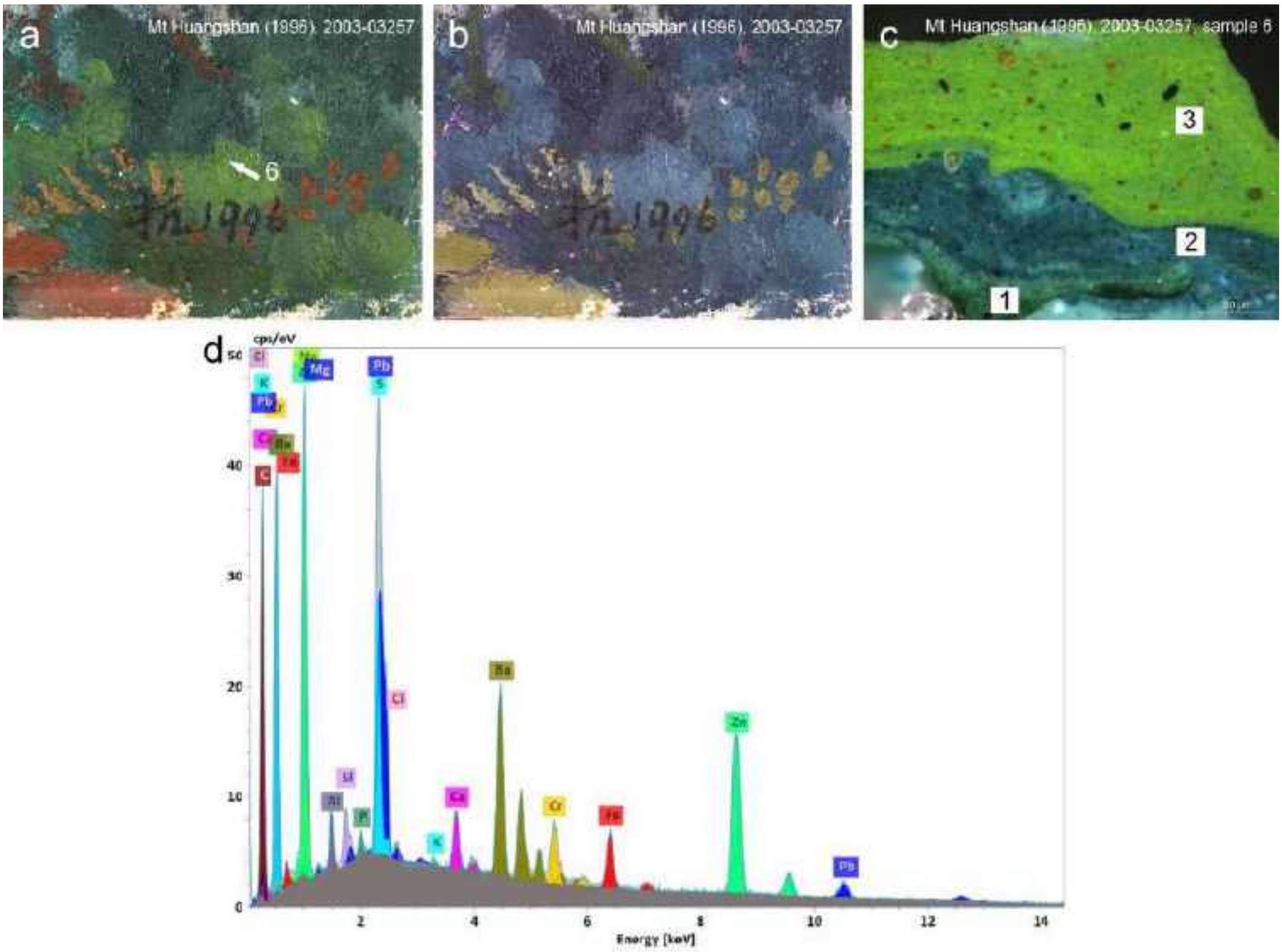

Figure 16. Detail of *Mount Huangshan*, 1996, photographed in VIS showing the extraction spot for sample 6 (**a**) and IRFC image of the same area (**b**). Optical microscopy image of the cross-section of the sample 6 at 200× magnification. Numbers indicate different layers of the paint structure (**c**). Corresponding SEM-EDS spectra of the green paint from layer 3 of sample 6 extracted from the sampling spot (**d**). A green colour recorded as blue in IRFC and the high concentration of Fe in the layer 3 suggested a presence of Prussian blue, which when combined with chrome yellow (assumed by strong Cr and Pb signals), resulted in the green hue of the layer.

Interestingly, the analyses of paint sample 3 from *Mount Huangshan* (1994) revealed a trace concentration of Co which, linked with Al or Zn, also present in the paint layer, may account for Co-containing pigments such as cobalt green or cobalt blue. Unfortunately, the PLM observation was not conclusive, probably due to the low concentration of the pigments in question in the sample, whereas FTIR provided only an absorption band at 640 cm^{-1}, which was insufficient to unequivocally determine the presence of cobalt blue or cobalt green [53]. However, a coinciding use of cobalt blue for developing a sky of the same composition (sample 2) may suggest the contamination of the green paint mixture with this blue pigment. The bone black found in a few green paint samples was probably employed as a minor admixture to modify green hues.

3.3.5. White and Black

Although the artist did not incorporate pure white highlights, white paints combined with some blue, brown, green and black pigments were extensively used to depict clouds. Thus, titanium white appears to be the primary white pigment, used not only in the white painted areas but also in other parts of the compositions as an admixture to produce the desired tints. Moreover, all investigated paint mixtures have in common the notable presence of lithopone and/or barium white and zinc white. However, an unequivocal determination of whether these compounds relate to titanium white as extenders or other incorporated pigments is complicated. Nevertheless, titanium white was available from Royal Talens in 1982 as pure titanium dioxide and in combination with zinc white under the name of mixed white and permanent white. W&N admixed titanium white with some zinc white according to their 1982 catalogue (Appendix A, Figures A1 and A2). The additional presence of Ca recorded in the majority of white paint mixtures could be attributed to chalk, yellow iron-rich earth admixtures [36] and bone black. Although at a low concentration, lead white was detected in three white paint samples. This white pigment also frequently appears in combination with other pigments, but its brightening role seems to be limited by the concurrent and prevailing presence of titanium white. Although progressively restricted from the market, lead white was still available from Royal Talens in 1982. Pure lead white was also listed in the W&N catalogues from 1979 and 1982 under the name of cremnitz white, whereas flake white and silver white usually contained an admixture of zinc white (Appendix A, Figures A1–A3). Regarding other pigments present in the white mixtures, ultramarine appears consistently, and it is very often paired with yellow iron-rich earths, probably to obtain greenish hues. The PLM and SEM-EDS analyses suggested that viridian and cobalt blue occurred intermittently at low concentrations in white mixtures.

Liu Kang did not employ pure black brushstrokes during the execution of the investigated landscapes. However, a trace presence of Ca and P elements and FTIR peak at 1023 cm^{-1} suggested a minor addition of bone black to modify the hue of complex paint mixtures.

3.4. Binding Media and Other Identified Compounds

FTIR analyses of all paint samples confirmed the use of a drying oil as a binding medium (Appendix A, Table A1). The spectra showed typical IR absorption bands at 2923, 2853, 1737, 1460, 1235, 1160, 1098 and 721 cm^{-1}. Additionally, thanks to the typical IR absorption band at 1540 cm^{-1}, a frequent occurrence of zinc soaps was detected. This result is consistent with the observation of zinc soaps in Liu Kang's nude paintings from 1992 to 1999 and probably painted with similar brands of the materials. The zinc soaps may be present in the investigated paint layers as a result of the reaction between the metal ions of the zinc-containing pigments and free fatty acids [54,55]. However, conservation problems, such as cleavage, paint loss, disfiguring lumps, increased transparency and surface efflorescence, associated with zinc soaps have not been observed in the investigated paintings.

3.5. Sketches, Drawings, Photographs and Preparatory Underdrawings

Previous research about Liu Kang revealed that he was a prolific sketcher whose complex drawing studies of the subject matter preceded the transference of the settled ideas onto the canvas [6,16,56]. Hence, in preparation for the painting of the Huangshan and Guilin landscapes, his approach did not differ from his earlier established practice and it resulted in an impressive number of pen, pencil, pastel and charcoal sketches and drawings, which form an important part of Liu Kang's artistic output (Figure 17).

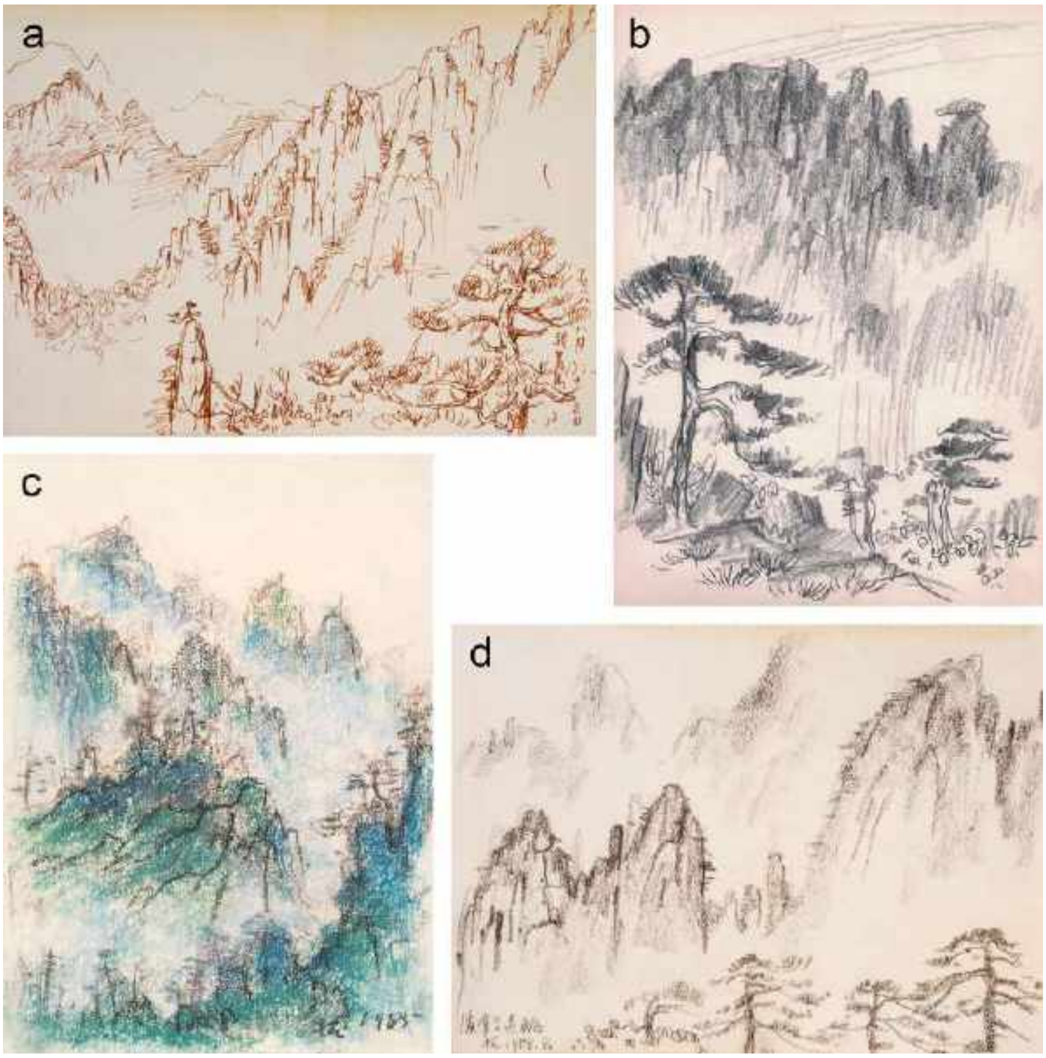

Figure 17. (**a**) Liu Kang, *Mount Huangshan*, 1988, pen on paper, 35 × 25.5 cm; (**b**) Liu Kang, *Mount Huangshan*, 1970s, pencil on paper, 18 × 25 cm; (**c**) Liu Kang, *Mount Huangshan*, 1985, pastel on paper, 35 × 25 cm; (**d**) Liu Kang, *Mount Huangshan*, 1988, charcoal on paper, 35 × 25.5 cm. Images (**a**,**d**) are from Liu Kang family collection. Images courtesy of Liu family. Images (**b**,**c**) are gifts of the artist's family. Collection of National Gallery Singapore.

Most of these sketches were executed rapidly, suggesting an initial probing of the subject matter to search for its potential as a painting composition. However, the comparative studies with the investigated paintings did not reveal direct similarities in the compositional details. Nevertheless, one view of Guilin mountains particularly attracted the artist's attention, resulting in a remarkable series of sketches and drawings from 1979, suggesting preparation for a major undertaking. Liu Kang probably began with two drawings that could have determined the idea for further detailed studies on paper and canvas. A view of the mountain peaks and river bend with boats in the focal point depicted in the blue crayon drawing from 1979 appears to be similar to that from *Mountain* (1995), probably recorded from the higher vantage point (Figure 18a,b). The drawing was executed with several free-flowing lines without shading. The other pencil drawing also from 1979 is technically advanced and contains more details. Its vertical orientation with composition constructed on strong divisions between the visual planes resembles *Mountains* (1991) (Figure 18c,d). Both drawings have the isolated rock formation emphasising the foreground, while the middleground encompassed the boat traffic in the mountain river with characterised in detail one mountain, and background composed of two mountain ranges with obliterated details due to aerial perspective. Despite these compositional similarities, the drawing and *Mountains* (1991) depict views from different observation points. The subject of the mountain river evolved further into three panoramic drawings that show the progression of details controlled by advanced shading and the introduction of colour in water-based technique (Figure 19). Unfortunately, the panoramic drawings and paintings—*Mountains* (1991) and *Mountain* (1995)—do not share any distinctive landscape features that could unequivocally link them together.

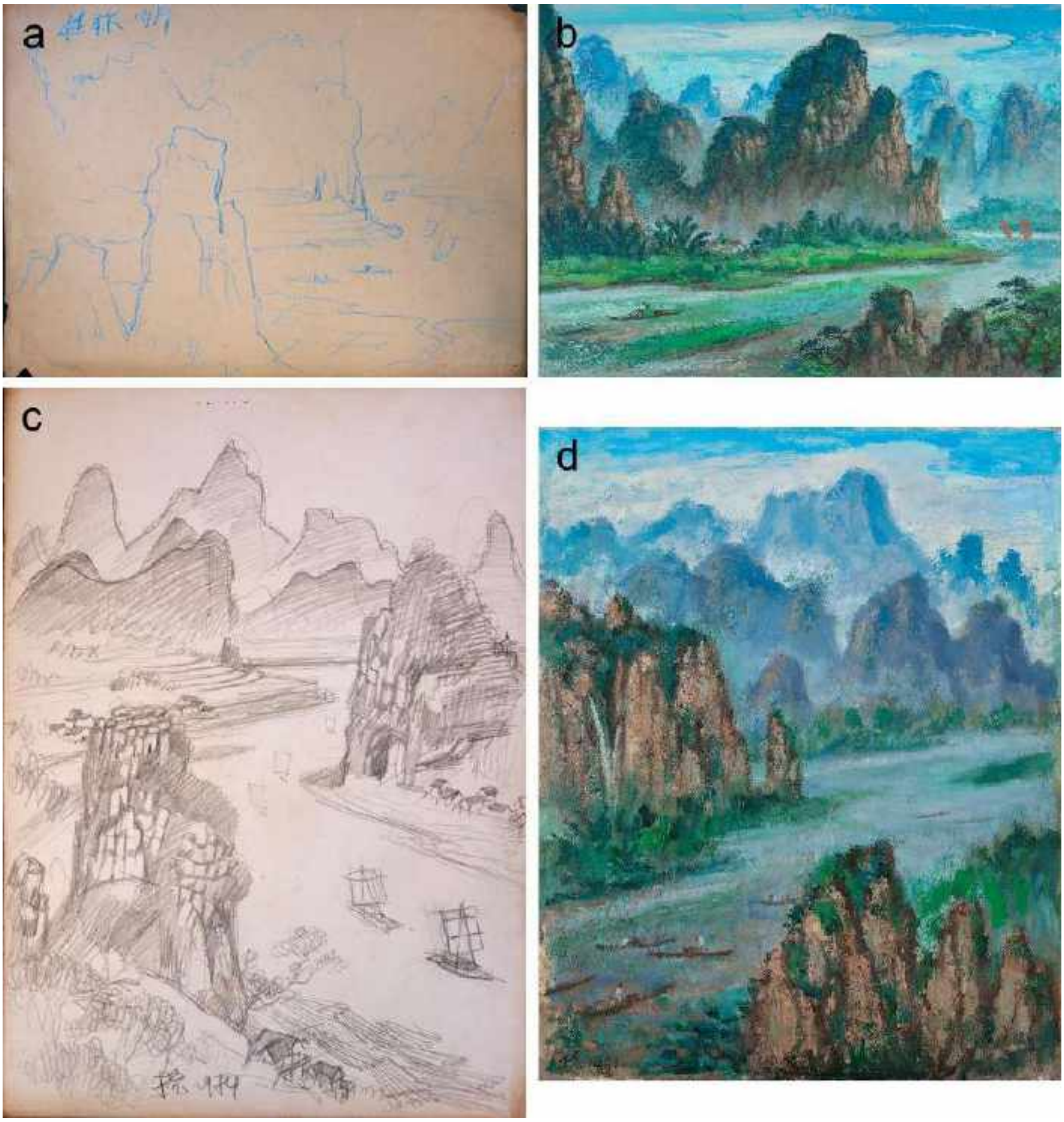

Figure 18. (**a**) Liu Kang, untitled, 1979, crayon on paper, 38 × 28 cm; (**b**) Liu Kang, *Mountain*, 1995, oil on canvas, 84.7 × 118.5 cm; (**c**) Liu Kang, untitled, 1979, pencil on paper, 38 × 28 cm; (**d**) Liu Kang, *Mountains*, 1991, oil on canvas, 76.5 × 61 cm. Images (**a**,**c**) are from Liu Kang family collection. Images courtesy of Liu family. Images (**b**,**d**) are gifts of the artist's family. Collection of National Gallery Singapore.

Figure 19. (**a**) Liu Kang, untitled, undated, pencil on paper, 26 × 88 cm; (**b**) Liu Kang, untitled, 1979, pencil and watercolour on paper, 28 × 107 cm; (**c**) Liu Kang, untitled, 1979, pencil on paper, 38 × 107 cm. Liu Kang family collection. Images courtesy of Liu family.

Liu Kang produced numerous undated photographs of Huangshan and Guilin landscapes that accompanied his sketches and drawings. They record a good deal of details and how they disappear in the misty mountain air (Figure 20). The camera was a very practical tool for the artist, and it is known that he used it extensively for recording subjects that interested him, treating the device like a sketchbook [6,56,57]. However, the available photographs did not show any correlation with the investigated paintings. Nevertheless, the variety of techniques employed by the artist to capture the scenic views suggest that they could have served as a source of inspiration for the creation of the compositions executed on the canvas. Moreover, considering that the development of the colour film rolls and images in the 1980s and 1990s required several days, the photographs were likely taken to document the interesting views for future reference than to use in the actual location.

Figure 20. Archival, undated photograph of Huangshan mountains by Liu Kang. Liu Kang family collection. Image courtesy of Liu family.

Judging by the extensive collection of Liu Kang's sketches, drawings and photographs of Huangshan and Guilin landscapes, one would expect the presence of elaborate preparatory drawings in the investigated paintings. Unfortunately, VIS and NIR examinations did not provide evidence of the underdrawings or discernible painterly contours. This could be due to the artist's painting technique, which efficiently conceals any preparatory layers, or an intentional omission of that phase in the creative process, the latter as illustrated in the photographs of Liu Kang at work taken in the 1990s (Figure 6a,b). The photographs capture an early stage of his painting process, most likely of some mountains, conducted over an earlier composition. Nevertheless, it is noteworthy that no compositional lines are visible, suggesting that he painted from memory or based his painting on a drawing or photograph that was sufficient for settling the composition. However, more technical studies of these paintings would be required to confirm these suggestions.

3.6. Development of Paintings

There is currently little information regarding Liu Kang's approach to painting the Huangshan and Guilin landscapes. The artist had never talked about the nuances of his working practice; very little archival material documenting him at work has been preserved; and the paintings have not been the subject of in-depth studies. However, thanks to a photographs of the artist in his studio taken in the 1990s, we can see him at an early stage of the painted composition, which could have been a mountainous landscape (Figure 6a,b). The initial painting steps were focused on establishing the structure of the composition and its dominant colours. He achieved that fairly simply with a palette knife and a decisive and broad application of a bright underpaint for the depiction of clouds or sky (Figure 6a). The subsequent application of blue-green colour patches, using the same tool, suggests that he started the layering process to characterise vegetation or distant hilltops (Figure 6b). A close look at his container with tools revealed that the artist intended to execute the painting only with palette knives (Figure 6a). Although the broad underpaint of the composition appears to be typical for the artist's initial approach to painting [6,13], further execution of the Huangshan and Guilin landscapes stands out from his earlier genres and artistic phases mainly due to the use of a limited palette of colours and a consistent shift towards rich texture as a way of artistic expression.

Despite his predilection for a solid build-up of paint layers in his earlier oeuvre, his abundant use of paint and its creative manipulation for achieving a repertoire of artistic effects sets a new stylistic quality in the investigated paintings.

Both *Mountain* (1977) and *Mount Huangshan* (1996) share a conventional handling of the paint. They were executed without hesitation wet-on-wet in dynamic brushstrokes (Figures 1a and 2e). Despite these similarities, some high impastos appear in *Mount Huangshan* (1996). They were introduced with palette knives and brushes within the foreground mountain peaks and foliage of the vegetation (Figure 21a). Such an approach could have been a result of the artist reworking of an earlier composition from 1981, as indicated in this article based on the canvas and ground analyses. The comparison of VIS and XRR images of the painting revealed that the underlying composition could be a vertically oriented mountainous winding path—seen in the foreground (Figure 21b,c). Hence, it could be speculated that the artist's idea for repainting a former artwork in 1996 was confined to major changes to the foreground areas, some minor shifts in the middle ground and a new colour of the background mountain ranges. Therefore, it is possible that he did not see a need for an extensive use of a palette knife to underpaint a large area for the new composition. Instead, most of the work was executed with brushes, while a palette knife was used for some minor impastos.

Although the overall impression of the paint texture in *Mountain* (1977) and *Mount Huangshan* (1996) is of a moderate level, the subsequent artworks from 1981 to 1995 demonstrate further development of the paint application methods toward the impasted and complex layer build-up to emphasise the subject matter. Hence, the manipulation of generously applied paint is achieved by the alternate use of brush and palette knife in both wet-on-wet and wet-on-dry colour patches. In particular, the varied brush sizes enabled multidirectional and tight dabbing, resulting in an accumulation of heavy impastos that emphasises the sculptural quality of the objects and isolates these objects from the surrounding environment. This approach turned out to be very successful in the characterisation of the rough texture of the rock masses and vegetation in *Mountain* (1981), *Mount Huangshan* (1983) and *Mount Huangshan* (1993) (Figure 21d). It is also apparent from all investigated paintings that, typical for Liu Kang, continuous and bold outlines of the shapes gave way to the complex texture to enhance forms emerging from the clouds. However, some reduced contours were incorporated for a depiction of the shadows and some foreground structures.

Clouds and mist played an important role in rendering the volatility of weather conditions, aerial perspective and separation of the landscape planes. These features were painted more softly than mountains and rock structures. The opaque clouds were obtained with a grey paint deftly spread with the palette knife, as can be exemplified in *Mount Huangshan* (1994) (Figure 2b). The misty air was rendered with heavily brightened blue and green tints with varied size brushstrokes juxtaposed with underlying colours relating to the mountains or blue sky. The best example of such execution can be observed in *Mount Huangshan* (1983) and *Mount Huangshan* (1986) (Figure 21e).

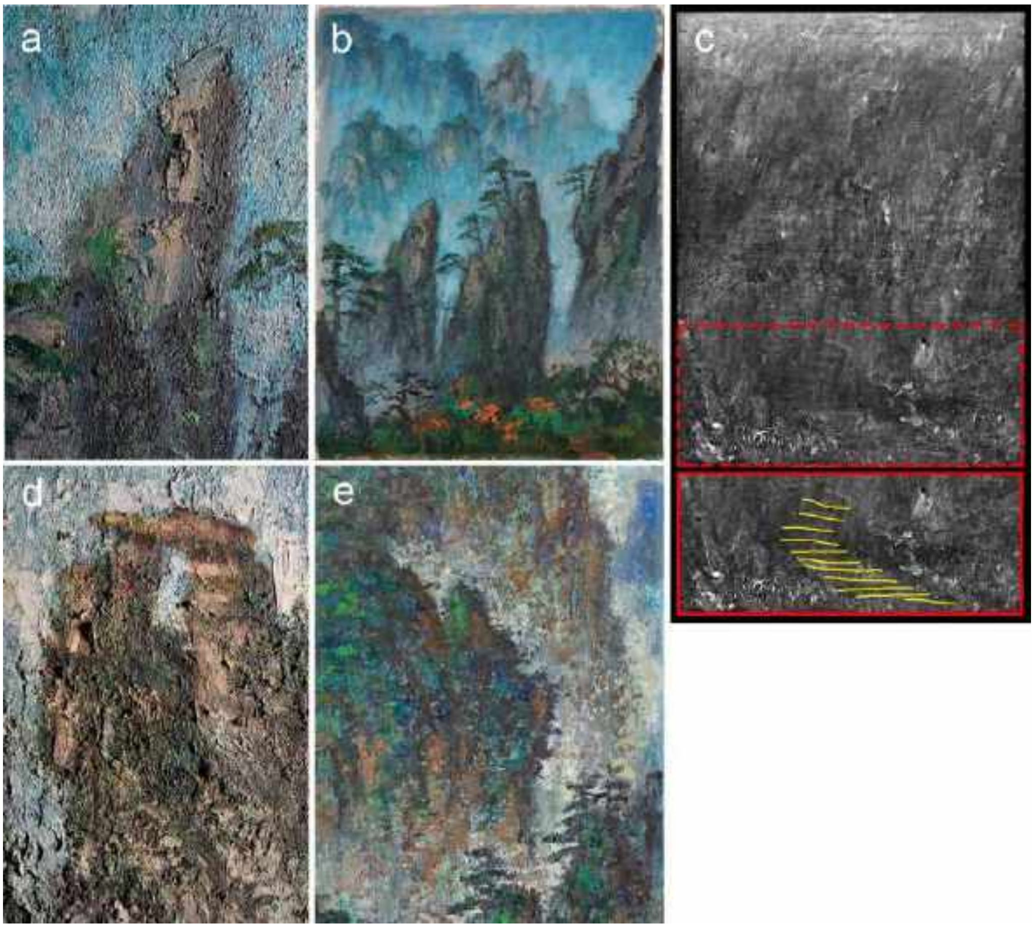

Figure 21. (**a**) Detail of *Mount Huangshan*, 1996, showing a brush and palette knife paint application. (**b**) Image of the same painting photographed in VIS and (**c**) corresponding XRR image and detail with superimposed tracing of the winding path. (**d**) Detail of *Mountain*, 1981, showing high impastos. (**e**) Detail of *Mount Huangshan*, 1986, showing the juxtaposing touches of paint for the execution of the misty and translucent air.

Regarding the vegetation, the artist frequently used small brushes for a calligraphic depiction of the trunks and limbs of trees, whereas the foliage was depicted using brushes and palette knives paint touches. It is also apparent from all the investigated paintings that the bold outlines of the shapes, Liu Kang is known for, were used intermittently and with reduced intensity as modulated texture sufficiently enhanced the forms.

Due to the complex paint application technique, the artworks were likely executed in more than one sitting. A disadvantage of this approach is a low sense of freshness and spontaneity observed in *Mount Huangshan* (1986), *Mount Huangshan* (1987) and *Mountain* (1995) (Figures 1d,e and 2d). Rendering of the compositional elements is monotonous mainly because of small dabs of paint and poor light effects. Nevertheless, the remaining paintings evoke the immediacy of the shape of the mountains in an expressive way. An interesting aspect of his technique is the occasionally occurring multicolour paint touches (Figure 22a) resulting from tools that are not completely cleaned, or from partially mixed paint. These features were additionally evidenced in the paint cross-sections, which show poorly blended raw colours within a single layer (Figure 22b). Moreover, this painting approach was recorded in a 1982 TV documentary about the artist (Figure 22c), revealing a cursory mixing of blue and white paints with a palette knife [35].

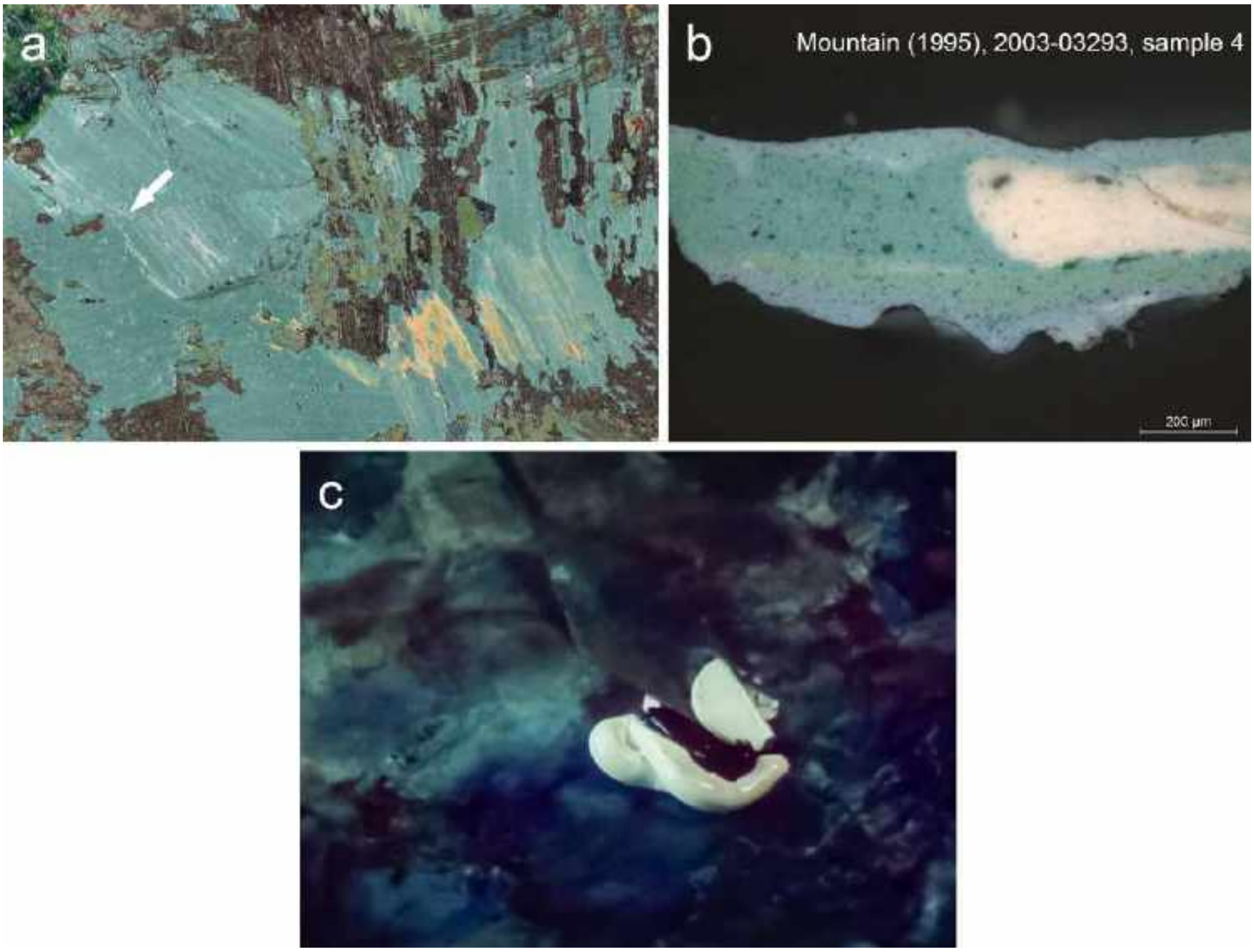

Figure 22. (**a**) Detail of partially mixed paint in *Mountain*, 1995. The arrow indicates the sampling spot. (**b**) Microscopy image of the cross-section of sample 4 taken from the sampling spot. (**c**) Still image from the 1982 TV documentary evidencing that the artist's paint mixing technique resulted in a partially mixed paint application. Copyrights of Mediacorp TV Singapore Pte Ltd.

3.7. Artist's Practice of Reusing Earlier Paintings

Combined use of the surface digital microscopy, VIS raking light imaging and XRR suggested that nine paintings underwent major alterations or were created over the earlier artworks. The evidence of the underlying paint schemes was found along the edges of the paintings (Figure 4a), through the losses of the current compositions or based on the unusual paint texture and XRR (Figure 23). However, the visualisation of hidden paintings was hampered by the complex paint application system of the current compositions. For this reason, VIS raking light photography revealed only the most pronounced paint texture relating to the hidden brushwork. The radiographic images mostly recorded the variations in the thickness of the paint layers as the primary source of contrast, resulting in poor rendering of the underlying compositions [58]. The thickness of the paint layers of the final images also significantly reduced the NIR penetrative capability. Nevertheless, some compositional details of the rejected composition were recorded with XRR in the painting *Mount Huangshan* (1996) (Figure 21c). In addition to the above-mentioned fragmentary evidence of the underlying paint schemes, Liu Kang's painting process over the recycled composition was documented in two archival photographs from the 1990s (Figure 6). These discoveries are especially interesting as they suggest that utilising unsatisfactory paintings became a norm during the twilight of Liu Kang's professional career.

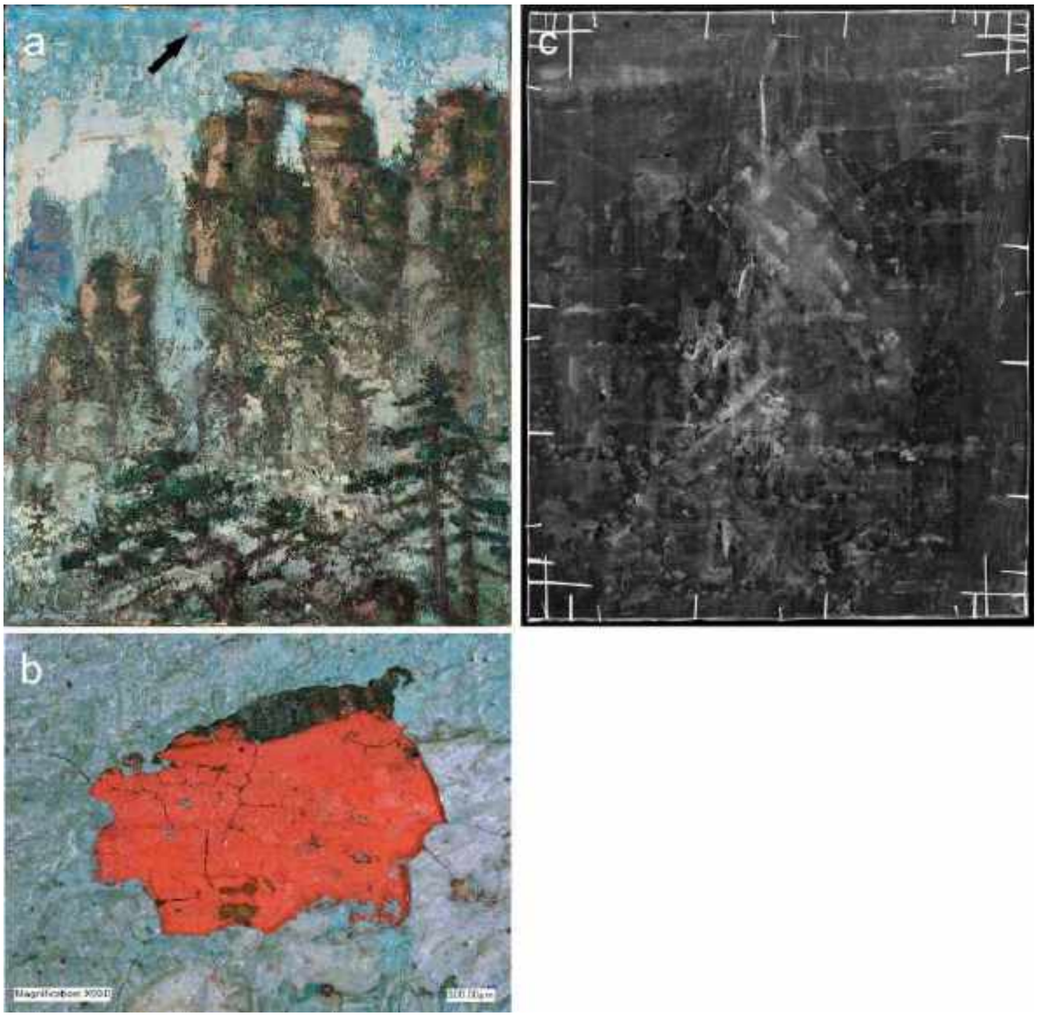

Figure 23. (**a**) Image of *Mountain*, 1981, photographed in VIS with the marked location of paint loss revealing a different paint scheme beneath the current composition. (**b**) Digital microscope image of red and black paint layer discernible through the paint loss of the same painting. (**c**) XRR image of the painting showing a poor rendering of the underlying composition.

3.8. Provenance of the Paintings

Of particular interest is establishing the provenance of the artworks. A preferential use of hardboards by Liu Kang appears to be adequate for outdoor painting. However, judging from the analytical data and archival photographs, it is fair to say that studio work played an important role in the development of the paintings—from the initial underpaint to final touches—which were often carried out over the recycled artworks in more than a single session (Figure 6). These findings converge with Liu Kang's 1981 interview, revealing: "He is now working on a series of landscapes on the theme of Huang-shan, the fabled mountains for Chinese landscape painters" [59]. Considering that the interview was conducted with the artist in Singapore, he likely worked concurrently on the mentioned landscapes in the studio. Moreover, due to his deteriorating eyesight in 1980s and 1990s, his painting productivity was reduced. In 1989 interview, he revealed: "I can't paint for periods now. Before, I could paint through the whole day. Now, I get tired. It is a problem" [60]. In 1992, the eyesight in his left eye was significantly reduced. However, the cornea transplant in 1993 enabled him to regain full functionality. Liu Kang made a reference to his laborious painting practice caused by worsening eyesight in the 1993 interview: "Since I couldn't see with my left eye, I am painting at much slower pace now. A painting which needed only two to three days to do in the past now takes me about two to three weeks" [61]. Judging from his health problems, it is very unlikely that the artist painted outdoor as this type of painting approach is characterised by rapid execution, usually in one or two sittings. Moreover, the detected combination of wet-on-wet and wet-on-dry paint application system reinforces this notion. Therefore, it seems reasonable to conclude that Liu Kang's main objective during his trips to China was forming an extensive visual library for future reference, whereas paintings were executed in his studio in Singapore based on photographs and sketches. Hence, his choice of hardboards was determined by the material's ability to endure his vigorous and complex way of handling of the paint contrary to the canvas.

4. Conclusions

The complementary use of analytical techniques, archival sources and art historical research significantly advanced our understanding of Liu Kang's painting materials and the working process employed for the creation of the Huangshan and Guilin landscapes.

As the investigated paintings span the period from 1977 to 1996, one would expect that the artist's painting methods and materials evolved during that time. Interestingly, this study showed otherwise. A degree of consistency with minor variability in his choice of materials and working practice was observed.

The technical examination highlighted a preferential use of hardboards resembling Masonite® Presdwood®. This type of the painting support was probably determined by the dynamic handling of the paint with the palette knives and brushes. The artist chose to paint on the hardboards directly, without a layer of the primer. Commercially made, oil-based grounds were found on a total of four cotton and linen canvases. The structure of the grounds strongly correlates with the type of the canvas. Hence, a single-layered mixture of lithopone and/or barium white and zinc white with some lead white was applied on dense cotton canvases. Linen canvases, although of different weave and density, were primed with double-layered grounds characterised by similar chemical compositions. The thick bottom layers comprise chalk mixed with lithopone and/or barium white and zinc white, lead white and titanium white. The upper layers are thinner than the bottom, but they are made of the same constituents, albeit mixed in different concentrations.

This study did not identify any preparatory underdrawings on the painting supports. The reason could be reduced NIR penetration capability through the thick paint layers or the artist's deliberate decision to skip the underdrawing stage and confidently establish the compositions with a broad laying of the colours. His painting technique is characterised by a skilled combination of wet-on-wet and wet-on-dry paint application systems with the alternate use of brushes and palette knives, resulting in peculiar impastos. Hence, the development of the compositions was probably laborious and involved more than one sitting. Moreover, the formation of an extensive reference material for future use and the evident practice of recycling earlier artworks suggests studio work rather than plein air sessions in China.

Given the fact that he used Royal Talens, Rowney and W&N oil paints in 1982 and the 1990s, it seems reasonable to conclude that the investigated landscapes were more likely executed using the same brands of the paints. The analytical results show that the artist employed a limited palette of colours characterised by a prevailing use of ultramarine, yellow and red iron-containing earths, viridian and titanium white. Other identified pigments used intermittently or at low concentrations are Prussian blue, cobalt blue, phthalocyanine blue, phthalocyanine green, naphthol red AS-D, umber, Cr-containing yellow(s), cadmium yellow or its variant(s), Hansa yellow G, lithopone and/or barium white and zinc white and bone black

Overall, the artist's predilection for a conventional and consistent colour scheme for depicting his subject matter is discernible. The artist mixed the paints on the palette rather than used them straight from the tubes. However, some identified pigment combinations suggest commercial mixtures, for instance, cadmium yellow with viridian or ultramarine and titanium white with zinc white. This interpretation was rendered based on the cross-referencing of the analytical data with Royal Talens's and W&N descriptions of the chemical composition of their oil paints in 1982 catalogues, which are contemporary to some of the landscapes created by the artist. Nevertheless, the information provided in the catalogues may be considered insufficient. Therefore, the analytical studies engaging reference samples of Royal Talens, Rowney and W&N would provide unambiguous information.

In addition to providing salient technical information regarding Liu Kang's painting process and materials, this study contributes to the growing knowledge of modern painting materials. The collected information may be taken as a reference for further in-depth research aiming to validate the use of Royal Talens, Rowney and W&N oil colours by the artist in the 1980s and 1990s.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of the materials identified or tentatively determined in the paint samples extracted from the investigated paintings.

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Mountain, 2003-03246	1977	Brown	3	**C, O**, Ca, Zn, Ti, Ba, S, Fe, Na, (Si, P, Al, Pb, Mg, Cl, Sr)	Lithopone and/or barium white and zinc white, titanium white, red iron-rich earth pigment, bone black, lead white	
		Brown	4	**C, O, Fe**, Si, Ca, S, (Cl, Pb, Sr, P, Ba, Na, Zn, Cr, Sn, Al, Ti)	Red iron-rich earth pigment, bone black, lithopone and/or barium white and zinc white, Cr-containing yellow(s), organic red on Sn and/or Al-containing substrate, titanium white	Lithopone and/or barium white and zinc white, iron-rich earth pigment, bone black, naphthol red AS-D, oil
		Blue	5	**C, O**, Na, Al, Si, S, Ca, (Sr, Zn, Mg, K, Ti, Fe)	Ultramarine, chalk, zinc white, titanium white	
		Blue	7	**C, O**, Ca, Zn, Ti, Ba, S, Na, (Al, P, Mg, Fe, Si)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, bone black	
		Blue	9	**C, O**, Ca, Zn, Ti, Ba, S, Na, (Al, Pb, Mg, Si, Cl)	Chalk, lithopone and/or barium white and zinc white, titanium white, ultramarine, lead white	
		Green	1	**C, O, Cr**, Zn, Ba, K, Na, (S, Al, Ca, Mg, Si, Ti, Cl, Fe, P)	Viridian, lithopone and/or barium white and zinc white, bone black, titanium white, Prussian blue	Viridian, lithopone and/or barium white and zinc white, zinc yellow, zinc soap, oil
		White	8	**C, O**, Ca, Zn, Ti, Ba, S, Na, (Mg, Si, Al, P)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, bone black	
Mountain, 2003-03313	1981	Brown	8	**C, O, Ba**, S, Al, Zn, Na, Sr, Si, Fe, (Pb, Ca, P)	Lithopone and/or barium white and zinc white, ultramarine, yellow iron-rich earth pigment, lead white, bone black	Lithopone and/or barium white and zinc white, bone black, zinc soap, oil
		Yellow	7	**O, C, Ba**, Zn, Ti, Ca, Cr, S, Fe, Si, Al, Na, (Mg, P, Pb, K)	Lithopone and/or barium white and zinc white, titanium white, chalk, viridian, yellow iron-rich earth pigment, bone black	Lithopone and/or barium white and zinc white, chalk, Hansa Yellow G, viridian, yellow iron-rich earth pigment, zinc soap, oil

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Blue	4	**C, O, Zn**, Ca, Ba, Ti, S, Pb, Na, Al, (Si, Mg, Cd, Cl, Fe, P, Sr, Cr)	Lithopone and/or barium white and zinc white, titanium white, lead white, ultramarine, cadmium yellow or its variant, bone black	
		Blue	6	**Zn, C, O, Na**, (Al, Si, Ba, S, Ti, Ca)	Lithopone and/or barium white and zinc white, ultramarine, titanium white, chalk	
		Green	3	**C, O, Zn**, Ca, Ba, Cd, Na, S, (Cl, Si, Mg, Al)	Lithopone and/or barium white and zinc white, chalk, cadmium yellow or its variant, ultramarine	Lithopone and/or barium white and zinc white, chalk, zinc soap, oil
		Green	9	**C, O**, Pb, Ba, Zn, Al, S, Cr, Si, Fe, (Na, Ti, Ca, Cl, Mg)	Lead white, lithopone and/or barium white and zinc white, ultramarine, viridian, chalk	
		White	5	**C, O, Ba**, Ti, S, Zn, Al, (Na, Si, Ca, Sr, P)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, bone black	
Mount Huangshan, 2003-03304	1983	Brown	3	**Zn, C, O, Na**, Fe, Ba, S, (Cr, Al, Si, K, Pb, Ti)	Lithopone and/or barium white and zinc white, red iron-rich earth pigment, Cr-containing yellow, organic red, lead white, titanium white	Lithopone and/or barium white and zinc white, naphthol red AS-D, zinc soap, oil
		Brown	6	**Zn, C, O**, Na, Cr, Ba, K, (S, Al, Fe, Si, Pb, Cl, Ti)	Lithopone and/or barium white and zinc white, Cr-containing yellow(s), ultramarine, red iron-rich earth pigment, titanium white	
		Blue	2	**C, O, Ba**, Ca, Zn, S, Al, Na, Ti, (Pb, Si, Mg, Cl)	Lithopone and/or barium white and zinc white, chalk, ultramarine, titanium white, lead white	
		Green	4	**Zn, C, O**, Ba, Cl, Na, Al, S, Si, (Cr, Fe, Mg, Cu, K, Pb, Sr, Ca)	Lithopone and/or barium white and zinc white, phthalocyanine green, Prussian blue, lead white, chalk	Lithopone and/or barium white and zinc white, phthalocyanine green, Prussian blue, zinc soap, oil
		Green	5	**C, O, Zn, Ba**, Al, S, Na, Cl, Ti, (Si, Ca, Pb, Sr, Mg, Fe)	Lithopone and/or barium white and zinc white, ultramarine, titanium white, chalk, lead white	Lithopone and/or barium white and zinc white, phthalocyanine green, ultramarine, zinc soap, oil
		White	1	**Zn, C, O**, Na, Ti, Ca, (Ba, Fe, Al, Si, S)	Lithopone and/or barium white and zinc white, titanium white, chalk, ultramarine, yellow iron-rich earth pigment	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
Mount Huangshan, 2003-03327	1986	Brown	5	**C, O, Zn**, Fe, Ti, Ca, Na, Mg, Si, Al, (P, Sr, S, Mn)	Zinc white, red iron-rich earth pigment, titanium white, organic red on Al-containing substrate, umber, bone black	Red iron-rich earth pigment, organic red, chalk, zinc soap, oil
		Blue	2	**C, Zn, O**, Na, Al, S, Ba, Ti, Si, (Ca, Fe, Cl, K)	Lithopone and/or barium white and zinc white, ultramarine, titanium white, chalk, Prussian blue	
		Blue	7	**C, O**, Al, Zn, Co, Ca, Si, Na, (Mg, S, Fe, Cu, Ti, Cl, Pb, Cr, P)	Ultramarine, zinc white, cobalt blue, phthalocyanine blue, titanium white, viridian, lead white, bone black	Phthalocyanine blue, cobalt blue, chalk, zinc soap, oil
		Green	3	**C, O, Zn**, Ca, Na, Ba, S, Si, Fe, (Al, Cl, Mg, Ti)	Lithopone and/or barium white and zinc white, chalk, ultramarine, yellow iron-rich earth pigment, titanium white	
		Green	4	**C, O, Fe**, Ca, Si, Al, Ba, S, Cl, (Ti, Zn, Mg, Cu)	Yellow iron-rich earth pigment, chalk, lithopone and/or barium white and zinc white, titanium white, phthalocyanine green	Yellow ochre, lithopone and/or barium white and zinc white, chalk, phthalocyanine green, zinc soap, oil
		White	6	**C, O, Ti**, Zn, Ca, Mg, Al, Na, (Fe, S, Si, Cl)	Titanium white, zinc white, chalk, ultramarine, yellow iron-rich earth pigment	
Mount Huangshan, 2003-03251	1987	Brown	4	**C, O, Fe**, Al, Si, Na, S, Ca, Ba, (P, Ti, Mn, Zn, Mg, Pb, K, Cl)	Umber, bone black, lithopone and/or barium white and zinc white, titanium white, lead white	Umber, lithopone and/or barium white and zinc white, oil
		Blue	2	**C, O**, Ti, Zn, Ca, Mg, Al, Na, (S, Si, Fe, Cl)	Titanium white, zinc white, chalk, ultramarine, Prussian blue	
		Blue	5	**O, Zn, Ba**, C, S, Na, Al, Ti, Si, Ca, (Mg, Fe, Cl, Sr, K, Pb)	Lithopone and/or barium white and zinc white, titanium white, ultramarine, lead white	Lithopone and/or barium white and zinc white, ultramarine, chalk, oil
		Green	3	**C, O**, Na, Al, S, Cl, Ti, Zn, Ba, (Fe, Ca, Si, Sr, Pb, Cu)	Ultramarine, lithopone and/or barium white and zinc white, titanium white, yellow iron-rich earth pigment, chalk, lead white, phthalocyanine green, lead white	
		Green	7	**C, O, Zn**, Ca, Na, S, Ti, Fe, Al, Si, (Ba, Mg, Cl, K)	Lithopone and/or barium white and zinc white, chalk, ultramarine, titanium white, yellow iron-rich earth pigment	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		White	6	**C, O, Ti**, Zn, Ca, Al, Mg, Na, (S, Si, Fe, Cl)	Titanium white, zinc white, chalk, ultramarine, yellow iron-rich earth pigment	
Mountains, 2003-03306	1991	Brown	6	**C, O, Zn**, Ti, Fe, Ca, Na, Ba, Al, Mg, (Si, S, Pb, P)	Lithopone and/or barium white and zinc white, titanium white, red and yellow iron-rich earth pigment, lead white, bone black	
		Blue	1	**C, O, Zn**, Ca, Na, Ti, (Mg, Al, Ba, Si, Pb, S)	Lithopone and/or barium white and zinc white, chalk, titanium white, ultramarine, lead white	
		Violet	5	**C, O, Zn**, Ti, Ba, Al, Ca, Na, Si, S, (Mg, Fe, Pb)	Lithopone and/or barium white and zinc white, titanium white, chalk, ultramarine, yellow iron-rich earth pigment, lead white	
		Green	8	**C, O, Ca, Zn**, S, Na, (Si, Cl, Mg, Al, Fe, Ti)	Chalk, zinc white, ultramarine, yellow iron-rich earth pigment, titanium white	Yellow iron-rich earth pigment, Hansa yellow G, chalk, zinc soap, oil
		Green	9	**C, O, Ca, Zn**, S, Na, (Cl, Si, Mg, Fe, Al, Ba)	Chalk, lithopone and or barium white and zinc white, ultramarine, yellow iron-rich earth pigment	Chalk, yellow iron-rich earth pigment, Hansa yellow G, zinc soap, oil
		Green	10	**C, O**, Ca, Zn, Fe, S, Ba, Si, Cl, Al, (Ti, Na, Mg, Cu, Pb)	Chalk, lithopone and/or barium white and zinc white, yellow iron-rich earth pigment, ultramarine, titanium white, phthalocyanine green, lead white	Chalk, lithopone and/or barium white and zinc white, yellow iron-rich earth pigment, phthalocyanine green, Hansa yellow G, zinc soap, oil
		Grey	4	**C, O, Ti**, Zn, Ca, Ba, Al, Mg, (Na, S, Si, Fe)	Titanium white, lithopone and/or barium white and zinc white, chalk, ultramarine, yellow iron-rich earth pigment	
Mount Huangshan, 2003-03376	1993	Brown	6	**C, O, Zn**, Ti, Fe, Na, Ca, Al, Mg, Si, (S, P)	Zinc white, titanium white, yellow and red iron-rich earth pigment, bone black	
		Brown	7	**O, C, Fe**, Zn, Ca, Si, Al, Na, P, Mg, Ti, (Mn, Pb, Sr, S, Cl, K)	Yellow and red iron-rich earth pigment, umber, bone black, titanium white, lead white	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Yellow	4	**C, O**, Ca, Ba, Cd, S, Zn, (Fe, Si, Al, Na, Mg, Cl, Ti, Pb)	Lithopone and/or barium white and zinc white, chalk, cadmium yellow or its variant, yellow iron-rich earth pigment, titanium white, lead white	
		Blue	2	**C, O, Zn**, Na, Ti, Ca, Al, Co, (Mg, Si, Fe, S)	Zinc white, ultramarine, titanium white, chalk, cobalt blue, yellow iron-rich earth pigment	Ultramarine, cobalt blue, chalk, zinc soap, oil
		Blue	8	**C, O**, Ti, Ca, Zn, Cr, Al, Pb, Mg, (Si, Na, Co, S)	Titanium white, chalk, zinc white, viridian, lead white, ultramarine, cobalt blue	
		Green	5	**C, O**, Cr, Zn, Ca, Ba, Ti, Fe, Si, Al, S, (Mg, Cd, P, Cl)	Viridian, lithopone and/or barium white and zinc white, titanium white, yellow iron-rich earth pigment, cadmium yellow or its variant, bone black	
		Grey	3	**C, O, Ti**, Zn, Ca, Al, Mg, (Na, S, Pb, Si)	Titanium white, zinc white, chalk, ultramarine, lead white	
Mount Huangshan, 2003-03307	1994	Brown	4	**C, O**, Ti, Fe, Zn, Ca, Mg, Al, (Na, Si, S, Pb, P)	Titanium white, yellow and red iron-rich earth pigment, zinc white, bone black, ultramarine, lead white	Iron-rich earth pigment, chalk, zinc soap, oil
		Brown	6	**C, O**, Fe, Ca, Si, Ti, Ba, S, Al, (Zn, Mg, P, Sr, Cl, Pb)	Red iron-rich earth pigment, bone black, lithopone and/or barium white and zinc white, lead white	
		Yellow (yellow cluster)	7	**C, O, Fe, Ca**, Zn, (Na, Mg, Si, S, Al)	Yellow iron-rich earth pigment, chalk, zinc white	
		Yellow (green cluster)		**C, O, Fe**, Ca, Zn, Al, (Si, Ti, Mg, S, Co, Ba, Cl)	Yellow iron-rich earth pigment, lithopone and/or barium white and zinc white, chalk, ultramarine, Co-containing pigment	
		Blue	2	**C, O**, Ti, Zn, Ca, Al, Ba, Mg, Co, (Si, Na, S)	Titanium white, lithopone and/or barium white and zinc white, chalk, ultramarine, cobalt blue	Lithopone and/or barium white and zinc white, chalk, ultramarine, cobalt blue, zinc soap, oil
		Green	3	**C, O, Ca**, Al, Ti, Cr, Zn, Si, (Fe, Mg, Co, Cl, Na, Sr, S, Pb, P)	Ultramarine, titanium white, viridian, zinc white, cobalt blue, yellow iron-rich earth pigment, lead white, bone black	Chalk, ultramarine, viridian, cobalt blue, chalk, zinc soap, oil

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Green	5	**C, O, Zn**, Fe, Na, (Cl, Ca, Al, Si, Ti, S)	Zinc white, yellow iron-rich earth pigment, ultramarine, chalk, titanium white	
		Grey	1	**C, O, Zn**, Ti, Na, Ca, Mg, Al, (S, Si, Co, Fe)	Zinc white, titanium white, chalk, ultramarine, cobalt blue contamination, yellow iron-rich earth pigment	
Mount Huangshan, 2003-03378	1995	Brown	8	**C, O, Zn**, Ca, Na, Fe, Si, (P, Al, Mg, S, Ti, Cr, Mn, Ba, K, Cl)	Lithopone and/or barium white and zinc white, bone black, umber, titanium white, Cr-containing yellow pigment, titanium white	
		Blue	1	**C, Zn, O**, Al, Ca, Co, Na, (Ti, Mg, Si, S, Ba)	Lithopone and/or barium white and zinc white, chalk, ultramarine, cobalt blue, titanium white	Chalk, ultramarine, cobalt blue, oil
		Blue	2	**C, O, Zn**, Ti, Ba, Ca, Al, Na, Mg, (Cr, Si, S, Fe)	Lithopone and/or barium white and zinc white, titanium white, chalk, ultramarine, viridian	
		Violet	5	**C, O**, Zn, Ti, Ca, Fe, Ba, Al, Si, Mg, (Na, P, S, K)	Lithopone and/or barium white and zinc white, titanium white, red iron-rich earth pigment, ultramarine, bone black	
		Green	3	**C, O, Zn**, Fe, Na, Ca, (Ti, Al, Ba, Cl, Si, Mg, S)	Lithopone and/or barium white and zinc white, chalk, titanium white, ultramarine, yellow iron-rich earth pigment, chalk	Hansa yellow G, yellow iron-rich earth, chalk, oil
		Green	4	**C, O, Cr**, Ca, Ba, Zn, Si, (Al, S, Mg, Na, Cl, Ti, Fe, K)	Viridian, chalk, lithopone and/or barium white and zinc white, titanium white, yellow iron oxide	
		Grey	7	**C, O**, Ti, Zn, Ba, Ca, Al, Mg, (Na, Fe, S, Pb, Si, Cr)	Titanium white, lithopone and/or barium white and zinc white, chalk, ultramarine, yellow iron-rich earth pigment, viridian, lead white	
Mountain, 2003-03293	1995	Brown	5	**C, O**, Ti, Fe, Ca, Zn, Al, (Mg, Na, Si, S, P)	Titanium white, yellow iron-rich earth pigment, bone black, zinc white	Chalk, yellow iron-rich earth pigment, bone black, zinc soap, oil
		Brown	8	**O, C, Fe**, Ca, Si, P, Al, Mg, Mn, Zn, (Na, S, K, Ti, Sr, Pb, Cl)	Red iron-rich earth pigment, umber, bone black, zinc white, titanium white, lead white	

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Blue	3	**C, O**, Zn, Ti, Ca, Na, Mg, (Al, Cr, S, Si, Cl, Pb)	Zinc white, titanium white, chalk, ultramarine, viridian, lead white	
		Green	6	**C, O**, Zn, Ti, Ca, Cr, Na, Fe, Al, (Mg, Si, S, Cl, Sr)	Zinc white, titanium white, chalk, viridian, yellow iron-rich earth pigment	
		Green	7	**C, O, Cr**, Ca, Ba, Si, Al, Zn, Ti, (S, Na, Mg, Cl)	Viridian, chalk, lithopone and/or barium white and zinc white, titanium white	Viridian, chalk, lithopone and/or barium white and zinc white, Hansa yellow G, oil
		Grey	4	**C, O, Ti**, Zn, Ca, Al, Mg, (Na, Co, S, Cr, Si, Fe)	Titanium white, zinc white, chalk, ultramarine, viridian, Co-containing pigment, yellow iron-rich earth pigment	
Mount Huangshan, 2003-03257	1996	Brown	8	**C, O, Zn**, Ba, Fe, Pb, Ca, S, Na, Al, (Si, Cr, Cl, P, Sr, Mg)	Lithopone and/or barium white and zinc white, Prussian blue, Cr-containing yellow(s), organic red on Al-containing substrate, ultramarine, bone black	Lithopone and/or barium white and zinc white, Prussian blue, chrome yellow, yellow iron-rich earth pigment, organic red, bone black, zinc soap, oil
		Yellow	7	**C, O, Fe**, Ca, Ba, Cd, S, Zn, (Cl, Sn, Mg, Na, Al, Si)	Yellow iron-rich earth pigment, chalk, lithopone and/or barium white and zinc white, cadmium yellow or its variant, organic red on Sn-containing substrate	Yellow iron-rich earth pigment, lithopone and/or barium white and zinc white, cadmium yellow or its variant, naphthol red AS-D, oil
		Blue	2	**C, O, Ti, Zn**, Ca, Na, (Fe, Si, Mg, Pb, Al, S, P, Cl)	Titanium white, zinc white, chalk, yellow iron-rich earth pigment, lead white, ultramarine, bone black	
		Blue	3	**C, O**, Ti, Zn, Ca, Ba, Fe, Al, Mg, (S, Si, Cl, Cr, Na, Pb)	Titanium white, lithopone and/or barium white and zinc white, chalk, Prussian blue, ultramarine, viridian, lead white	
		Green	5	**C, O, Zn, Ca**, S, Na, Ba, (Mg, Cl, Al, Si, Sr, P, Ti)	Lithopone and/or barium white and zinc white, ultramarine, bone black, titanium white	Lithopone and/or barium white and zinc white, chalk, Hansa yellow G, ultramarine, yellow iron-rich earth pigment, zinc soap, oil

Table A1. *Cont.*

Title and Inventory Number	Date	Colour	Sample	SEM-EDS * Detected Elements	PLM, SEM-EDS Tentative Assignments	FTIR Identification
		Green	6	**C, O, Zn, Ba**, Pb, S, Fe, Cr, Na, Ca, (Al, Si, P, Mg, Cl, K)	Lithopone and/or barium white and zinc white, chrome yellow, Prussian blue, bone black	Lithopone and/or barium white and zinc white, chrome yellow, Prussian blue, chalk, zinc soap, oil
		Grey	4	**O, C, Ti**, Zn, Ca, Ba, Na, (Mg, Si, P, Al, Pb, S)	Titanium white, lithopone and/or barium white and zinc white, ultramarine, bone black, lead white	

* Major elements are provided in bold type, minor elements in plain type and trace elements in brackets.

Blanc			
Blanc d'argent	++ 101		Carbonate bas. de plomb
Blanc de titane	+++ 105		Dioxyde de titane
Blanc de zinc	+++ 104		Oxyde de zinc
Blanc mélangé (titane.zinc)	+++ 103		Dioxyde de titane + oxyde de zinc
Blanc permanent	+++ 115		Dioxyde de titane + oxyde de zinc
Jaune			
Auréoline	++ 242	4	Nitrites de potassium et de cobalt
Jaune brillant clair	+++ 239	2	Sulfure de cadmium + oxyde de zinc
Jaune brillant foncé	+++ 240	2	Sulfure de cadmium + oxyde de zinc
Jaune cadmium	+++ 209	5	Sulfure de cadmium
Jaune cadm. citron	+++ 207	5	Sulfure de cadmium
Jaune cadm. clair	+++ 208	5	Sulfure de cadmium
Jaune cadm. foncé	+++ 210	5	Sulfure de cadmium
Jaune chrome citron	++ 217	★2	Chromate de plomb
Jaune chrome clair	++ 218	★2	Chromate de plomb
Jaune chrome foncé	++ 219	★2	Chromate de plomb
Jaune Naples clair ex.	+++ 222	2	Sulfure de cadmium + oxyde de zinc
Jaune Naples foé. ex.	+++ 223	2	Sulfure de cadmium + oxyde de zinc
Jaune Naples rougeâtre ex.	+++ 224	2	Sulfure de cadmium + sélénio de cadmium + oxyde de zinc
Jaune indien	++ 244	3	Sulfure de cadmium + pigment organique
Jaune oxyde transp.	+++ 265	3	Oxyde de fer synthétique
Jaune Rembrandt	+++ 252	3	Sulfure de cadmium + oxyde de zinc + oxyde de chrome hydraté
Jaune Talens	++ 248	3	Pigment azoïque
Jaune Talens citron	+++ 246	3	Pigment azoïque
Jaune Talens clair	++ 247	3	Pigment azoïque
Jaune Talens foncé	++ 249	3	Pigment azoïque
Ocre d'or	+++ 231	1	Terre naturelle
Ocre jaune	+++ 227	1	Terre + oxyde de fer synth.
Ocre jaune claire	+++ 228	1	Terre + oxyde de fer synth.
Stil de grain jaune	+ 251	3	Pigment organique
Terre de Sienne nat.	+++ 234	1	Terre naturelle
Orange			
Jaune de cadm. orange	+++ 211	5	Sélénio-sulfure de cadmium
Jaune de chr. orange	++ 220	★2	Chromate bas. de plomb
Jaune Talens orange	++ 250	3	Pigment azoïque + pigment organique
Rouge			
Carmin brûlé	++ 323	3	Laque de gar. synth. + outremer synth.
Carmin d'alizarine	++ 319	3	Laque de gar. synth.
Cramoisi d'alizarine	++ 326	3	Laque de gar. synth.
Laque gar. claire	++ 327	3	Laque de gar. synth.
Laque gar. d'al.brunâtre	++ 333	3	Laque de gar. synth. + pigment organique
Laque gar. d'al. cl.	++ 328	3	Laque de gar. synth.
Laque gar. foncée	++ 331	3	Laque de gar. synth.
Laque gar. rose	++ 329	3	Laque de gar. synth.
Laque géranium	++ 356	3	Pigment organique
Laque de gar. rose ant.	++ 330	3	Laque de gar. synth.
Ocre de chair	+++ 373	1	Terre
Rose Rembrandt	+++ 368	6	Pigment quinacridone
Rouge anglais clair	+++ 340	1	Oxyde de fer synth.
Rouge cadmium clair	+++ 303	6	Sélénio-sulfure de cadmium
Rouge cadm. écarlate	+++ 308	6	Sélénio-sulfure de cadmium
Rouge cadm. fcé	+++ 306	6	Sélénio-sulfure de cadmium
Rouge cadm. pourpre	+++ 309	6	Sélénio-sulfure de cadmium
Rouge de Venise	+++ 349	1	Oxyde de fer synth.
Rouge indien	+++ 347	1	Oxyde de fer synth.
Rouge oxyde transp.	+++ 378	3	Oxyde de fer synth.
Rouge Pouzzoles	+++ 355	1	Oxyde de fer synth.
Rouge Talens clair	++ 364	3	Pigment azoïque
Rouge Talens foncé	++ 365	3	Pigment azoïque
Rouge Talens pourp.	++ 379	3	Pigment organique
Tête morte violette	+++ 344	1	Oxyde de fer synth.
Vermillon de Holl. ex.	++ 316	3	Pigment organique
Vermillon de Chine ex.	++ 315	3	Pigment organique
Brun			
Bitume extra	+ 414	1	Pigment organique
Brun oxyde transp.	+++ 426	3	Oxyde de fer synthétique
Brun Rembrandt	+++ 419	3	Terre brûlée + outremer synth. + produit de carbonisation
Brun Talens	++ 413	3	Outremer synth. + terre + pigment organ.
Brun Van Dyck	+++ 403	1	Terre brûlée + produit de carbonisation
Ocre brune claire	+++ 405	1	Terre nat. + terre brûl. + prod. de carbon.
Ocre brune foncée	+++ 406	1	Terre nat. + terre brûl. + prod. de carbon. + oxyde de fer synth.
Ocre foncée	+++ 407	1	Terre nat. + terre brûl. + prod. de carbon.
Ocre rouge	+++ 423	1	Oxyde de fer synth.
Sépia extra	+++ 416	1	Terre brûlée + produit de carbonisation
Stil de grain brun	+ 418	3	Pigment organique
Terre de Sienne brûl.	+++ 411	1	Terre brûlée
Terre d'ombre brûlée	+++ 409	1	Terre brûlée
Terre d'ombre nat.	+++ 408	1	Terre naturelle
Terre d'ombre verdâtre	+++ 410	1	Terre naturelle
Terre verte brûlée	+++ 412	1	Terre nat. + terre brûl.
Violet			
Outremer violet	+++ 507	2	Outremer synth.
Violet de cobalt clair	+++ 540	6	Phosphate de cobalt alum. + phosphate de cobalt ammonium
Violet de cobalt fcé	+++ 541	6	Phosphate de cobalt
Violet de cobalt roug.	+++ 544	6	Phosphate de cobalt ammonium
Violet permanent	+++ 553	3	Pigment dioxazine
Violet perm. rougeâtre	+++ 567	4	Pigment quinacridone + pigment dioxazine
Bleu			
Bleu céruléum	+++ 534	4	Stannate de cobalt
Bleu de cobalt clair	+++ 513	4	Aluminate de cobalt
Bleu de cobalt foncé	+++ 515	4	Aluminate de cobalt
Bleu de manganèse	+++ 521	3	Manganate de barium
Bleu de Prusse	+++ 508	★2	Ferrocyanure de fer
Bleu de Sèvres	+++ 530	3	Phtalocyanine de cuivre + oxyde de zinc
Bleu Rembrandt	+++ 520	3	Phtalocyanine de cuivre
Bleu royal	+++ 517	3	Aluminate de cobalt + oxyde de zinc + chromate bas. de plomb
Bleu turquoise	+++ 522	3	Phtalocyanine de cuivre + oxyde de zinc + poly-cl-phtalocyanine de cuivre
Indigo extra	++ 533	★2	Produit de carbonisation + ferrocyanure de fer + outremer synth.
Outremer clair	+++ 505	2	Outremer synth.
Outremer foncé	+++ 506	2	Outremer synth.
Vert			
Cendre verte extra	+++ 639	2	Poly-cl-phtalocyanine de cuivre + ox. de zinc
Cinabre vert clair	++ 626	2	Chromate de plomb + poly-cl-phtalocyanine de cuivre
Cinabre vert clair ex.	+++ 642	4	Sulfure de cadmium + outremer synth.
Cinabre vert foncé	++ 627	2	Oxyde de fer synth. + pigment organique
Cinabre vert foncé ex.	+++ 643	4	Sulfure de cadmium + ox. de chrome hydraté
Terre verte	+++ 629	1	Terre
Vert bleuâtre Rembrandt	+++ 647	3	Phtalocyanine de cuivre + poly-cl-phtalocyanine de cuivre
Vert de cadmium clair	+++ 604	5	Sulfure de cadmium + ox. de chrome hydraté
Vert de cadm. foncé	+++ 605	5	Sulfure de cadmium + ox. de chrome hydraté
Vert de cobalt clair	+++ 611	4	Combinaison d'oxyde de cobalt et de zinc
Vert de cobalt foncé	+++ 612	4	Combinaison d'oxyde de cobalt et de zinc
Vert de Sèvres	+++ 650	3	Poly-cl-phtalocyanine de cuivre + ox. de zinc
Vert de vessie	++ 623	3	Pigment organique
Vert émeraude	+++ 616	4	Ox. de chrome hydraté
Vert jaunâtre perm.	++ 633	3	Pigment azoïque + poly-cl-phtalocyanine de cuivre
Vert olive	+ 620	2	Pigment organique
Vert oxyde chrome	+++ 668	4	Oxyde de chrome
Vert permanent clair	++ 618	3	Ox. de chrome hydraté + pigment azoïque
Vert permanent foncé	+++ 619	3	Ox. de chrome hydraté
Vert P. Véronèse	+++ 615	2	Poly-cl-phtalocyanine de cuivre + ox. de zinc
Vert Rembrandt	+++ 634	3	Poly-cl-phtalocyanine de cuivre
Vert Talens clair	++ 635	3	Poly-cl-phtalocyanine de cuivre + pigment azoïque
Vert Talens foncé	++ 636	3	Poly-cl-phtalocyanine de cuivre + pigment organique
Noir et gris			
Gris chaud	+++ 718	2	Oxyde de zinc + terre brûlée + produit de carbonisation
Gris froid	+++ 717	2	Oxyde de zinc + produit de carbonisation
Noir de bougie	+++ 702	1	Produit de carbonisation
Noir d'ivoire	+++ 701	1	Produit de carbonisation

Pour la signification des signes voir au verso.

Figure A1. Oil colours and their pigment compositions, listed in the catalogue of Royal Talens (French edition) from 1982. The highlighted details indicate colours that could be tentatively linked to the identified pigment mixtures.

Aurora Yellow	Sulphide of cadmium.	Yellow 37 (77199)
Cadmium Lemon	Different shades of sulphide of cadmium.	Yellow 37 (77199)
Cadmium Yellow		Yellow 37 (77199)
Cadmium Yellow Pale		Yellow 37 (77199)
Naples Yellow	In Water Colour it is a combination of cadmium sulphide, ferric oxide and zinc oxide. In Oil it is a mixture of Cadmium Yellow, Flake White, Light Red and Yellow Ochre.	
Cremnitz White	Pure basic carbonate of lead, ground in safflower oil.	White 1 (77597)
Flake White No.1 Flake White No.2 (less stiff than No.1)	Basic carbonate of lead combined with a small percentage of zinc oxide, ground in safflower oil. N.B.The addition of a little zinc oxide not only improves the consistency and general working properties of the pigment, but also conduces to the maintenance of its whiteness and enables it to give clearer tints with the colder colours. Artists who prefer to work with the pure basic carbonate of lead employed by the Old Masters should use Cremnitz White.	White 1 (77597)/ White 4 (77947)
Silver White	Synonymous with Flake White.	
Titanium White	In Oil, Titanium dioxide, with a small percentage of zinc oxide ground in safflower oil. N.B. The addition of a little zinc oxide not only improves the consistency and general working properties of this pigment, but also conduces to the maintenance of its whiteness and enables it to give clearer tints with colder colours. In Acrylic, this is Titanium dioxide.	White 6 (77891) White 4 (77947)
Winsor Blue	Copper phthalocyanine.	Blue 15 (74160)
Winsor Green	Chlorinated copper phthalocyanine. In Alkyd an azo methane pigment.	Green 7 (74260) Yellow 109 Blue 15 (74160)
Winsor Yellow	Arylamide Yellow.	Yellow 1 (11680)

Figure A2. Selected compositions of pigments, listed in the catalogue of W&N from 1982, used for manufacturing of oil, watercolours, acrylic and alkyd paints for artists.

Whites List

Cremnitz White	A	©	Permanent White	AA	
Flake White No 1	A	©	Silver White	A	©
Flake White No 2 (Less stiff than No 1)	A	©	Titanium White	AA	
			Zinc White	AA	

Figure A3. White oil colours listed in the catalogue of W&N from 1979.

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Observations on Selected Aspects of Liu Kang's Painting Practice

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ABSTRACT This article gathers, for the first time, some intriguing technical features of Liu Kang's painting practice, which spans seven decades. These features encompass retouching, alteration as well as the painting over of rejected compositions and painting on the reverse sides of earlier artworks. As Liu Kang (1911–2004) did not discuss the technical details of his artistic process, an exploration of these aspects of the artist's expression helps us understand the motivation behind his unconventional decisions. The paint layers were characterised through imaging methods like visible light (VIS), ultraviolet fluorescence (UVF), near-infrared (NIR), reflectance transformation imaging (RTI), digital optical microscopy (DOM) and X-ray radiography (XRR). The technical analyses were additionally supplemented with archival sources. The results showed that some aspects of the artist's painting practice may distort the provenance of the paintings, impact dating, visual interpretation of his painting technique and style, as well as future conservation and display decisions. The presented case studies discuss the influence of Liu Kang's unconventional painting approaches on the perception and interpretation of his artworks. Additionally, some hidden alterations and entirely new compositions were revealed for the first time and presented here, adding to growing knowledge about the artist's painting technique. Moreover, universal aesthetical and ethical considerations were discussed in the context of the conservation and display approach to the artist's retouching work and double-sided paintings. Besides, this research promotes a need for obtaining a comprehensive understanding of Liu Kang's painting practice and coherent guidelines to ensure proper presentation of his artworks and to prevent misinterpretation of his technique and artistic outcomes.

Key Words Liu Kang, Retouches, Alterations, Hidden paintings, Double-sided paintings

1. INTRODUCTION

Liu Kang (1911–2004) was a Chinese emigree to Singapore who gained art education in two major East and West art centres – Shanghai and Paris (Chow, 1996; 2000; Hoe, 1955). He became widely known in Southeast Asia for his contribution to the Nanyang style – a painting concept practised in Singapore from the late 1940s to the 1960s (Sabapathy, 1982). The style drew from two opposite artistic sources – the School of Paris and Chinese painting traditions. His amalgamation of different techniques and aesthetics was applied to depicting Southeast Asian or local subject matter (Ong, 2012; Rawanchaikul, 2011; Sabapathy, 1987; Sullivan, 1957). The incorporation of stylistic elements of the batik technique was an additional feature of the style (Chow, 1996; Lizun *et al.*, 2022a; Ong *et al.*, 2011). Besides having a vital role in developing the Nanyang style, Liu Kang repeatedly departed from his established artistic way to search for new sources of inspiration and to experiment with various forms of expression (Liu, 1997). Moreover, his frequent re-evaluations of old themes resulted in the creation of his iconic series of Huangshan and Guilin mountains as well as studies of nudes. Additionally, the artist's painting practice is characterised by various unconventional technical solutions. For instance, the alteration of completed compositions is a frequently observed feature of the paint layers (Lizun, 2021a; Lizun *et al.*, 2022a; Lizun *et al.*, 2022b), even though the artist thoroughly studied the subject matter (Wai Hon, 1997) through intensive sketching and photography prior to the actual painting (Liu, 2002; Yow, 2011). This suggests that the paintings did not always arise in a linear workflow. Besides consisting of compositional and colouristic changes, which were often conducted in distinct stages, his creative process was also shaped by unpredictable emotions. Hence, some of his artistic outcomes remain difficult to interpret (Lizun *et al.*, 2022b). Moreover, the artist's painting practice was also impacted by financial difficulties or the lack of art materials. Therefore, to continue with his artistic development, he was forced to paint over earlier compositions (Lizun, 2021a; Lizun *et al.*, 2021b; Lizun *et al.*, 2021c; Lizun *et al.*, 2021d).

Despite the fact that Liu Kang was an active art educator and critic (Liu, 2011), he did not publicly share information about his painting materials and techniques, and this provokes questions about how his paintings were made. The unusual features, such as retouching, alteration as well as the painting over of rejected compositions and painting on the reverse sides of earlier compositions, although mentioned in the previous research in the context of his different artistic phases, have never been thoroughly discussed. Hence, this article gathers the findings of earlier analytical campaigns and additional unpublished data in an attempt to gain a deeper understanding of the artist's creative process and his motivations behind the unconventional technical decisions. Particularly interesting is the impact of his painting practice on provenance studies, dating, aesthetic perception, the interpretation of his techniques, compositions and colour schemes, as well as decisions about conservation and display.

2. MATERIALS

This study focuses on 25 oil paintings on canvas and hardboard by Liu Kang from National Gallery Singapore (NGS) and Liu family collections. The selected paintings were created by the artist during different artistic phases between 1930 and 1999, and hence provide an overview of the artist's oeuvre. As the artworks from Liu family have remained in their original condition and those from NGS were donated by the artist, the unconventional technical and stylistic features can be attributed to Liu Kang. Hence, this study avoids the misinterpretation that could be caused by the presence of paint features applied by other parties. Table 1 summarises the inventory and technical data of the studied paintings.

3. METHODS

The adopted analytical approach relied on non-invasive imaging techniques to enhance the rendering of the peculiarities of the paint layers and to reveal the presence of the underlying compositions. For consistency with the results obtained in the previous research campaigns, the workflows of the acquisition and processing of the images were identical. In this respect, the technical photography was conducted with a Nikon D850 DSLR modified camera with a sensitivity of 360 – 1100 nm. The camera was equipped with a Nikon AF Micro NIKKOR 60 mm f/2.8D lens. The images were acquired according to the workflow proposed by Cosentino (Cosentino, 2014; 2015; 2016). The X-Rite ColorChecker Passport and the American Institute of Conservation Photo Documentation (AIC PhD) targets were used for camera calibration and colour management of the images. Visible (VIS) and ultraviolet fluorescence (UVF) photography were acquired by mounting on the lens X-Nite CC1 and B+W 415 filters. The near-infrared (NIR) photography was acquired with Heliopan RG1000 filter.

The illumination systems for UVF photography consisted of two lamps equipped with eight 40 W 365 nm UV fluorescence tubes. Two 500 W halogen lamps provided the lighting system for VIS and NIR photography. Further processing of the images was conducted using Adobe Photoshop CC according to the standards described by the American Institute of Conservation (Warda *et al.*, 2011).

The texture of the paint layers was studied with reflectance transformation imaging (RTI), following the workflow developed by Cultural Heritage Imaging. The captured images were processed using Adobe Photoshop CC and RTIBuilder. The generated images were interactively viewed using RTIViewer (Schroer *et al.*, 2011; Schroer *et al.*, 2013). Then, digital optical microscopy (DOM) provided insights into the structure of the individual features of the artist's technique. DOM was conducted using Keyence VHX-6000 with a zoom lens at a magnification range of 20x to 200x. Further verification of the hidden compositions was conducted with NIR and a digital X-ray radiography (XRR) system – Siemens Ysio Max. The instrument utilises a 7 MP

Table 1. Inventory and technical details of the studied paintings

Title and inventory number	Owner	Date	Dimensions H × W (cm)	Primary support	Unconventional technical feature
French countryside	Liu family	1930	46 × 54.5	Primed canvas	Recto of a double-sided painting.
Cottage with blue shutters, France	Liu family	1930	46 × 54.5	Raw canvas	Double-sided painting. Painted on the verso of *French countryside*.
Nude	Liu family	1940	38.5 × 46	Primed canvas	- Recto of a double-sided painting. - Painted over an earlier composition.
Still life	Liu family	1931	38.5 × 46	Raw canvas	Double-sided painting. Painted on the verso of *Nude*.
Village scene, 2003-03320	NGS	1931	46 × 55	Primed canvas	Recto of a double-sided painting.
Slope, 2003-03319	NGS	1931	46 × 55	Raw canvas	Double-sided painting. Painted on the verso of *Village scene*.
Still life with books, Paris	Liu family	1931	45 × 38	Primed canvas	Recto of a double-sided painting.
Portrait of a man with his pipe, Paris	Liu family	1931	45 × 38	Raw canvas	Double-sided painting. Painted on the verso of *Still life with books, Paris*.
Breakfast, GI-0257 (PC)	NGS	1932	46 × 54	Primed canvas	Painted over an earlier composition.
Chinese house, 2003-03328	NGS	1934	64.5 × 50.5	Primed canvas	Alteration of the composition.
Nude, 2003-03367	NGS	1936	46 × 54.5	Primed canvas	Painted over an earlier composition.
Waterfall, 2003-3247	NGS	1936	65 × 50	Primed canvas	Painted over an earlier composition.
Seaside, 2003-03318	NGS	1936	45 × 54	Primed canvas	Painted over an earlier composition.
Malay man, 2003-03244	NGS	1942	94 × 73	Primed canvas	Retouches.
Bathing in the river, 2003-03291	NGS	1947	126.5 × 86.5	Primed canvas	- Retouches. - Backdating. - Re-signing. - Alteration of the composition.
View from St. John's Fort	Liu family	1948	46 × 55	Primed canvas	Painted over an earlier composition.
Climbing the hill, 2003-03298	NGS	1947	75 × 61	Primed canvas	- Painted over an earlier composition. - Alteration of the composition. - Retouches.
Batik workers, P-0197	NGS	1954	88.5 × 69	Primed canvas	Retouches.
Boats, 2003-03275	NGS	1956	91 × 70	Primed canvas	Painted over an earlier composition.
Char Siew seller, 2003-03311	NGS	1958	59.5 × 72.5	Primed canvas	Painted over an earlier composition.
Fruit sellers, 2003-03295	NGS	1969	122 × 91.5	Primed canvas	Retouches.
Chinese bridge over river, 2003-03386	NGS		71 × 91.5	Primed canvas	Alteration of the composition.
Mount Huangshan, 2003-03304	NGS	1983	84.6 × 64.5	Unprimed hardboard	Painted over an earlier composition.
Beauties at rest II, 2003-03470	NGS	1998	85 × 127	Primed canvas	Alteration of the composition.
In conversation, 2003-03305	NGS	1999	61 × 76	Primed canvas	Painted over an earlier composition.

resolution detector of dimensions 35 × 43 cm. The X-ray tube operated at 40 kV and 0.5 – 2 mAs. The radiographic images were visualised and processed using iQ-LITE, then exported to Adobe Photoshop CC for final alignment and merging. The results of the imaging techniques were cross-referenced with the artist's photographs of the paintings and exhibition catalogues to trace the history of the paintings and confirm their condition and further modifications.

4. RESULTS AND DISCUSSION

4.1. Retouches

Paradoxically, Liu Kang's compensation of paint and ground layer losses is a predominant factor impacting the condition of some of his paintings. The probable cause of the initial losses could be linked to distortions of the canvas painting supports caused by the humid tropical climate of Singapore or by direct contact with water (Figure 1a, b). The tight storage space in the artist's studio (Figure 1c, d) or inadequate handling and transportation conditions (Figure 1e) could also have negatively contributed to the poor condition of the paint layers.

The artist attempted to address the issue of the severe paint losses by liberally retouching the areas of loss and the surrounding original paint. This intervention is easily noticeable by its technical and aesthetic drawbacks. The artist's failure to use filling material to reconstruct the primer resulted in visible differences between the thickness of the original paint layers and their compensation. Moreover, low-quality colour matchings, executed with oil paints which additionally discoloured over time, as well as their poor application manner, in brush strokes incompatible with the surrounding paint application style, additionally reduce the

Figure 1. Image of *Batik workers* by Liu Kang, 1954, oil on canvas, 88.5 × 69 cm (a). The painting was photographed in transmitted VIS to show the losses of the paint and ground layers. The reverse side of the painting shows water marks that could have been responsible for distortions of the canvas and subsequent losses of the ground and paint layer (b). Gift of the artist's family. Collection of National Gallery Singapore. Archival, undated photographs of Liu Kang's studio, showing paintings stacked against the wall (c, d). Archival, undated photograph showing loading of Liu Kang's paintings into the vehicle. Images (c–e) are from Liu Kang family collection. Images courtesy of Liu family.

aesthetic properties of the paintings, as the cases of *Malay man* (1942), *Bathing in the river* (1947), *Climbing the hill* (1948) and *Fruit sellers* (1969) (Figure 2a, d, b, e). Regarding the extensive paint losses in *Batik workers* (1954), the artist's approach involved reworking the affected passages following the original paint scheme, but without infilling (Figure 2c, f, g).

Although it remains unknown when, specifically, Liu Kang retouched his paintings, his family recalled that some retouchings were done in the 1980s and 1990s, when he struggled with deteriorating eyesight. The artist mentioned worsening eyesight problems in two interviews in 1981 (Mahbubani, 1981) and 1989: "Before the operations, I was very upset and reluctant to work. […] I was depressed. But after the cornea operations in 1986, I slowly started to paint again. Of course, there is a difference. The colours are different. I used too much blue and green and my children would point it out to me. I can't paint for periods now. Before, I could paint through the whole day. Now, I get tired. It is a problem" (Sasitharan, 1989). Indeed, the problems with the left eye cornea relapsed, and he lost sight in that eye in 1992 until a successful corneal transplant in 1993. In a 1993 interview, he recalled: "Since I couldn't see with my left eye, I am painting at much slower pace now. A painting which needed only two to three days to do in the past now takes me about two to three weeks" (Weng Kam, 1993). Hence, it is clear from the artist's statements that, besides low productivity, the eyesight problems affected his colour sensitivity, which might have resulted in the low-quality retouching, as it is an intensive activity that puts a heavy strain on the eyes.

Today, although it is obvious that most of Liu Kang's retouches are intrusive elements of the paintings, it is challenging to develop a coherent conservation strategy to satisfy conflicting aesthetic and ethical considerations. Despite the arguable quality of the retouching work, the amendments are a legitimate part of the history of the artworks. Regarding the extensively reworked passages of *Batik workers* (1954), the new colour remains better integrated with the original paint scheme; however, these repairs stand out due to the absence of a filling material.

A review of the ethical guidelines produced by the American Institute of Conservation (AIC) and the Institute of Conservation (ICON) highlighted a few of the most relevant recommendations. The AIC states that: "All actions of the conservation professional must be governed by an informed respect for the cultural property, its unique character and significance, and the people or person who created it" (AIC, 1994). Similarly, the ICON advises conservators to "Act with awareness of and respect for the cultural, historic and spiritual context of objects and structures" (ICON, 2020). Hence, a universal conservation approach is to leave the artist's additions or alterations intact as artists are often inspired to return to their earlier artworks. Nonetheless, exceptions can be considered if the artist's restorations and retouches are distracting (Von der Goltz and Stoner Hill, 2012). Despite its subjectivity, such judgement should be made with reference to historical facts (Appelbaum, 2010; Talley, 1996), which, when combined with the technical analyses, may assist in clarifying the intended artistic concept and decisions. Hence, for some of his paintings, the archival sources can reveal the original state of the paint layers and provide information about the possible circumstances behind the retouching process. On the other hand, there is a possibility that the artist was conscious of the inadequacy in his retouching works but fully accepted them as a legitimate and integral constituent of the artistic concept, or he believed that these imperfections were irrelevant to the overall perception of the artworks. Unfortunately, as oil-based retouches inevitably discolour over time, it is impossible to determine the initial colour inaccuracy, which may have been the reason the artist tolerated them at the time of their execution. It also remains unknown if he would accept the hue deviation observed today. Nevertheless, there is no evidence that Liu Kang relished the effects of deterioration of his paintings; on the contrary, the retouches themselves indicate the artist's intention to reverse some negative processes that occurred in his paintings. Hence, these speculations lead to the conclusion that we may never be able to fully understand the artist's intentions and that our interpretations may never entirely cover the truth (Van de Wetering, 1996).

As for the treatment, the considered professional standards support the notion that the artist's interventions should be preserved as long as they do not endanger the original paint. This approach was recommended in the study of John Linnell's practice of retouching his own paintings. The study accepts Linnell's retouches as a legitimate part of the

Figure 2. The paintings by Liu Kang: (a) *Malay man*, 1942, oil on canvas, 94 × 73 cm; (b) *Climbing the hill*, 1948, oil on canvas, 75 × 61 cm; (c) *Batik workers*, 1954, oil on canvas, 88.5 × 69 cm. Corresponding details indicate the artist's retouches (d, e) and reworked passages for compensating the ground and paint losses seen in VIS raking light (f) and UVF (g). Paintings (a-c) are gifts of the artist's family. Collection of National Gallery Singapore.

compositions that need to be respected but does not recognise these interventions as integral to his artistic process (Sperber, 2017). It is worth noting that Linnell's retouches are stable and indistinguishable from the original paint layer in visible light; hence, they do not cause aesthetic issues that were observed in Liu Kang's paintings.

As continued discolouration of Liu Kang's retouched areas increases the risk of further reduction of the aesthetic properties of the paintings, the considered approach may be to infill and inpaint the retouched areas of very low quality and which cause the most visually damaging effects. On the other hand, the retouched areas that appear convincing or less distracting could be left untreated. This approach adheres to the ethical conservation standard of reversibility and, at the same time, provides a compromise between the preservation of the historic material embedded in the paint layers and respect for the visual integrity of the paintings. The AIC states: "The conservation professional must strive to select methods and materials that, to the best of current knowledge, do not adversely affect cultural property or its future examination, scientific investigation, treatment, or function. […] Such compensation should be reversible and should not falsely modify the known aesthetic, conceptual, and physical characteristics of the cultural property, especially by removing or obscuring original material." However, if the most conservative solution – leaving all retouches untreated – is the only option, then adequate display labelling should be provided to prevent public misconception about Liu Kang's painting practice.

Finally, the utmost caution is recommended when confirming or ruling out the authorship of Liu Kang's retouches. Besides conducting technical analyses of the paintings, checking the state of the paint layers against the archival data and tracing previous conservation treatments may help in ascertaining the original concept and in elucidating the artist's intentions.

4.2. Alterations

Many Liu Kang's paintings did not always arise in a linear workflow. His studio practice and extensive visual library comprising sketches and photographs enabled the depiction of the subject to be done in several steps. Furthermore, as part of the creative process, Liu Kang often returned to his paintings to add some minor finishing touches or conduct major alterations of certain parts of the compositions. The alterations reflect the artist's quest for a satisfactory artistic outcome. However, regardless of their extent, the revisions often affect the visual aspects of the paintings because of the inconsistency between new and old paint application techniques. Additionally, the revisions may hinder the art historical studies about the artist due to misinterpretation of the provenance and dating of his artworks.

Chinese house (1934) is an example of a minor revision of the painting's composition. The most intriguing area of this painting is the sky. It is characterised by a texture of vigorous brush strokes relating to the underlying dark paint seen in the areas of its high impastos not completely covered with new paint (Figure 3a–d). RTI, transmitted NIR and XRR imaging revealed that, on the right side of the composition, the artist initially painted a massive tree with rich foliage, which he later replaced with the present silhouettes of two young trees (Figure 3e–f).

The cases of *Climbing the hill* (1948) and *Bathing in the river* (1947) show how the artist's revisions interfered with the dating and provenance of his artworks. The alteration of the greenery area in the bottom left corner of *Climbing the hill* (1948) (Figure 2b) obscured the original signature and 1948 date, which were visualised in NIR image and which corroborated with the archival photograph taken by the artist before the intervention. According to an earlier study (Lizun, 2021a), the XRR imaging did not reveal any paint losses in that area that could have prompted that alteration. Moreover, the optical microscopy showed that the additional paint touches were added after the paint surface had dried. It can be speculated that, after the adjustments were done, the painting was probably left unchanged until the preparation for the exhibition in 1993, when the artist re-signed and backdated the work to 1937 as he was not able to recall the actual date of creation of the artwork. Hence, due to incorrect backdating, the landscape was believed to have been created in Shanghai instead of Singapore.

Signed and dated 1947, *Bathing in the river* (1947) (Figure 4a, d) presents a similar issue, which was clarified by cross-referencing the analytical data with archival sources. The drawing of the composition bears the artist's signature and date, which could be read as 1945(8) (Figure 4b, e). The ambiguous style of the last digit prompted comparison with

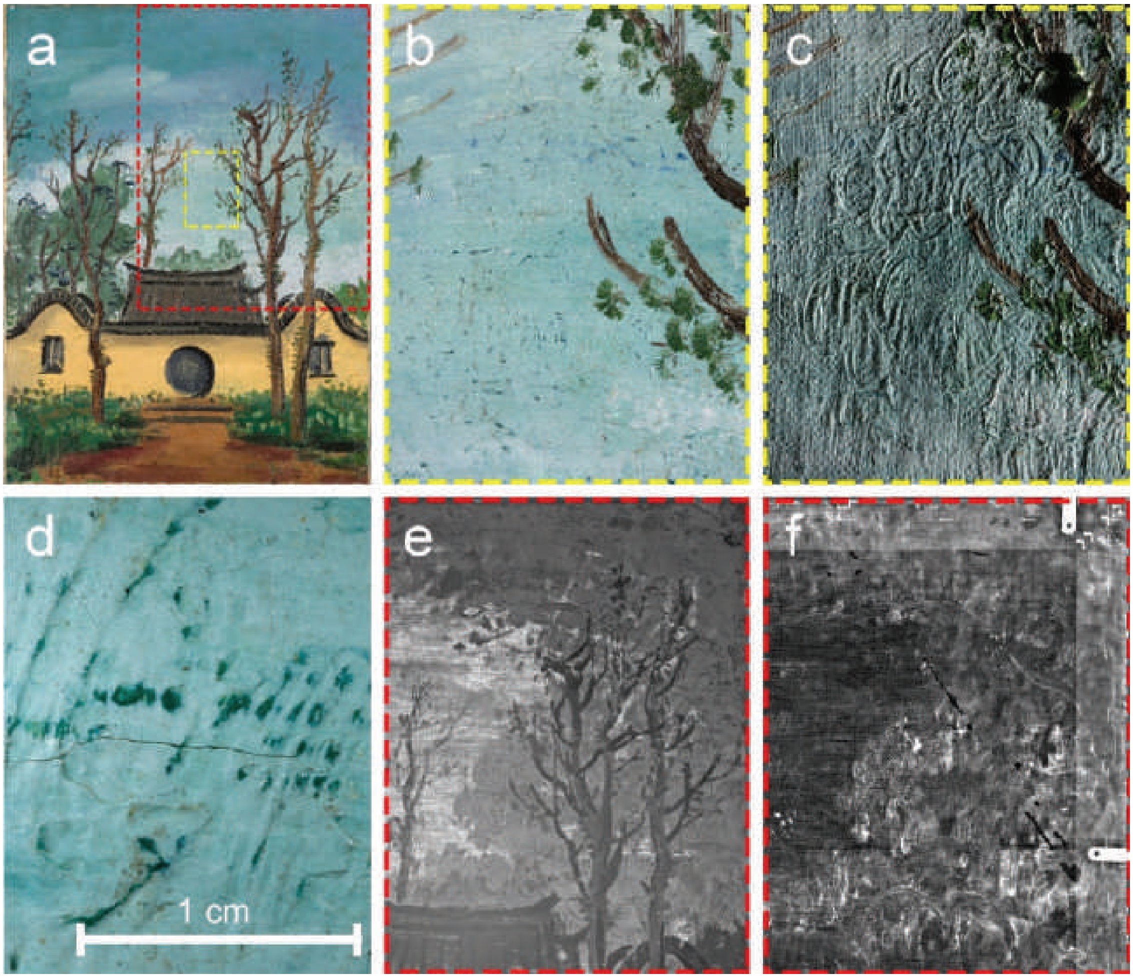

Figure 3. Liu Kang, *Chinese house*, 1934, oil on canvas, 64.5 × 50.5 cm (a) and corresponding VIS diffused (b) and VIS raking light (c) details of the sky area showing the texture of vigorous brush strokes relating to the underlying dark paint seen in the areas of its high impasto that are not completely covered with new paint (d). Transmitted NIR (e) and XRR (f) detail images reveal a tree with rich foliage. Gift of the artist's family. Collection of National Gallery Singapore.

other handwritten dates containing the digits "5" and "8" (Figure 4f–i). It was concluded that the artist's usual style of writing the digit "5" incorporated two strokes – a bulge and a horizontal mark above it. On the other hand, his digit "8" was made in a continuous movement resulting in a loop with either a closed or an open upper part. Hence, the date on the drawing is 1948 and not 1945, suggesting that it was conceived after the painting, which would be an unusual artist's approach. Interestingly the archival, undated photograph of the painting taken by the artist shows it as unsigned and undated (Figure 4c); therefore, it is conceivable that the artist incorrectly backdated the composition after the archival photograph was taken. Judging from the drawing and photograph, the painting was created in 1948 or later. Moreover, it is assumed that the alterations of the greenery in the bottom-right corner, the shape of the background mountains and upper part of the sky and backdating were executed at the same time (Figure 4a, c).

Major alterations by Liu Kang aimed to change the style of the existing compositions. This approach can be illustrated by a signed but undated *Chinese bridge over river* (Figure 5a). At first glance, the composition strikes the viewer with a stylistic inconsistency. A well-executed bridge in the focal point is surrounded by a roughly expressed lake in the foreground and mountain ranges and sky in the background. Technical analyses coupled with the archival search

Figure 4. Liu Kang, *Bathing in the river*, 1947, oil on canvas, 126.5 × 86.5 cm (a) and corresponding detail showing a signature and 1947 date (d). Gift of the artist's family. Collection of National Gallery Singapore. Liu Kang, *Bathing in the river*, 1948, pencil on paper, 27 × 21 cm (b) and corresponding detail showing a signature and 1948 date (e). Undated archival photograph of *Bathing in the river* by Liu Kang (c). Details showing the: (f) 1945 date and signature from Liu Kang's drawing of *Portrait of a man*; (g) signature and 1952 date from Liu Kang's drawing of *Boats from Bali*; (h) 1948 date and signature from Liu Kang's drawing of *Brick factory*; (i) signature and 1978 date from Liu Kang's drawing of *New Zealand landscape*. Images (b, c, e, g–i) are from Liu Kang family collection. Images courtesy of Liu family. Image (f) is a gift of the artist's family. Collection of National Gallery Singapore.

evidenced some underlying painted features and advanced the interpretation of this artwork. Hence, the roughly painted parts of the composition conceal a brushwork (Figure 5d, e) relating to a signed and dated 1974 preparatory drawing and a signed and dated 1975 painting (Figure 5b, c) presented at the Singapore Art Society 26th Annual Art Exhibition in 1975 (The Singapore Art Society 26th anniversary art exhibition, 1975). Judging from these findings, it is conceivable that, after the exhibition, Liu Kang decided to make a major revision of the foreground and background of the composition by a rough underpainting with local colours, which could serve as a base for further manipulation of the paint with palette knives, followed by detailed brushwork. This resulted in his covering the foregrounded trees, cloudy backgrounded sky and an original signature and 1975 date in the bottom-left corner (Figure 5f, g). Unfortunately, for an unknown reason, he left the work in an apparently unfinished state, judging from the lack of refined foreground details; however, the new signature in the bottom-right corner suggests that he considered his work completed. On the other hand, Liu Kang's artistic output contains many signed and dated paintings that can be considered unfinished or coloured sketches (Lizun *et al.*, 2021b; Lizun *et al.*, 2022a). Interestingly, the artist, being aware of some inconsistencies

Figure 5. Liu Kang, *Chinese bridge over river* (undated), oil on canvas, 71 × 91.5 cm (a) and corresponding NIR (d) and XRR (e) detail images revealing the painted features of an earlier version of the composition relating to Liu Kang's preparatory pen drawing on paper, measuring 27.5 × 37 cm, signed and dated 1974 (b). Detail of an NIR image of the painting revealing an earlier signature and a 1975 date (f). Photograph of an earlier version of the painting (c) and corresponding detail showing a signature and 1975 date (g). Painting (a) and drawing (b) are gifts of the artist's family. Collection of National Gallery Singapore.

in his painting practice, provided an explanation in a 1997 essay: "Though my paintings are guided by a central principle in terms of style, there were some short periods when there would be styles or works that took an entirely different direction from my established style. This was due to the fluctuations of my mood" (Liu, 1997). This revealing statement indicates that emotions impacted Liu Kang's creative process. Hence, it can be hypothesised that once he lost inspiration or was dissatisfied with the outcome, he was able to abandon the subject or redo it.

Figure 6. A 1993 archival photograph of an earlier version of *Beauties at rest* (a). Liu Kang family collection. Image courtesy of Liu family. *Beauties at rest II*, 1998, oil on canvas, 85 × 127 cm, painted over earlier version (b). Gift of the artist's family. Collection of National Gallery Singapore.

Chinese bridge over river is not an isolated example of a major alteration of the composition, as a similar approach was reported earlier with regard to *Beauties at rest II* (1998) (Lizun *et al.*, 2022b). The analyses, supported by the archival search, revealed that the first version of the two reclining nudes was probably created in 1993 and repainted in a new style in 1998 (Figure 6). However, it remains unknown what caused a rejection of the earlier version of the painting and the drastic change of the style of its second version. It can only be conjectured that the artist's decision was either driven by strong artistic self-criticism or inspired by new stylistic concepts.

Such approach to *Chinese bridge over river* and *Beauties at rest II* (1998) bears some resemblance to the case studies of *Handsome pork butcher* (1935) and *Portrait of a doctor* (1935) by Francis Picabia, which were altered in a bizarre way due to the death of the subject and an unsuccessful exhibition. Picabia's reaction to these external circumstances was interpreted as disappointment and anger, which motivated him to reject and rework the paintings in a radical and destructive way to provoke the viewer (King *et al.*, 2018). Although we do not know the circumstances surrounding Liu Kang's *Chinese bridge over river* and *Beauties at rest II* (1998), it is possible that he was disappointed at public reaction to the two artworks and made a radical decision to reject and expressively repaint them.

4.3. Paintings over former compositions

Routine visual examination of Liu Kang's paintings from his different artistic phases revealed colours and textural irregularities unrelated to the painted subject matter, while DOM enabled the detection of cracks and voids in the surface paint layers, through which different underlying colours are visible. Some of these unusual features blend with the current compositions and remain indiscernible to the average viewer. Other features remain visible and may hamper the perception of Liu Kang's compositions and colour schemes. For instance, a milk mug from *Breakfast* (1932) was painted white outside and green inside, whereas a plate is painted with blue, green and orange colours, confusing the viewer about their content or decorative motives (Figure 7a, b). The green and blue patches on the foreground and background of *Nude* (1936) do not match the main colour scheme of the composition (Figure 7c, d). An unusual paint texture is noticeable on the surfaces of *Boats* (1956) (Figure 6e, f) and *Char Siew seller* (1958) (Figure 7i, j). Distinctive green brush strokes are seen on the grey cloudy sky of *Mount Huangshan* (1983) (Figure 7g, h). Imaging techniques like surface DOM, RTI, NIR and XRR indicated that the visual inconsistency of the paint layers was caused by underlying compositions of the reused painting supports. The artist was not meticulous about hiding former compositions while painting new scenes over them. However, the colouristic and textural incompatibility between the old and new paint schemes seems to point to some randomness in the creative process rather than to the artist's conscious choice.

With regard to the reasons behind the recycling of the former compositions, the XRR imaging of artworks from Liu Kang's Paris (1929–1932) and Shanghai (1933–1937) artistic phases did not detect any major ground layer losses that could have encouraged such practice. However, judging from

Figure 7. Paintings by Liu Kang and corresponding details showing colour and textural irregularities unrelated to the painted subject matter: (a, b) *Breakfast*, 1932, oil on canvas, 46 × 54 cm; (c, d) *Nude*, 1936, oil on canvas, 46 × 54.5 cm; (e, f) *Boats*, 1956, oil on canvas, 91 × 70 cm; (g, h) *Mount Huangshan*, 1983, oil on board, 84.6 × 64.5 cm; (i, j) *Char Siew seller*, 1958, oil on canvas, 59.5 × 72.5 cm. Gifts of the artist's family. Collection of National Gallery Singapore.

the archival photographs from these periods evidencing Liu Kang's reuse of auxiliary supports, the artist's financial constraints could have motivated him to save on art materials and use them creatively (Lizun *et al.*, 2021c). Besides financial difficulties, the scarcity of art materials in post-war Singapore in the late 1940s may have forced him to reach for the old artworks from the Paris and Shanghai phases to paint *Climbing the hill* and *View from St. John's Fort*, both from 1948 (Lizun, 2021a). This radical approach ultimately resulted in the irreparable loss of some completed by signing and dating earlier artworks. In the 1950s and beyond, the artist still considered recycling his paintings as a practical measure. As Liu Kang enjoyed growing professional recognition after the famous Bali exhibition in 1953 (Liu, 1997; Noi and Sin Weng Fong, 1998), it can be hypothesised that his finances improved sufficiently for him to afford the necessary painting materials. Therefore, extensive paint losses of the completed and signed painting of a Balinese dancer created between 1952 and 1958 motivated the artist to reuse the composition for a street scene *Char Siew seller* (1958) (Lizun *et al.*, 2022a). Another example is *In conversation* (1999), which has National Art Show exhibition label attached to the back of the canvas (Figure 8a, b). Written in Chinese characters, the information on the label indicates that the title of the artwork is *Still life*. However, this title and the pronounced brush strokes found across much of the surface do not accord with the current composition (Figure 8c). Further transmitted NIR and XRR imaging techniques confirmed the presence of an underlying still life composition depicting a plant in a flowerpot and a watering can (Figure 8d, e). Interestingly, the label indicated that *Still life* had initially been earmarked for sale, thus confirming the artist's confidence in his work at the time of the exhibition. However, the possible unsuccessful sale of the painting could have resulted in its rejection and reuse for *In conversation* (1999).

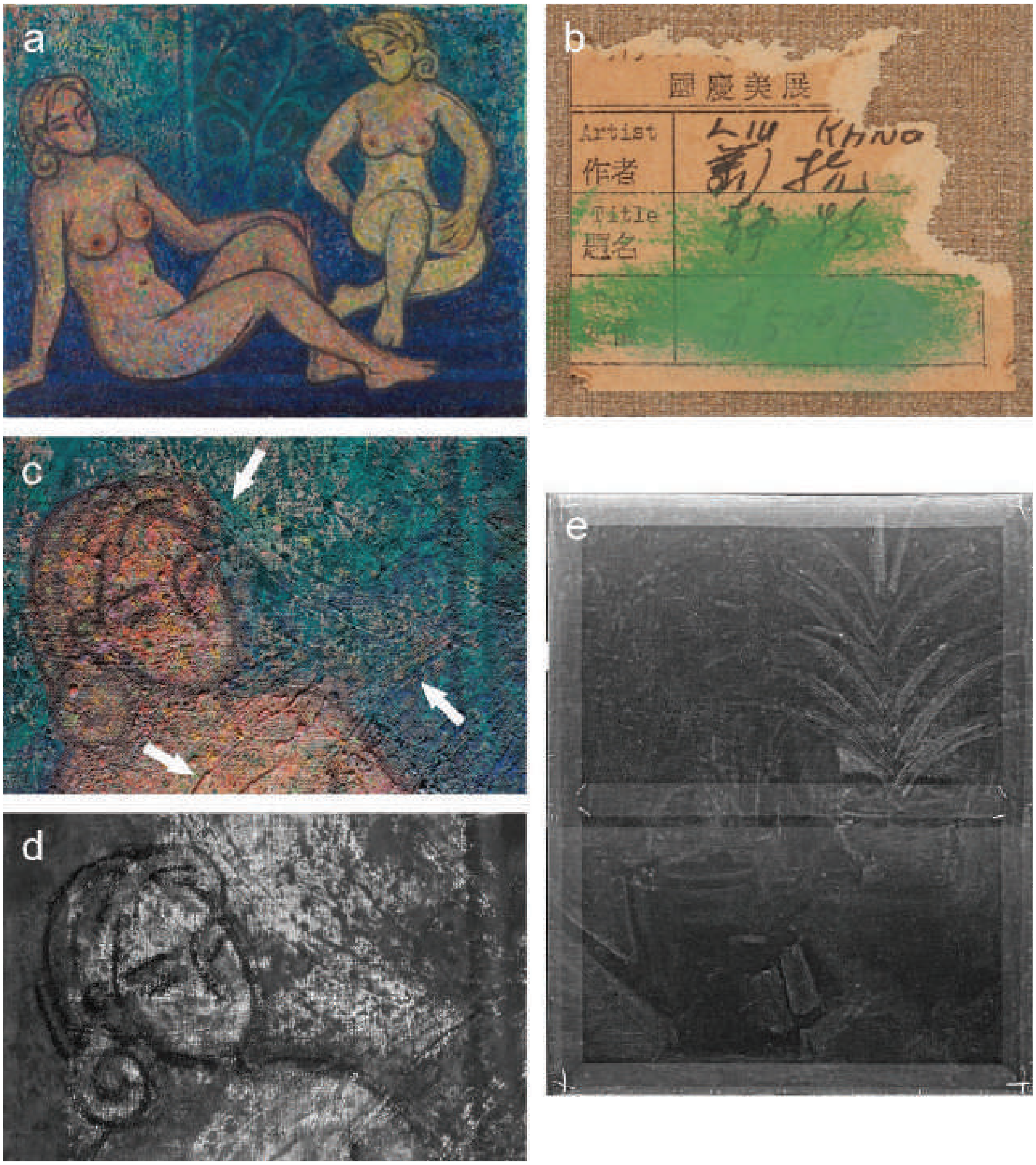

Figure 8. Liu Kang, *In conversation*, 1999, oil on canvas, 61 × 76 cm (a). Exhibition label attached to the back of the canvas (b). Detail VIS raking light (c) and transmitted NIR (d) images of the painting revealing brush strokes of the underlying composition. XRR image of the painting rotated at 90° clockwise, showing a vertical composition depicting a plant in a flowerpot and a watering can (e). Gift of the artist's family. Collection of National Gallery Singapore.

4.4. Double-sided paintings

Besides overpainting former compositions, Liu Kang utilised the reverse sides of some existing paintings in order to continue the artistic practice despite occasional financial problems and inadequate painting materials. This cost-saving approach reflects his reluctance to overpaint the subject on the main, recto side if it is an artwork that he seemed to have considered satisfactory. All known examples of paintings done on both sides of the same support represent Liu Kang's early career in Paris (1929–1932) and period of emigration to Malaya (1937–1945). The painting supports were identified as commercially prepared canvases with the primed recto side used first and the verso, raw canvas side used for subsequent paintings. It remains unknown if the artist ranked the paintings on both sides of the support. From subjective assessment, the quality of the paintings on the verso side is in no way inferior to that of the paintings on the recto. Hence, it is likely that both sides were equally important to him. The original framing could have given an insight into the artist's preference in this matter; however, as such is not existent. One of the investigated double-sided paintings was re-mounted and framed during the artist's lifetime. Two were restretched after his death, whereas two others remain unstretched.

In this context, *Self-portrait* (1931) is a rare example of a double-sided canvas painting mounted on a hardboard auxiliary support and framed (Figure 9). The mounting on the hardboard was probably motivated by the poor condition of the tacking margins, which were eventually cut off. Based on the information from the artist's family, the mounting was done in Singapore by Liu Kang or by a local framer whom he commissioned the framing to. Visual examination revealed that *Self-portrait* (1931) was executed on the verso of the unknown composition and glued with its recto side to the hardboard. The presence of the paint layer on the main side was visually detected by lifting a corner of the canvas that was detached from the hardboard. As the hidden composition was painted first, it is reasonable to conclude that it was created between the artist's arrival in Paris (1929) and the execution of *Self-portrait* on its verso (1931). Although it remains hidden, the XRR could permit its visualisation and assessment of the possible paint losses that could have justified the artist's decision to discard that composition.

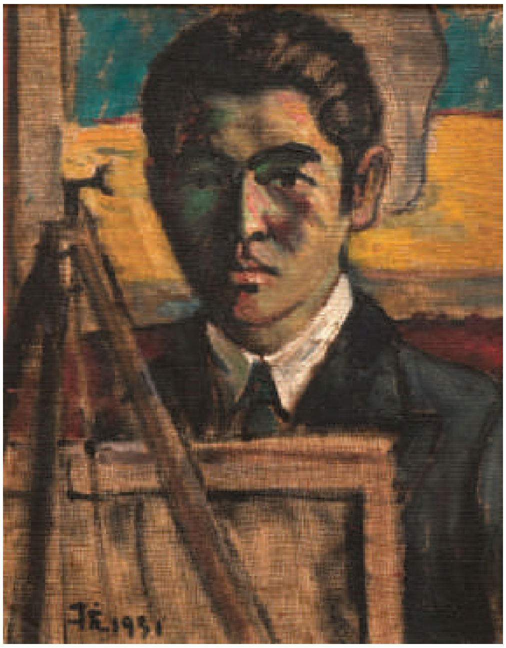

Figure 9. Liu Kang, *Self-portrait*, 1931, oil on canvas, 55 × 46 cm. The painting was executed on the raw verso side of the unknown composition. Liu Kang family collection. Image courtesy of Liu family.

Double-sided *Nude* (1940) and *Still life* (1931) are examples of more complex painting structures, which require careful visual examination backed by knowledge of the artist's working practice to achieve the correct interpretation (Figure 10a, b). As the artist usually painted on the primed side of the canvas first, the execution of *Still life* (which is earlier than *Nude*) on the raw reverse side of the painting support is intriguing (Figure 10c, d). However, the fact that the texture of the brush strokes and exposed colours do not correspond to the final composition of *Nude* left no doubt about the possible presence of a main underlying scene painted on the primed side of the canvas (Figure 10e, f). Hence, it can be hypothesised that the hidden painting was created in Paris between 1929 and 1931, while *Still life* (1931) was painted next, on the reverse side. The artist's decision to recycle the main side of the painting support and overpaint it with *Nude* (1940) was probably motivated by the poor technical condition of the main composition or the scarcity of painting supports during his emigration to Malaya (Lizun, 2021a). This rare case exemplifies the artist's unconventional approach to painting supports, which was employed for three compositions.

Figure 10. Double-sided paintings by Liu Kang: (a) recto depicting *Nude*, 1940, oil on canvas, 38.5 × 46 cm; (b) verso depicting *Still life*, 1931, oil on canvas, 38.5 × 46 cm. Detail showing the: (c) signature and 1940 date from *Nude*; (d) signature and 1931 date from *Still life*; (e) texture and (f) red colour that do not correspond to the final composition of *Nude*, suggesting the presence of an underlying composition. Liu Kang family collection. Images courtesy of Liu family.

Liu Kang's double-sided paintings may create conservation and display challenges, especially if alternate or simultaneous viewing is required. In this context, *Village scene* (1931) and *Slope* (1931), which are painted on both sides of the same support, are interesting examples (Figure 11). At present, the canvas is temporarily stretched over the strainer and both compositions remain unframed, making them unsuitable for public presentation. The new stretching method may involve a combination of strip lining and a symmetrical strainer or stretcher with key slots on the outside of the bars to allow the display of both the recto and verso image in its entirety (Foulke, 2008; Prins, 2008). As the paintings are oriented horizontally, alternate and simultaneous presentation is possible. However, due to their inversion, a frame rotatable

Figure 11. Double-sided paintings by Liu Kang: (a) recto depicting *Village scene*, 1931, oil on canvas, 46 × 55 cm; (b) verso rotated at 180° depicting *Slope*, 1931, oil on canvas, 46 × 55 cm. Gift of the artist's family. Collection of National Gallery Singapore.

about the horizontal axis can be considered for a visually acceptable display of both sides of the painting support (Runeberg, 2019). As this case is the subject of an ongoing design and fabrication of an auxiliary support and frame to enable future display at NGS, details of the adopted solutions may be discussed in a future publication.

Nevertheless, the ultimate recommendation for the future protection of Liu Kang's double-sided paintings is to avoid ranking the recto and verso compositions, which may lead to preferential framing of one side and negligence and deterioration of the other side. Considering both sides of the painting support as equal enables the viewer to appreciate one or the other side while acknowledging the co-presence of two images. Such an approach will also shed light on the complex nature of Liu Kang's practice and, in particular, the motivation behind his recycling the verso sides of completed paintings (De Chassey, 2015).

4.5. Relation between the recycled painting supports and the painting techniques of new compositions

The artist's choice to reuse earlier compositions sometimes determined his painting technique for executing new painted scenes. For instance, *Waterfall* (1936), *Seaside* (1936) (Figure 12a, b) and *Climbing the hill* (1948) (Figure 2b) were created over former, unknown artworks (Figure 12c, d), and the creative process for new paintings involved the extensive use of palette knives followed by florid brushwork (Figure 12e, f) (Lizun, 2021a). A similar approach was observed in executing the special theme of Huangshan and Guilin mountains in the 1980s and 1990s. These paintings were largely created over reused compositions on hardboard. Palette knives were employed for a quick and effortless covering of rejected scenes with new paint and for developing the new compositions.

Judging from the undated archival photograph documenting the transition from the earlier to present version of *Beauties at rest II* (1998), a broad and flat application of the local colours with brushes was required for the quick underpainting (Figure 13). As the artist intended to work within the existing composition, the choice of brushes for the underpainting seems adequate as they provided better control of the paint application around the shapes he wanted to reuse. Further development of the scene involved palette knives for hiding the remains of the rejected paint scheme and producing a base for the manipulation of the colours with brushes (Lizun *et al.*, 2022b).

Nevertheless, the most significant impact of the recycled compositions on the adopted painting technique and the artistic outcome of the new paintings can be observed in *Boats* (1956) and *Char Siew seller* (1958). Both artworks were executed in the batik-inspired painting technique characteristic of Liu Kang's Nanyang-style paintings. Their technical principle was an intentional exposure of white ground for enhancing the shapes of the compositional elements and increasing their colour contrast as can be seen in *Fruit sellers* (1969). The colour effects

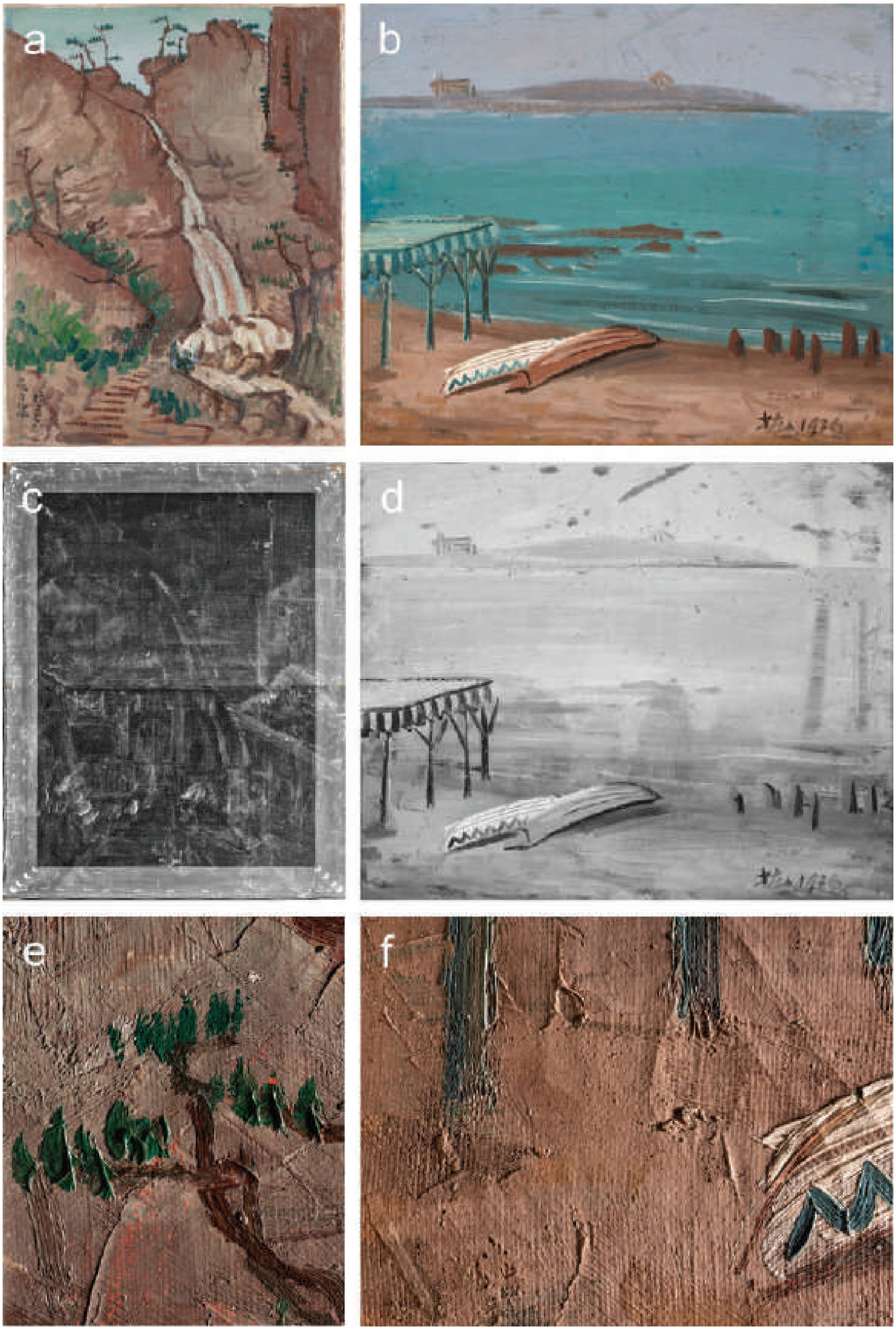

Figure 12. The paintings by Liu Kang: (a) *Waterfall*, 1936, oil on canvas, 65 × 50.3 cm; (b) *Seaside*, 1936, oil on canvas, 45 × 54 cm. Corresponding XRR (c) and NIR (d) images showing illegible underlying compositions. Detail of *Waterfall* (e) and *Seaside* (f) indicating palette knife paint application followed by detailed brushwork. Gifts of the artist's family. Collection of National Gallery Singapore.

Figure 13. An undated archival photograph showing *Beauties at rest* during the transition from an earlier to the present version of the composition (a). Liu Kang Collection, National Library Singapore. *Beauties at rest II*, 1998, oil on canvas, 85 × 127 cm, the final version of the painting (b). Gift of the artist's family. Collection of National Gallery Singapore.

were based on simple tonality, and the paint was applied confidently with brushes, producing minimal texture (Figure 14a, d) (Lizun *et al.*, 2022a). Hence, a painting support with a white ground layer was crucial for achieving these optical effects. As *Boats* (1956) and *Char Siew seller* (1958) were executed over earlier compositions, the white ground layer was unavailable. Hence, it had to be substituted with white paint applied in the final stage of the creative process to delineate the forms. This approach produced a lower contrast between the colours mainly due to the contamination of the white paint with other colours present on the palette and painting. Moreover, the act of painting over the earlier compositions produced tonal transitions and rich texture – radically different features from typical Liu Kang's batik-inspired technical solution (Figure 14b–f). The identification of these unusual technical features on his batik-inspired paintings may indicate the artist's departure from applying a pure Nanyang style, motivated by the limitations of the painting support. It may also tentatively signal the presence of the underlying compositions.

Figure 14. Paintings by Liu Kang: (a) *Fruit sellers*, 1969, oil on canvas, 122 × 91.5 cm; (b) *Boats*, 1956, oil on canvas, 91 × 70 cm; (c) *Char Siew seller*, 1958, oil on canvas, 59.5 × 72.5 cm. Gifts of the artist's family. Collection of National Gallery Singapore. The corresponding detail images show features of the original batik-inspired painting technique with a white ground exposed (d) and substituted colour of ground with a white paint applied in the final stage (e, f).

5. CONCLUSIONS

The collaborative endeavour entailing technical imaging and archival research allowed to identify and categorise some intriguing technical features of Liu Kang's paintings, which define the less known and mysterious side of his oeuvre.

The presence of compositional or colouristic alterations may either reflect the artist striving to achieve satisfactory artistic outcomes or indecision despite his having conducted extensive studies of the subject matter through drawing and photography. Nevertheless, the studies of Liu Kang's painting alterations may add to the knowledge about the artist's development of individual compositions from conception of the idea to execution. An important point of the discussion is that the alterations were sometimes carried over the initial signatures and dates, and subsequent re-signing and backdating do not accord with the factual creation of the artwork or its revision. Cross-referencing the technical analyses with the archival sources seems to be an adequate approach to resolving ambiguous cases.

The artist often reused painting supports for new compositions, created either on the recto or verso side of his earlier artworks. However, there were different reasons behind these decisions. During the period from the 1930s, which marks the beginning of his career in France, to the late 1940s, before he became a well-known artist, the decision to paint over earlier compositions was often caused by financial constraints and the non-availability of art materials. In the case of rare double-sided paintings, the material evidence suggests that they are typical of his early career in Paris (1929–1932) and period of emigration to Malaya (1937–1945), and they are the result of saving on painting supports while preserving the recto side from overpainting. The discovery of the underlying compositions in paintings from his successful, mature years (1950s–1990s) points more to the practical aspect of utilising rejected artworks than an extreme cost-saving solution. Hence, extensive losses to the paint layer might have been another reason for his overpainting the original composition of a Balinese dancer with *Char Siew seller* (1958). However, if the composition presented itself as valuable to the artist, he was inclined to retouch even the extensive paint losses as is the case of *Batik workers* (1954). The emotional reactions to the external circumstances surrounding *Chinese bridge over river* and *Beauties at rest II* (1998) are also considered as potential causes of the radical reworking of these paintings.

The study highlighted the correlation between Liu Kang's recycling of painting supports and the painting technique he adopted for new compositions that were created over earlier artworks. Moreover, it demonstrates how recycled painting supports may determine the primary or secondary quality of Liu Kang's batik-inspired paintings.

As for the conservation and display considerations, special attention is particularly necessary for assessing his writing character and the authorship of retouches and alterations. This can reduce the risk of incorrect dating and unintentional removal or cover of the original material. Furthermore, the study took an opportunity to overview the ethical and aesthetical considerations in the context of potential treatment of Liu Kang's low-quality and discoloured retouches. The artist's approach to paintings on the reverse sides of earlier compositions was discussed. The study traced the intricate painting sequence of two double-sided artworks and highlighted potential stretching and framing challenges of the double-sided *Village scene* and *Slope*, both from 1931. However, the detailed approach to alternate or simultaneous presentation of Liu Kang's double-sided paintings was beyond the scope of the current research and will be addressed in the next phase. Finally, the highlighted aspects of Liu Kang's creative process may raise the awareness of the complexity of his unconventional approach to painting among the conservator, art historians and the public, and encourage further research in this field.

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materials and working practice of the important Singapore artist Liu Kang.

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Article

Overview of Materials and Techniques of Paintings by Liu Kang Made between 1927 and 1999 from the National Gallery Singapore and Liu Family Collections

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Article

Overview of Materials and Techniques of Paintings by Liu Kang Made between 1927 and 1999 from the National Gallery Singapore and Liu Family Collections

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Abstract: This article summarises the extensive research conducted in recent years on the paintings by Liu Kang (1911–2004), a renowned modern Singaporean artist. The investigation considered 97 paintings made between 1927 and 1999 from the National Gallery Singapore and Liu family collections. While detailed results of the analytical studies were presented in a series of publications, the scope of this article comprises an overview of the artist's preferential painting supports and pigments and an outline of the evolution of his working methods. The collected information considerably increases the knowledge about Liu Kang's painting practice and may assist conservators in the diagnosing, treatment, dating and authentication of artworks of uncertain origin. The results demonstrate the importance of comprehensive multi-analytical studies, which combined with documentary sources and art history research, provide a full understanding of the artist's painting practice.

Keywords: Liu Kang; painting supports; pigments; Shanghai Art Academy; Nanyang style

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1. Introduction

Liu Kang (1911–2004) (Figure 1a) obtained an artistic education from Xinhua Arts Academy in Shanghai (1926–1928) and went for further study at the Académie de la Grande Chaumière in Montparnasse, France (1929–1932), where he developed a fascination for impressionism and post-impressionism painting [1–4]. Liu Kang's early artistic achievements in Paris were publicly recognised in 1930 and 1931, when he exhibited at the Salon d'Automne (Figure 1b,c) [5,6]. In 1933, he returned to Shanghai and took up the position of professor at the Shanghai Art Academy, a prestigious art training institution in China at the time [3,7], with his artistic activity focused on developing an individual expression. He lived and worked in Shanghai until 1937, when the Second Sino-Japanese War (1937–1945) broke out, forcing him to move to Malaya. He eventually settled permanently in Singapore in 1945 and continued the artistic development with renewed vigour, leading ultimately to major contributions to the Nanyang style in the 1950s. The Nanyang style was a local art movement that adopted selected principles of the School of Paris and Chinese painting traditions for representing Southeast Asian subject matter [8–10]. Although Liu Kang's further artistic activity was guided by the general principles of the Nanyang style, the artist also searched for new sources of inspiration and passionately expressed himself in special artistic themes unrelated to the tropical flavour, namely, the Huangshan and Guilin mountains in China and nudity. The exploration of these genres triggered unconventional painting approaches, such as exceptionally heavy impastos and a reduced palette of colours, which accentuated some inconsistencies in the artist's oeuvre [11]. Additionally, some technical peculiarities, such as artist's retouching and alteration, as well as painting over earlier compositions or utilising their reverse sides, were integral to Liu Kang's creative process and contributed to the unique character of the artist's works [12].

Figure 1. (**a**) Archival photograph of Liu Kang from the 1950s showing the artist in the studio; (**b**) certificate of the artist's participation at the Salon d'Automne in 1930 and in (**c**) 1931. Liu Kang family collection. Images courtesy of Liu family.

The literature relating to Liu Kang's oeuvre is limited and includes academic dissertations and studies about his professional activity in the context of other Singapore artists or the Nanyang style. Other sources comprise various exhibition catalogues, press releases, interviews and TV documentaries. Moreover, none of the authors have discussed the artist's painting techniques comprehensively or analysed the peculiarities of his working practice. The first attempt at presenting the artist's main artistic achievements is an article by Ho Kok Hoe from 1955 [6]. Ho's publication is also the only one in which the artist's three favourite paint pigments, namely vermilion, viridian and Prussian blue, are briefly mentioned. Two press interviews with Liu Kang conducted by Gretchen Mahbubani [13] and Thiagarajan Kanaga Sabapathy [14] in 1981 enrich our knowledge with anecdotes from the artist's life, which help explain certain aspects of his painting practice. Contrarily, a 1982 TV documentary shows some of his painting materials, but it does not discuss the artist's painting practice [15].

Liu Kang presented his artworks at numerous individual and collective exhibitions. The most important are the first individual exhibition in Singapore in 1957, the retrospective exhibition at the National Museum Singapore in 1981 and exhibitions in Taiwan (1983), Hong Kong (1985), Japan (1997) and China (2000). The catalogues of these exhibitions serve as additional sources of knowledge about Liu Kang. Two of these catalogues, from 1997 [16] and 2000 [1], as well as a monograph from 2011, published in conjunction with an exhibition organised by the National Art Gallery in Singapore [17], contain the most extensive descriptions of Liu Kang's painting style and his artistic inspirations. Other valuable sources of information are Liu Kang's collections of essays, written between 1937 and 1980 and published in 2011 [18], though, unfortunately, the artist was focused on social, cultural and art topics and did not share information about his approach to painting.

The identified sources of information reveal that very little is known about the technical aspects of Liu Kang's painting practice, despite public recognition of the artist as one of the leading figures of the Singapore modern art. In addition, none of Liu Kang's paint tubes have been preserved. Therefore, to compensate for this gap in our knowledge, recent technical analyses carried out by Lizun et al. have focused on Liu Kang's artistic phases, special themes and case studies, providing a new and comprehensive body of knowledge of his working methods [12,19–27]. In particular, the types of painting supports and the methods of their preparation, as well as the structure and chemical composition of the ground and paint layers, have been identified. In addition, the role of preparatory studies in the artist's creative process and the intriguing features of his painting techniques have been thoroughly explored.

Hence, based on the key technical features—which have been determined—of the artist's working practice, the present article traces the evolution of Liu Kang's preferences with regard to painting materials and techniques through the eight decades of his career. The results may assist in the revision of the provenance and dating of Liu Kang's paintings and clarify the presence of unconventional stylistic and technical solutions. Moreover, the yield data can aid conservation diagnostics and the treatment of his artworks.

2. Materials and Methods

The research focused on 97 of Liu Kang's paintings from the National Gallery Singapore (NGS) and Liu family collections created on canvas and hardboard between 1927 and 1999. The inclusion of 41 paintings from the Liu family collection was an attempt to ensure a balanced representation of the artist's genres, painting materials and techniques from which conclusions can be made.

A total of 448 ground- and paint-layer samples and 152 fibre samples were taken from the study group paintings for analyses.

Research strategy comprised non- and micro-invasive techniques applied to provide a wide array of significant data. However, the scope of the analytical methods differed between the NGS and Liu collections. Aligning with the wishes of the late artist's family, the majority of their paintings were investigated using non-invasive in situ methods, while some invasive analytical techniques were conducted only on selected artworks. For example, to provide an insight into the complex structure of the Paris and Shanghai painting supports, the extraction of fibre and ground-layer samples was applied to 20 NGS paintings, as well as to 35 works from the Liu family collection [21]. This decision was motivated by insufficient data from the NGS paintings, which did not allow the making of correlations between the structure of the textiles and ground layers from the two pivotal artistic phases. On the other hand, not all paintings from the Liu family collection were subjected to invasive sampling of the paint mixtures—in some cases, inventory and imaging were the only techniques employed to support the analyses of the artist's painting process. Nevertheless, in the case of seven NGS paintings, *Slope* (1931), *Portrait of C.Y. Hwang* (1939), *Malay man* (1942), *Bathing in the river* (1947), *Batik workers* (1954), *Fruit sellers* (1969) and *Chinese bridge over river* (c. 1974), this limited analytical approach turned out to be sufficient for providing insights into the technical features of Liu Kang's practice. Table S1 presents a chronological listing of the paintings selected for the study.

As an informative first-step approach, standard technical data were obtained from all paintings, including dimensions, characteristics of the painting supports and surface paint layers. Then, detailed analyses of the canvas structure, such as the weave, density and twist of threads, were performed using a Keyence VHX-6000 digital microscope.

The recto and verso sides of the paintings were photographed with Nikon D90 DSLR and later with D850 DSLR modified cameras with a sensitivity of 360–1100 nm to record the characteristic features of the paintings and to tentatively identify the pigments and determine the sample extraction sites. The photography techniques comprised visible light (VIS), ultraviolet fluorescence (UVF), reflected ultraviolet (UVR), near-infrared (NIR) and infrared false-colour (IRFC) imaging [12,19,20,22–31].

Raking light photography, reflectance transformation imaging (RTI) [32–34] and digital microscopy were used with regard to the possible presence of underlying compositions, which were later visualised with NIR and X-ray radiography (XRR) [12,19,20,22–26] using a Siemens Ysio Max digital system. Hidden paint layers were also revealed with a macro-

X-ray fluorescence (MA-XRF) Bruker M6 Jetstream scanner [19,22]. This instrument and the portable XRF Thermo Scientific ™ Niton ™ XL3t 970 spectrometer later allowed the initial identification of pigments in the ground and paint layers [20,22,24].

The following step involved the extraction of fibres for morphologic identification and the phloroglucinol stain test carried out using a Leica DMRX polarising microscope (PLM) [21,23,24,26,35]. The stain test determined the presence and concentration of lignin in the natural fibres and allowed the distinguishing between cotton, linen and hemp. Then, ground and paint fragments were taken from the areas of the existing paint losses for the preparation of pigment dispersions and paint layer cross-sections. All samples were photographed using a digital microscope and polarised microscope coupled with a digital camera. The structure of the samples and their organic and inorganic constituents were analysed using PLM [36], field-emission scanning electron microscope with energy dispersive spectroscopy (FE-SEM-EDS) Hitachi SU5000 coupled with Bruker XFlash® 6/60 EDS, followed by total reflectance–Fourier transform infrared spectroscopy (ATR-FTIR) [19–27] using a Bruker Hyperion 3000 FTIR microscope with a mid-band mercury cadmium telluride (MCT) detector connected to a Vertex 80 FTIR spectrometer [19–27]. The processed FTIR spectra were also compared to references in the material collection of the Institute for Conservation, Restoration and Study of Cultural Heritage, Nicolaus Copernicus University, spectral library of the Infrared and Raman Users Group (IRUG) [37], database of ATR-FT-IR spectra of various materials [38] and reference spectra published in the literature.

However, the acquired data did not always result in a positive pigment identification. For instance, some organic reds remain unknown and the potential presence of additional compounds has to be considered; therefore, further investigations involving chromatography and a range of mass and vibrational spectroscopy techniques should be conducted [39,40].

Moreover, the advertisements of the local art materials suppliers gave insights into the possible range of painting materials available to Liu Kang during his artistic phases.

When necessary, the interpretation of the analytical data was cross-referenced with contemporary colourmen catalogues, such as Lefranc, Bourgeois Ainé, Reeves & Sons (R&S), Rowney, Winsor & Newton (W&N) and Royal Talens. The catalogues enabled us to confirm the availability of certain materials. However, conclusions about the brands of materials used by the artist should not be hastily drawn. The archival photographs of the artist at work further expanded our knowledge of his materials and tools, whereas his drawings and watercolours shed light on the development of the compositions from the initial concepts to the completed artworks.

It is worth noting that the adopted naming convention of Liu Kang's artistic phases builds upon the structure of the artist's oeuvre proposed by Chow, Sen and Mo [1]. Hence, his artistic phases correspond to the places where Liu Kang was active or relate to his major contributions.

3. Results and Discussion

3.1. Painting Supports

The vast majority of Liu Kang's paintings were created over commercially prepared and unbranded canvases. The lack of stamps on the examined canvases could imply the purchase by the length from various small-scale retailers who did not brand their products. Manufacturers' stamps, however, with poor print and thus remaining unattributable to any colourmen known to the authors, were found only in two paintings—*Rustic landscape* (1934) and *Village* (1950) [21,24].

Although the research did not point to the brands of the painting supports Liu Kang used in his career, the advertisements of the art materials suppliers consistent with the time period and location of Liu Kang's activities suggest that he might have had access to a range of canvases from local and overseas manufacturers [21,23,24]. Nevertheless, conclusions about their brands should not be hastily drawn.

Reliance on commercial canvases was probably a convenient way for the preparation for painting as it only involved cutting the canvas to the required size and stretching it on the strainer or stretcher. Possibly due to poor quality, many of the original auxiliary supports were replaced by the artist or local framer whom he commissioned for the stretching and framing. This procedure sometimes involved cutting off weakened tacking margins, which necessitated mounting the canvas to the hard support with an adhesive, as in the cases of *French lady* (1931), *Self-portrait* (1931) and *Mount Huangshan* (1996) [12,21,26].

As can be seen from Table S1, linen canvases were frequently employed. However, it is worth noting that cotton canvases were the norm during the Shanghai phase [21]; the analyses highlighted the occasional use of cotton textiles in much later artworks—*Mountain* (1981) and *Mount Huangshan* (1996). Both linen and cotton painting supports are made in plain weave; however, two exceptions are represented by *Mountains* (1991) and *Nude* (1995), which are characterised by a basket-weave structure (Figure 2a,b) [26].

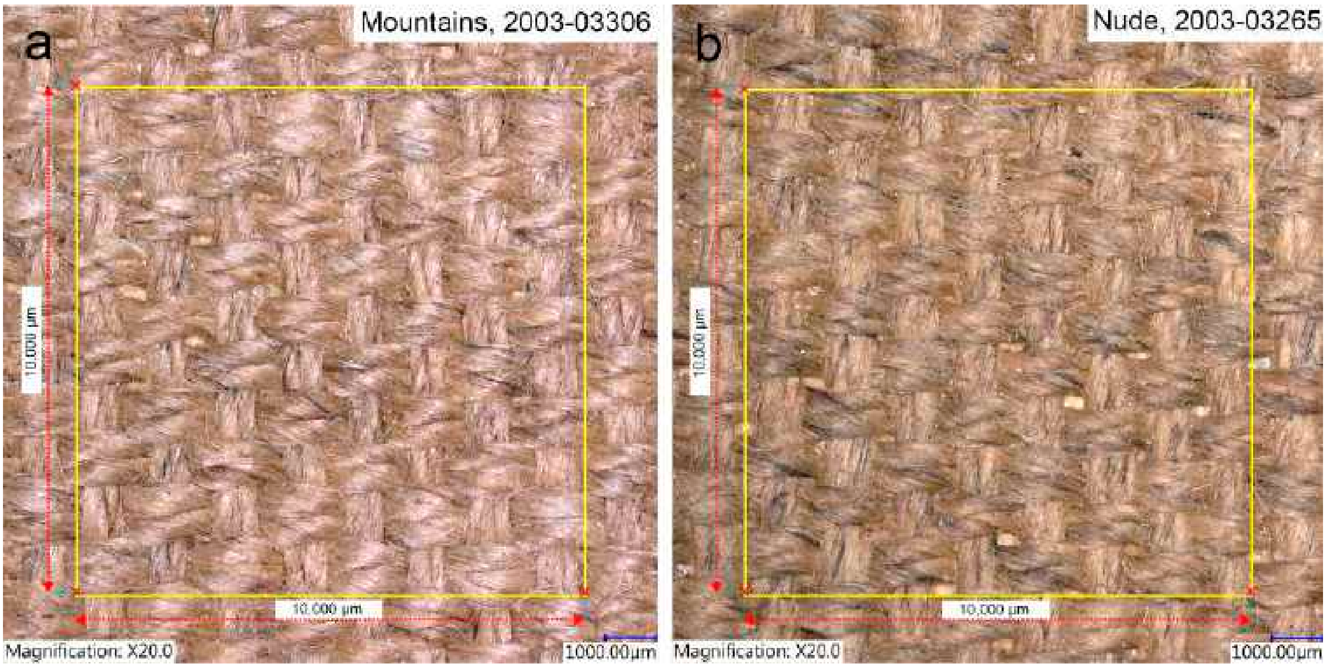

Figure 2. Photomicrographs of basket-weave structure identified in: (**a**) *Mountains*, 1991; (**b**) *Nude*, 1995.

The research revealed that Liu Kang utilised the recto and verso sides of his existing artworks for painting. This approach was probably motivated by extreme cost-saving solutions during the Paris phase [21,22] and the non-availability of the painting materials during the period of emigration to Malaya [23], whereas the practice of painting over earlier compositions during the mature years (the 1950s–1990s) likely resulted from the utilisation of unsuccessful and rejected artworks (Table S1) [12].

Hardboard resembling Masonite (pressure-moulded wood fibres) was the second type of painting support employed by Liu Kang, and the earliest documented example of its application is *Portrait of C.Y. Hwang* (1939), which was executed over the textured side (Figure 3a,b). The remarkably consistent use of the hardboards was recorded in the artworks depicting mountainous Chinese landscapes, created between the 1970s and 1990s. The artist seemed to favour utilising the smooth side of the hardboards, which he probably considered adequate for the vigorous handling of the paint with brushes and palette knives, contributing to heavy impastos and robust scraping [26].

Liu Kang's frequent outdoor painting sessions in Paris and Shanghai encouraged the use of small-sized painting supports, which were convenient to carry around [21]. His artistic activities of the 1940s do not show a radical change with regard to the size of painting supports, as he often painted over the recycled Paris and Shanghai artworks [23].

In the 1950s, there was a shift in the size of Liu Kang's paintings, with some exceeding 100 cm in height or width [24]. This observation was additionally corroborated by Frank Sullivan in the introduction to Liu Kang's 1957 exhibition catalogue: "He loves big canvases, over which his brush can sweep and range with firm touch and definite line" [5]. Liu Kang already enjoyed a well-established professional position; hence, it is conceivable that he could have afforded the required painting materials as their availability had improved in Singapore in the 1950s. Thus, the paintings created until the twilight of Liu Kang's artistic career show a variety of sizes, as seen in *Mountain* (1981), which measures 36 × 29.5 cm, and *Beauties at rest II* (1998), which measures 85 × 127 cm [25,26].

Figure 3. Liu Kang, *Portrait of C.Y. Hwang*, 1939, oil on hardboard, 61 × 46.4 cm (**a**) and detail showing the perforation of the hardboard visible through the paint (**b**). Painting is a gift of C.Y. Hwang family. Collection of National Gallery Singapore. Image courtesy of National Heritage Board, Singapore.

3.2. Priming Layers

The artist habitually worked on white grounds as they played a fundamental role in the painting process. For instance, a successful employment of the white ground as a colour in Paris paintings reflects an inspiration from Modernists' techniques [22,41,42]. Likewise, as a mature artist, he skilfully exposed the white colour of the ground, which was later pivotal in the batik-inspired painting technique [24].

The structure of the ground layers displays some variability as the artist purchased ready-primed canvases from various suppliers during his oeuvre. However, the painting *Nude* (1927), created during the artist's academic years at Xinhua Arts Academy in Shanghai, is an interesting peculiarity as it shows the bare tacking margins, evidencing an artist's preparation of the painting support (Figure 4a,b). The ground was applied over the cotton canvas as a single layer (Figure 5a,b) composed of chalk (PW18), lithopone (PW5) and/or barium white (PW21) and zinc white (PW4) and some lead white (PW1) bound in drying oil (Figures 5c and 6). Hence, it is conceivable that the craft of the preparation of the canvas for painting was part of his artistic education. However, the analyses of his subsequent painting practice proved Liu Kang's reliance on commercially prepared canvases.

The grounds of the paintings created during the Paris and Shanghai phases are single layered. The grounds from Paris are predominantly made of lead white combined with extenders and drying oil. Absorbent grounds bound in natural glue or semi-absorbent grounds bound in a combination of natural glue and drying oil occur less frequently. Although it is conceivable that the oil originated from the artist's paint, as can be exemplified by *My landlady, Madame Normand* (1932), where oil from the thinned paint had penetrated through to the back of the canvas [21].

As for the grounds from Shanghai, the majority are made of chalk as a principal component combined with additives and bound in drying oil and proteinaceous compound, suggesting absorbent or semi-absorbent structures. However, the oil detected in the latter might also have come from the paint [21]. The ability of these two types of ground to accelerate the drying of oil paint was probably a key factor determining their use for the outdoor painting sessions and rapid execution at the studio in Paris and Shanghai. It is also possible that the artist appreciated the matt finish of his paintings, which resulted from light scattering on a rough paint surface with lower oil content.

Figure 4. Liu Kang, *Nude*, 1927, oil on canvas, 45 × 60 cm (**a**) and detail of the painting showing unprimed tacking margins (**b**). Liu Kang family collection. Images courtesy of Liu family.

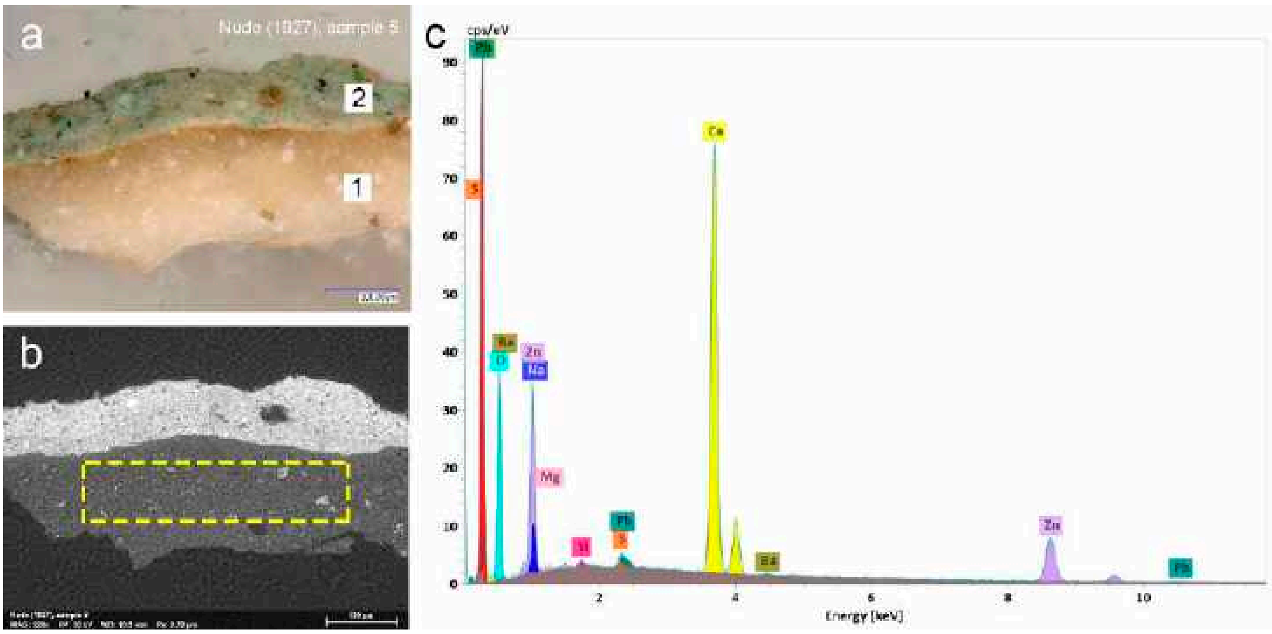

Figure 5. Optical microscopy image of the paint cross-section of sample 5 at × 200 magnification, extracted from *Nude*, 1927, photographed in VIS (**a**). The image shows the ground layer (1) and paint layer (2). Corresponding backscattered electron image (BSE) of the same sample with marked area of analysis (**b**) and SEM-EDS spectra of the white ground layer indicating strong Ca and Zn signals, as well as Pb, S and Ba, which can be assigned to chalk, lithopone and/or barium white and zinc white and lead white (**c**).

The comparative studies of the structures of the painting supports revealed that the artist reused those from Paris and Shanghai in the 1940s, which might have resulted from harsh economic realities during the post-war period and reflects his determination to continue his artistic career [23].

The research revealed that a double-layered oil-based ground was the most common type identified in the paintings created by the artist between the 1950s and 1990s. The constituents of both layers are the same, with the provision that they were mixed in different concentrations. Hence, lead white is the main component of the top layers, whereas chalk features as the main compound in the bottom layers. Admixtures of lithopone and/or barium white and zinc white and titanium white (PW6) are present in both layers. The artist also employed the canvases primed with an oil-based single layer of zinc white and occasionally used grounds composed of lead white with other common additives. Triple-layered oil-based and single-layered semi-absorbent grounds are interesting peculiarities as they were used only once in the 1950s [24]. Table S2 presents a synoptic overview of the composition of the ground layers.

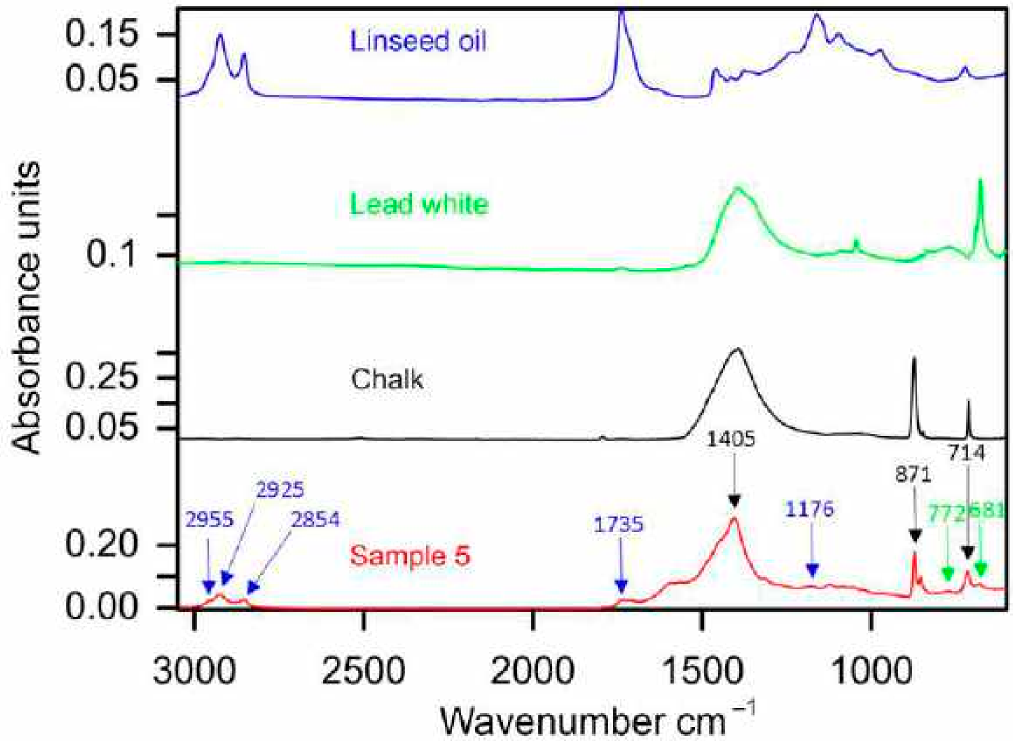

Figure 6. ATR-FTIR spectra of the white ground layer of sample 5 extracted from *Nude*, 1927, with labelled marker peaks of chalk (black), lead white (green), oil (blue) and reference spectra of the same compounds.

As for the hardboards, the artist chose to paint on them directly without the primer [26]. Moreover, as he often recycled earlier paintings, he did not apply an intermediate layer of ground or a uniform coat of paint to create a neutral surface on the recto or verso of the reused paintings [20,23].

3.3. Pigments

Although Liu Kang kept his working process private and none of his paint tubes are preserved, the archival sources provide some clues about the brands of the materials he employed. However, firm conclusions about any links between the archival information and materials used by Liu Kang should not be made because of weak evidence. Nevertheless, tracing some colourmen through the advertisements consistent with the time and location of the artist's activities, his studio photographs and TV documentary allowed better interpretation of certain data derived from the pigment analyses.

The use of Lefranc oil paints during the Paris phase can be speculated based on two pages from the October 1928 Lefranc catalogue the artist had preserved and brought home. The catalogue pages contain a list of oil colours and their prices [20]. However, it is likely that Liu Kang might have had access to a greater range of painting materials, including local and imported brands from Europe and America [21,22].

With regard to the paintings executed in Shanghai, there is no evidence pointing to the brand name of the paints Liu Kang employed during the Shanghai phase. However, the archival search revealed that paints were widely available from local manufacturers like Marie's and Eagle, as well as W&N and Reeves & Sons R&S [27]. There is also a possibility that Liu Kang used paints purchased during his earlier sojourn in Paris.

As for the post-war period of the late 1940s and 1950s in Singapore, local newspapers', magazines' and trade directories' advertisements showed the availability of R&S, W&N and Royal Talens painting materials. Liu Kang's three favourite pigments of unknown brand—viridian, vermilion and Prussian blue—were mentioned for the first time in the 1955 essay by Ho Kok Hoe [6].

Oil paint tubes from Royal Talens (Van Gogh series), Rowney (Georgian series) and W&N can be seen in the TV documentary, *Portrait of an artist: Liu Kang*, presented on 26 February 1982. Although the design and labelling of Royal Talens and Rowney tubes conform with those manufactured by these companies in the 1980s, the W&N tube appeared much older, supporting the notion that the artist used the old stock paints as well [15,26].

Royal Talens (Rembrandt series) oil paints were evidenced in the photographs of the artist at work taken for his 1997 and 1998 exhibition catalogues [11,43]. In addition, an archival photograph of the artist in his studio taken in the 1990s shows his painting trolley neatly stocked with Royal Talens and Rowney (Georgian series) paint tube box sets [25]. Judging from these visual sources, it can be speculated that the paint brands were used separately or mixed by the artist. It can further be inferred that he may have preferred bulk purchases of paint tubes to avoid interruption to the artistic process.

Colour usually played a more dominant role than the texture in Liu Kang's way of expression. This preference became more evident after he settled in Singapore and exposed himself to the lush tropical landscapes. On the other hand, the special theme of the Huangshan and Guilin mountains (1977–1996) strikes one with a restricted colour scheme while the visual effects are achieved with a rich texture.

The overview of the pigmentary palette employed by the artist throughout his oeuvre enabled us to observe several changes, although it is uncertain if these changes accompanied a stylistic evolution. Nevertheless, Liu Kang's choice of pigments can be charted based on the most common colours found in his paintings. As for the binding medium of the pigment mixtures, drying oil was confirmed in all instances. This finding conforms with the Lefranc 1928 listing of oil paints preserved by Liu Kang, archival photographs and the TV documentary from the 1980s and 1990s, which show some of his oil paint tubes in detail. An overview of the identified pigments in Liu Kang's paint mixtures is presented in Table S3.

3.3.1. Blue

Ultramarine (PB29) and Prussian blue (PB27) are two major blue pigments appearing in Liu Kang's paintings (Figure 7). Ultramarine was commonly used for the depiction of sky and water, while Prussian blue was restricted to the role of a tint for green and black colours and was rarely employed to depict the sky, as is the case of *Zuo La Lu* (1930). Cobalt blue (PB28) was used intermittently from the beginning of Liu Kang's career in Paris until his artistic twilight in the 1990s. Regarding other Co-containing cerulean blue (PB35) and cobalt violet (PV14) (Figure 8), the artist did not seem to have been particularly attracted to them; hence, they appeared only in two paintings dated to 1953 and 1968. Detection of manganese blue (PB33) only in *Scene in Bali* (1953) is an interesting peculiarity; however, this pigment was used as an admixture; therefore, its appearance is considered as accidental. The analyses highlighted the sole use of phthalocyanine blue (PB15) in *Painting kampong* (1954) to depict water and sky. The painting successfully represents the primary batik-inspired technique by Liu Kang [12,24], and blue is the most dominant colour determining the composition of the scene. Further use of phthalocyanine blue by the artist is considered as low as it was detected in three artworks dated to 1986, 1998 and 1999. It appears to have been combined with ultramarine and Prussian blue to alter the hue of the paint mixtures [25,26]. This observation points to the artist's doubts about the permanent incorporation of phthalocyanine blue into his colour palette.

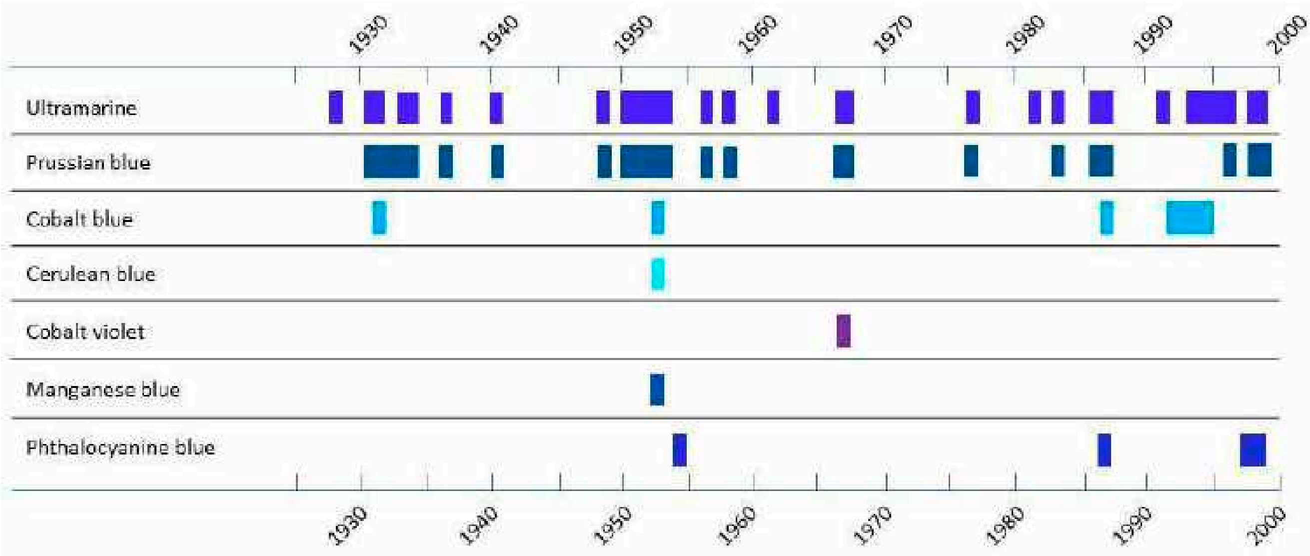

Figure 7. Timeline of Liu Kang's blue pigments.

3.3.2. Green

The analytical results of the green-painted areas showed an uninterrupted use of viridian (PG18) throughout the group of the investigated paintings, reflecting Liu Kang's predilection for vivid colours. The occasional incorporation of phthalocyanine green (PG7), starting in the early 1950s, supports this notion as both pigments have a similar hue. However, phthalocyanine green had never superseded viridian in Liu Kang's colour palette. Emerald green (PG21) appears sparsely and sometimes in combination with viridian. Despite the fact that some grades of emerald green were commercially adulterated with chromium pigments [44,45], the analyses pointed to a partial co-location of copper and chromium in the green passages, enabling us to infer that emerald green was not modified by the manufacturer but mixed on the palette with viridian by the artist. However, its low usage suggests some hesitation in giving this pigment a more pronounced role in the painting process. Nevertheless, due to its high toxicity, emerald green was progressively abandoned and was no longer available from major colourmen by the end of the 1960s [45]. Hence, based on the investigated paint samples, it seems that the artist used this green pigment up until the 1950s [24]. The analyses revealed that some green passages contain a mixture of Prussian blue and chrome yellow (PY34). Such composite paint could have been obtained by the artist on the palette, but it was also available from the colourmen under the name of chrome green (PG15) [46,47]. Similarly, a concomitant presence of viridian and cadmium yellow (PY35) may imply an artist's made mix or a commercially prepared cadmium green (PG14) [47], whereas mixtures of viridian and zinc yellow (PY36) may imply commercial permanent green [47]. Figure 9 shows a summary of Liu Kang's green pigments.

3.3.3. Yellow, Orange and Brown

The artist showed a strong reliance on yellow and red iron-containing earths, which in mixtures with other pigments often made a precise identification challenging. However, yellow ochre (PY43) was confirmed in a few paint samples based on the FTIR detection of additive minerals, such as kaolinite, gypsum and silicate materials [48,49]. Besides iron-containing earths, chrome yellow and other yellow chromate pigments based on Zn, Ba and Sr were often employed by the artist for painting yellow and green areas. Interestingly, their prevailing use was detected in the paintings representing the Paris and Shanghai phases. However, it is also conceivable that Cr-containing yellows were present in the analysed paint samples as commercial admixtures to other pigments like yellow iron-containing earths [49,50], Prussian blue [46] and viridian [47]. The incorporation of zinc yellow appears unexpectedly, as it was unpopular among artists because of its poor hiding and tinting power [50].

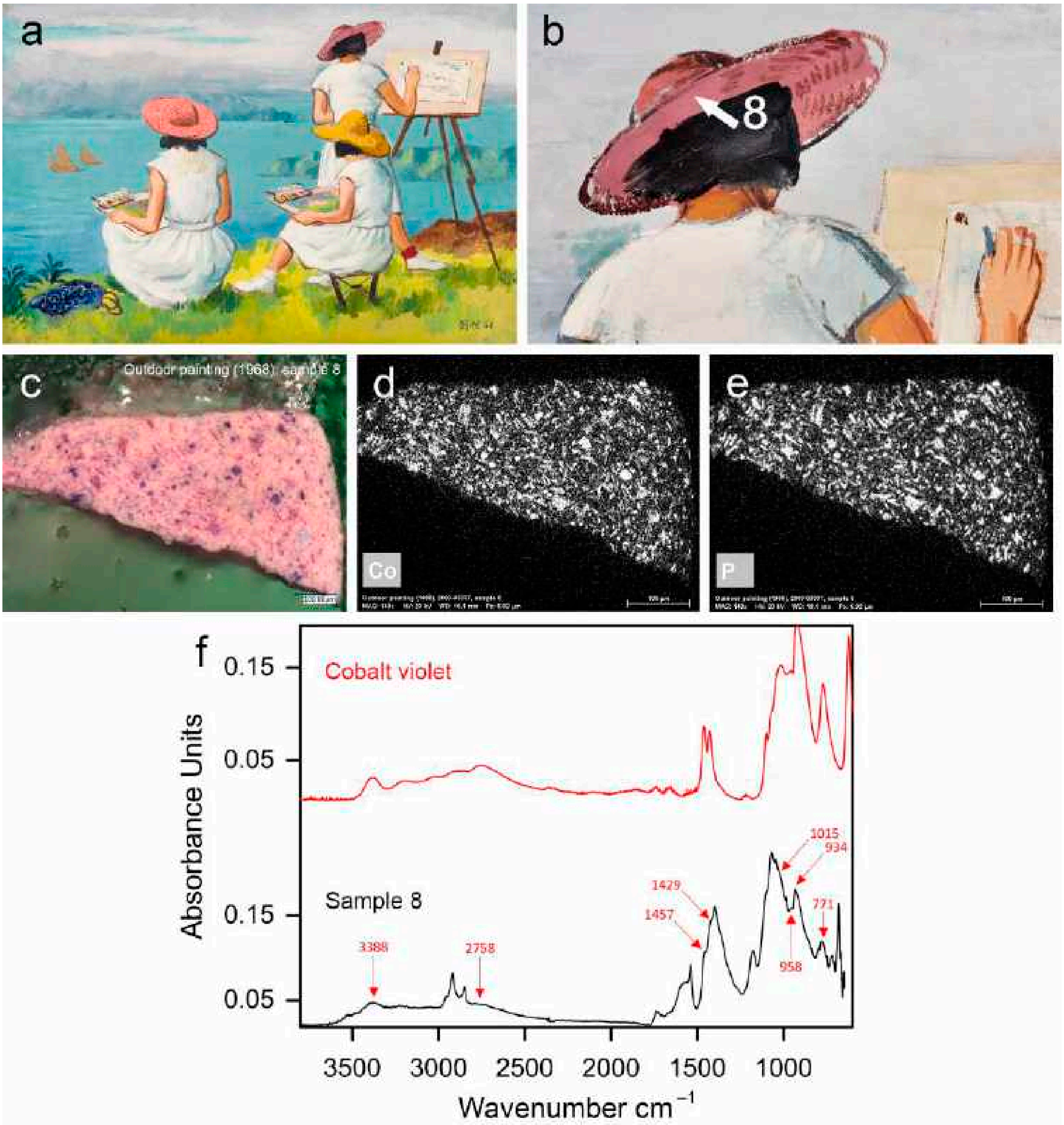

Figure 8. Liu Kang, *Outdoor painting*, 1968, oil on canvas, 85 × 126.5 cm (**a**) and detail of the painting showing the extraction area of the sample 8 (**b**), followed by optical microscopy image of the cross-section of the sample at 150× magnification (**c**), SEM-EDS distribution maps of Co and P (**d**,**e**). The concomitant presence of cobalt and phosphor corresponds to the acicular shape of the red-violet particles of cobalt violet (cobalt phosphate). ATR–FTIR spectra of the sample with labelled marker peaks of cobalt violet and reference spectra of the same pigment (**f**). Painting (**a**) is a gift of the artist's family. Collection of National Gallery Singapore. Image courtesy of the National Heritage Board, Singapore.

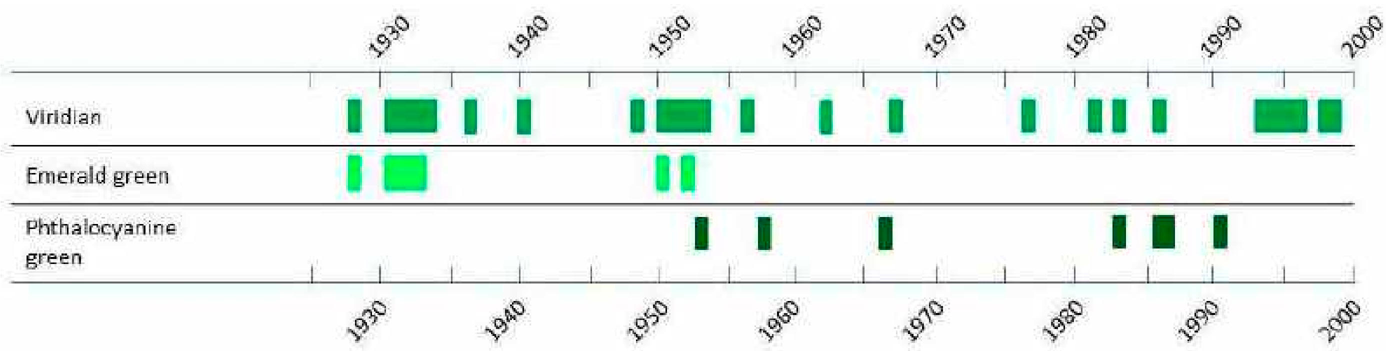

Figure 9. Timeline of Liu Kang's green pigments.

Cd-containing yellows, which could be cadmium yellow or cadmopone (co-precipitated cadmium sulphide and barium sulphate) or zinc-modified light cadmium yellow [51], appeared on Liu Kang's palette as early as in the 1930s and were used infrequently until the 1940s. The analyses revealed that the artist heavily used Cd-containing yellow pigments in the 1950s and 1960s, but their use declined in the following decades.

Cadmium orange (PO20) or its variant were used sparingly and were identified in the paintings from the 1940s, 1950s and 1990s. The earliest incorporation of synthetic organic Hansa yellow 10G (PY3) by Liu Kang was dated to 1932, but the investigation allowed us to infer that it was an isolated example. The artist seemed to have reconsidered inorganic yellow and used Hansa yellow G (PY1) for obtaining green hues in the 1980s and 1990s.

Cobalt yellow (PY40) was identified only in three paintings dated to 1930, 1953 and 1958, suggesting the artist's lack of confidence in this pigment, which was probably because of its undesirable low hiding power in oil medium [52,53].

Brown hues were achieved with yellow and red iron-containing earths additionally modified with other pigments; however, the use of umber (PBr7) for deeper brown hues was positively confirmed in the entire oeuvre of Liu Kang. Figure 10 provides a summary of Liu Kang's yellow and brown pigments.

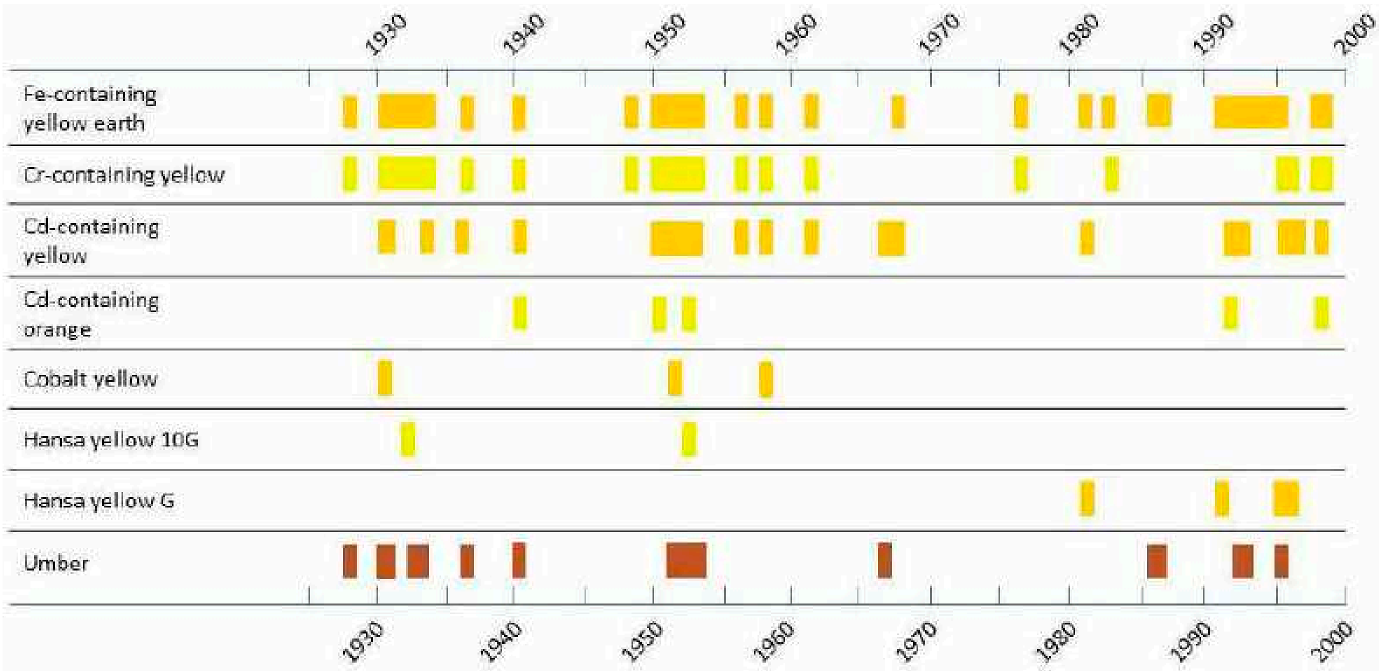

Figure 10. Timeline of Liu Kang's yellow and brown pigments.

3.3.4. Red

The variety of organic reds features strongly all over Liu Kang's artistic career. Despite the challenging identification because of an insufficient suit of FTIR bands and incorporation with other pigments, alizarin crimson (PR83), synthetic alizarin lake (PR83:1), Hansa red (PR3), brazilwood (NR24), geranium lake (PR90:1) and naphthol red AS-D (PR112) were positively confirmed [20,22,24–26]. The artist's predilection for organic reds was probably motivated by their intense brilliance and hue saturation. Regarding the inorganic reds, the artist frequently used red iron-containing earth pigments. It is worth noting that Liu Kang was not attracted much to cadmium-based reds, which were detected in only five paintings (Table S3). Figure 11 shows the use of red pigments by Liu Kang.

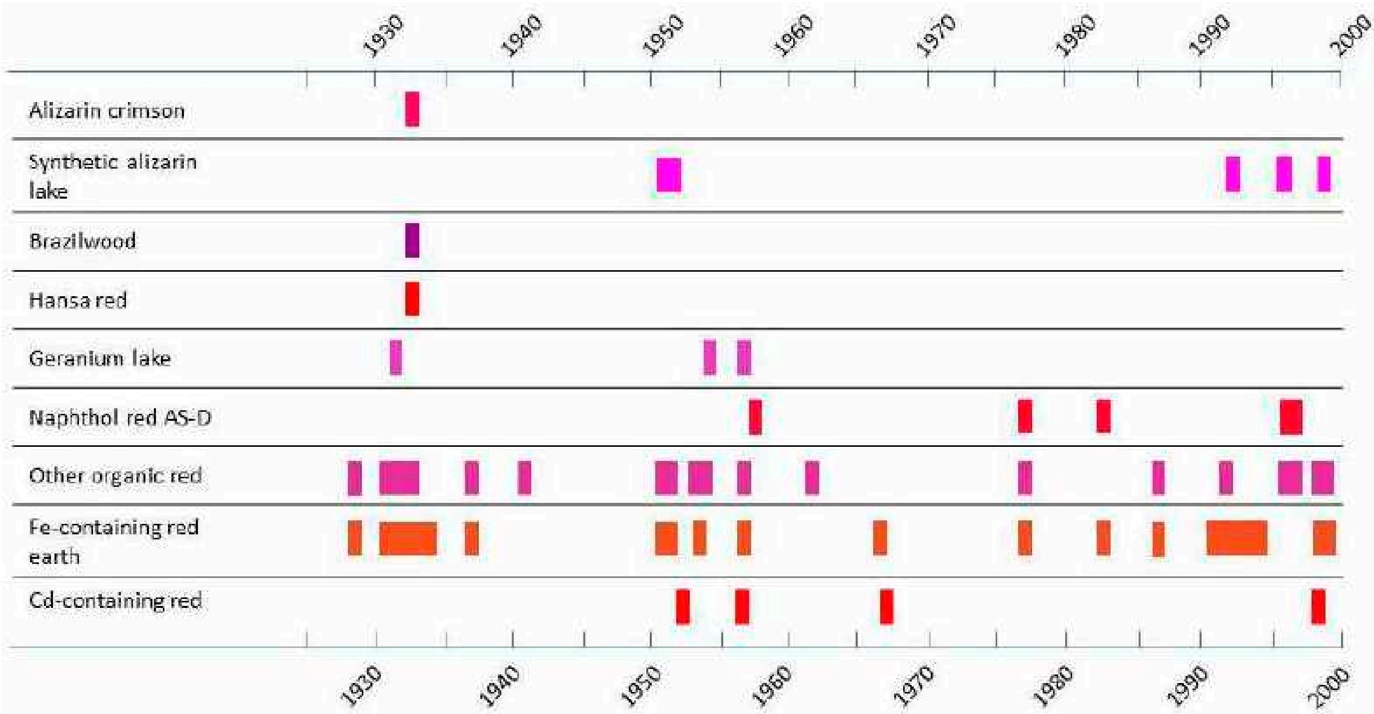

Figure 11. Timeline of Liu Kang's red pigments.

3.3.5. White and Black

White pigments and different extenders were identified in the white-painted areas. For instance, lead white in combination with chalk was predominantly used by Liu Kang during his stay in Paris, whereas lithopone and/or barium white and zinc white were commonly present in the white brushstrokes from the Shanghai phase. The analyses of his post-war paintings from the late 1940s revealed a greater use of lead white admixed with Zn-based compound, while the whites from the paintings created in the 1950s and 1960s showed a balanced presence of lead and zinc whites. However, from the 1970s onwards, the role of lead white on the artist's palette was gradually reduced, probably because of concerns about its toxicity than of decreased availability as the pigment was listed in the catalogues of major colourmen in the 1970s and 1980s [26]. Moreover, it is possible that the artist used old stock paints as he displayed a preference for a bulk purchase [25].

Although lead white was continuously present in the mixtures with other pigments until the 1990s, it was superseded by titanium white in highlights [25,26]. Hence, the role of titanium white in Liu Kang's paintings evolved from a possible commercial admixture characteristic of his early practice to the most frequently employed white pigment in the 1980s and consistently used thereafter.

Chalk presence was detected in different paint mixtures from all investigated artistic phases and themes; however, it is considered to be present as an extender [54]. Similarly, barium white, an inert pigment, is known as a common extender for lead white, lake pigments [55], titanium white [56], chrome yellow [50], earth pigment [49], emerald green [45] and viridian [46]. The recorded occurrences of starch correlate with the high concentration of Sn in the red paint samples and point to the commercial addition of a substrate to the organic reds [57,58] detected in the paintings from the Paris phase [20,22].

Although bone black (PBk9) features strongly in Liu Kang's pigmentary palette, he did not employ pure black brushstrokes. Instead, he often admixed bone black with ultramarine, Prussian blue, cobalt blue, viridian and umber to produce intensive shades. Additionally, the minimal admixture of bone black and carbon black was suspected in other paint mixes to modify their shade. The summary of the use of white and black pigments is presented in Figure 12.

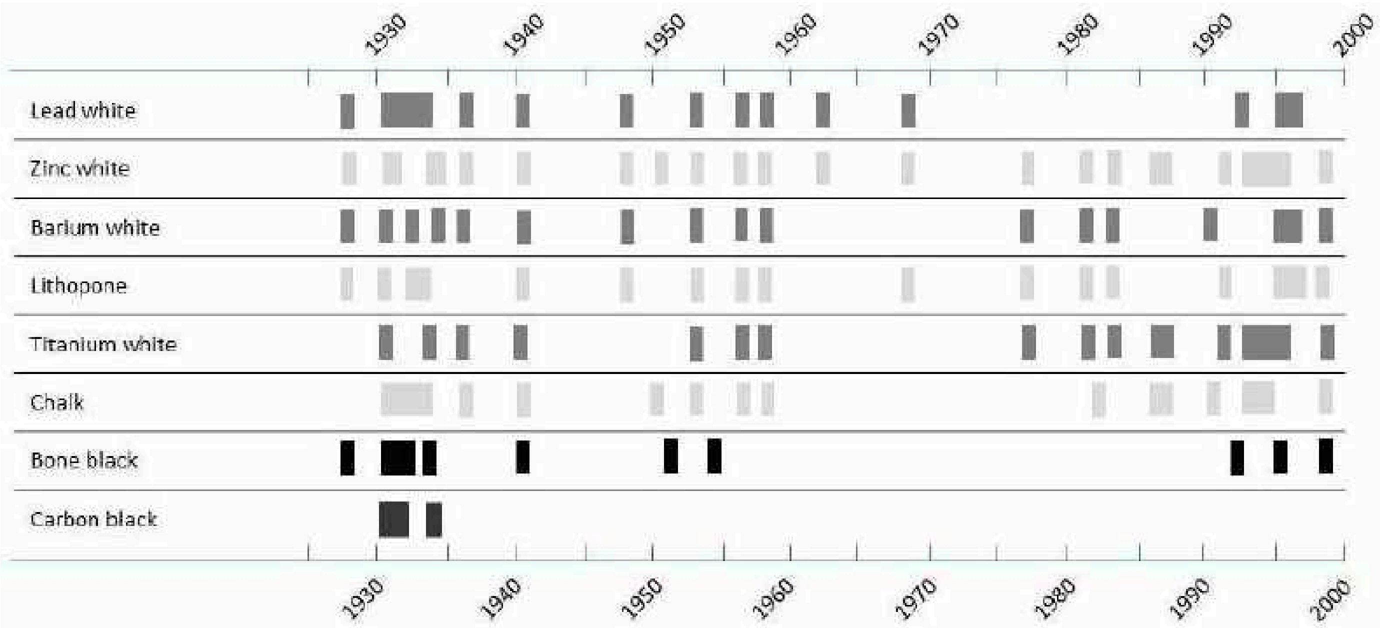

Figure 12. Timeline of Liu Kang's white and black pigments.

3.4. Other Materials

Metal soaps were frequently found in the ground and paint layers containing drying oil as a binder (Tables S2 and S3) [21,22,24–26]. However, it remains uncertain if these compounds result from the reaction of metal ions present in the lead- and zinc-containing pigments with free fatty acids from the oil binder or if the detected metal soaps are the commercial additives to the grounds and paints [59,60]. Nevertheless, their formation may be accelerated by environmental factors like moisture and heat, which are typical for the tropical climate of Singapore and occur in the conservation laboratories as part of the treatment strategy [59,61–63]. Although one would expect accelerated ageing and degradation associated with the presence of the metal soaps in Liu Kang's paintings, no signs of deterioration, such as cleavage, paint loss, disfiguring lumps, reduced opacity and surface efflorescence, have been observed. Nevertheless, the monitoring of the condition of the paintings and further investigation of the metal soaps in Liu Kang's paintings would ensure scientifically supported conservation treatments.

3.5. Development of the Compositions

Small-scale sketching on paper with pencil, crayon, charcoal, pastel, pen and watercolour was an integral part of Liu Kang's development of the artistic ideas prior to painting. The comparative studies of these drawings with the final paintings revealed a distinctive conceptual work of the artist who attempted to design the most satisfactory compositions.

On the other hand, the collected evidence from the 1940s onwards seems to point to a growing role of photography in his artistic process. Although Liu Kang rejected photography as an art, he was convinced about its merits for capturing interesting subjects and motifs for future reference [64]. Hence, based on analyses of the detailed photographs and preparatory drawing, *Climbing the hill* (1948), depicting St. John's Fort in Malacca, was probably executed in the artist's studio in Singapore [23]. Liu Kang's famous trip to Bali in 1952 resulted in an impressive number of photographs of daily life of local communities. The artist conveniently used these photographs as a reference for designing the compositions of the paintings and depicting details upon his return to Singapore [24]. Liu Kang's continued reliance on photographs and drawings was observed in Huangshan and Guilin landscapes painted between the 1970s and 1990s, as well as in the paintings of nudes from the 1990s [25,26].

Liu Kang's practice of making preparatory underdrawings on the painting supports remains relatively unknown. One reason could be that thickly applied paint effectively limits the visibility of the underdrawings in NIR. On the other hand, preliminary sketching studies enabled the artist to establish the composition on the painting support with effortless brushwork and skip the underdrawing stage, as in the cases of *Countryside in France* (1930), *Village scene* (1931) and *Orchids* (1952) [16]. Nevertheless, a few documented examples of the underdrawing show subtle pencil lines, whereas in *Painting kampong* (1954), the artist scratched the surface of the ground layer, creating barely discernible compositional lines that guided his subsequent paint application. In *Two nudes* (1996), he skilfully integrated red and blue crayon outlines with bold and red paint contours [25].

As for the painting process, *Nude* (1927), executed during a live painting class at the Xinhua Arts Academy in Shanghai, gives a rare insight into Liu Kang's painting skills before graduation. The model was depicted realistically with a proper rendering of shadow and light reflections on her body. However, his handling of the paint with short brushstrokes reflects a lack of confidence and some effort in transferring the subject onto the canvas [25].

Liu Kang's early artistic phases in Paris and Shanghai are mostly characterised by *plein air* execution, which encouraged small formats, spontaneity and wet-on-wet paint application with minimal finishing touches after the paint surface has dried. However, despite these similarities, there are some subtle differences in the approach to painting between these two phases. In Paris, Liu Kang intensively experimented with different paint application techniques. Short, vigorous and descriptive brush touches built the compositions of *Zuo La Lu* (1930) and *Autumn colours* (1930), reflecting the artist's attention to detail. Parallel brushstrokes in *St Gingolph, Lac Leman, Switzerland* (1929), *Landscape in Switzerland* (1930), *Farmer's house* (1930), *Village scene* (1931) and *Still life with books, Paris* (1931) strongly resemble van Gogh's style (Figure 13a,b). A broad and flat application of paint synthesising forms and colours can be observed in *Boat near the cliff* (1931). The deliberate exposure of the white ground in most of the Paris paintings enhances the brightness of the compositions and contrast between the forms [22]. Overall, Liu Kang's handling of the paint during the Paris phase became increasingly fluid and spontaneous, contrary to the technique observed in *Nude* (1927), executed at the Academy in Shanghai a few years earlier. The variety of the adopted means of expression by the artist during his stay in Paris demonstrates his determination to improve and grow as an artist, despite the circumstances.

Upon return to Shanghai, Liu Kang consolidated the knowledge acquired in Paris and his painting technique became more uniform, showing a predilection for reduced shading, which resulted in flat and simplified forms, such as in the *Rustic landscape* (1934) and *Seascape in China* (1936). However, the occasional need for a description of the forms was achieved by the introduction of expressive outlining resembling Chinese calligraphy, scraping into wet paint, and building moderate impastos where exploiting tonal contrasts would have been inefficient [5,65]. Besides brushes, palette knives proved to be useful for a quick and broad handling of the paint in the outdoor conditions.

The 1940s confirmed the artist's departure from the painting techniques practised in Paris and reflected a strong need to develop his own style. His new aesthetics is best represented by the combination of flattened surfaces with bold lines that negate the illusion of depth, as in *Nude* (1940) [25]. The increased role of palette knives in the painting process is exemplified in *Malay man* (1942) and *Climbing the hill* (1948) [12,23].

Figure 13. (**a**) Liu Kang, *Farmer's house*, 1930, oil on canvas, 45.5 × 53.5 cm and (**b**) corresponding detail showing parallel brushstrokes. (**c**) Liu Kang, *National day*, 1967, oil on canvas, 86 × 127.5 cm and (**d**,**e**) corresponding details showing incorporation of white ground into the colouristic scheme of the composition. Paintings (**a**,**c**) are gifts of the artist's family. Collection of National Gallery Singapore. Images courtesy of the National Heritage Board, Singapore.

The artist's painting technique entered a period of a remarkable evolution in the 1950s, resulting in the contribution to the Nanyang style depicting Southeast Asian subject matter by means of an amalgamation of the School of Paris and Chinese traditional ink painting techniques [8–10]. The additional aspect of the style is the batik-inspired stylistic innovation, which successfully accommodated Liu Kang's preference for the exposed colour of white ground (Figure 13c–e). The research enabled us to distinguish between two types of Liu Kang's batik-inspired paintings based on the quality of the technique.

Batik-inspired paintings considered to be of primary quality often featured minimal texture, flatness of the forms and contrast between vivid colours achieved through the exposure of a white ground subsequently reinforced with dark paint outlines, as seen in *Outdoor painting* (1954) and *Fruit sellers* (1969) [12,24]. Where necessary, the artist introduced distinctive scraping strokes into the wet paint to add unique and descriptive elements to the composition. Batik-inspired paintings with a multi-layered paint build-up, pronounced texture and white paint outlines of the forms applied in the final stage of the creative process substituting the absence of the exposed ground layer likely indicate that the technique was of inferior and secondary quality. The observation of these features may imply the presence of the underlying compositions as being a direct cause of the unavailability of the white ground for the newly painted scene [12,24].

The years following Liu Kang's Bali trip are considered the peak that yielded many key paintings in his new style; however, the artist actively searched for new sources of inspiration, reworked old themes and expanded the repertoire of the forms of expression. The execution of a series of mountainous Chinese landscapes (1977–1996) distinguishes itself from his earlier artistic phases primarily because of the muted palette of colours and abundant use of paint applied in alternate wet-on-wet and wet-on-dry, tight dabbing with brushes and palette knives, giving an impression of dimensionality and rough texture of the rock formations, as can be seen in *Mountain* (1981) [26].

The choice of subject matter and the use of specific painting techniques allowed the artist to convey his own emotions, such as a sense of isolation and a reverence for the power of nature. This aligns with the Eastern approach to painting outlined by Liu Kang in his essay from 1969: "Eastern artists treat natural scenery as the starting point for depicting their emotions" [66]. However, the theme of nudity manifests the Western spirit of the artist who stated in the same essay from 1969: "Western paintings, inheriting the Greek preference for physical might, uphold the beauty of the body as their highest principle. Hence, they have always used human figures as the main subject matter and nature as scenery. The majority of their paintings of human figures are nude paintings" [66]. The theme of nudity in Liu Kang's paintings from the 1990s demonstrates various painting techniques and styles. Contrary to the theme of the Huangshan and Guilin mountains, the rich texture was successfully paired with the abundance of colours and pointillist finish, resulting in attractive optical effects, as seen in *In conversation* (1999). On the other hand, a flat paint application combined with abbreviated and generalised forms and reduced details, seen in *Nude* (1992) and *Two nudes* (1996), represent an unconventional painting approach. Due to the complex paint application technique and Liu Kang's deteriorating eyesight between the 1980s and 1990s [13,67,68], the artworks representing both themes were routinely executed in more than one sitting in the studio.

Distinctive features of the artist's working practice are the retouchings, revisions and recycling of former compositions. Liu Kang habitually retouched the paint losses in his paintings; however, a worsening eye condition might have impacted the colour accuracy of these amendments. Minor and major revisions may indicate that, despite extensive drawing studies and photography preceding the painting, the artist's concept of the final composition evolved, and in some cases, changes were made in very distinct stages. Financial constraints, changes in availability of art materials, the poor condition of the paintings or a shift in Liu Kang's personal taste resulted in an unfinished state of artwork, or a rejection of the completed artwork, leading to their being recycled [12].

4. Conclusions

For the first time, an overview of Liu Kang's painting materials and techniques was conducted based on 97 artworks created by the artist between 1927 and 1999. The systematic multidisciplinary approach revealed a few key aspects of Liu Kang's painting practice. Linen canvases of varied densities were the artist's preferred painting supports. Except for *Nude* (1927), the canvases represented a consistent kind of commercial preparation. Although absorbent and semi-absorbent grounds occurred only in paintings originating from Paris and Shanghai, grounds bound in drying oil are prevalent in Liu Kang's artistic output. Besides textile supports, the artist occasionally used unprimed hardboards resembling Masonite boards. Additionally, Liu Kang's frequent outdoor painting sessions in Paris and Shanghai led to the use of small-sized painting supports, but as his career progressed, he began to favour larger formats.

The palette of colours is economical, but it is uncertain if these limitations were external, imposed by the availability of the painting materials, or self-imposed for aesthetic reasons. Nevertheless, the research demonstrated that his pigmentary palette evolved over time. In fact, a wide reliance on viridian, ultramarine, Prussian blue, Cr- and Cd-containing yellows, yellow and red Fe-containing earth pigments and organic reds was detected in the course of the paint analyses. The artist introduced—very briefly—manganese blue, phthalocyanine blue and green, reduced the role of lead white by replacing it with titanium white and withdrew emerald green.

Liu Kang strongly relied on preliminary drawings and photographs for the development of artistic ideas. The study revealed variations in his paint application techniques, from small dabs, short or long directional and parallel strokes that sometimes juxtaposed with the exposed ground, to fluid brushwork that evolved into broad and flat application or pointillist finish, impasted wet-on-wet or wet-on-dry execution with both brushes and palette knives. Moreover, the study demonstrated that the artist occasionally departed from established painting convention of the Nanyang style and explored different means of artistic expression, although he remained conservative in his choice of painting materials and avoided experimentation with new paint formulations.

The obtained results may be of great value to conservators and art historians who further explore Liu Kang's painting materials and technique. In particular, the knowledge gained from this comprehensive research may be useful in the dating of undocumented paintings and authenticating works attributed to him. In addition, the presented information sets a foundation for future research focusing on the painting practices of other modern Singapore and Southeast Asian artists.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/heritage6030173/s1: Table S1: chronological listing of the paintings selected for the study; Table S2: overview of the composition of the ground layers; Table S3: summary of the materials found in the paint mixtures.

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Table S1. Chronological listing of the paintings.

* Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection.

** NGS – National Gallery Singapore, LF – Liu family

Painting number	Title and inventory number*	Date	Owner**	Dimensions H × W (cm)	Primary support	Painted on an earlier composition	Painted on a reverse side
1	*Nude*	1927	LF	45 × 60	Cotton canvas	Yes	
2	*St Gingolph, Lac Leman, Switzerland*	1929	LF	45.5 × 37.5	Linen canvas		
3	*My room in Paris*	1929	LF	54 × 45.5	Linen canvas		
4	*Zuo La Lu*, 1993-00998	1930	NGS	46 × 55	Linen canvas	Yes	
5	*Autumn colours*, GI-0255 (PC)	1930	NGS	38.3 × 45.3	Linen canvas	Yes	
6	*Countryside in France*, 2003-03365	1930	NGS	46 × 54.7	Linen canvas		
7	*Landscape in Switzerland*, P-1229	1930	NGS	45.6 × 55.7	Linen canvas		
8	*Street scene in France*, 2003–03366	1930	NGS	46 × 54.6	Linen canvas	Yes	
9	*Farmer's house*, GI-0254-(PC)	1930	NGS	45.5 × 53.5	Linen canvas		
10	*Landscape*	1930	LF	46 × 38	Linen canvas		
11	*French countryside*	1930	LF	46 × 54.5	Linen canvas		
12	*Cottage with blue shutters, France*	1930	LF	46 × 54.5	Linen canvas		Yes
13	*Portrait of a man with his hat, Belgium*	1930	LF	55 × 45	Linen canvas	Yes	
14	*Autumn landscape*	1930	LF	38.5 × 46	Linen canvas		
15	*Man in blue coat, Paris*	1930	LF	46 × 37	Linen canvas		
16	*Village street, France*	1930	LF	46 × 55.5	Linen canvas	Yes	
17	*Village scene*, 2003-03320	1931	NGS	46 × 55	Linen canvas		
18	*Slope*, 2003-03319	1931	NGS	46 × 55	Linen canvas		Yes
19	*French lady*, 1993-00996	1931	NGS	60.7 × 45.8	Linen canvas		
20	*Boat near the cliff*, 2003-03249	1931	NGS	53.7 × 72.4	Linen canvas		
21	*Winter*, GI-0256	1931	NGS	46 × 55	Linen canvas	Yes	
22	*Still life with books, Paris*	1931	LF	45 × 38	Linen canvas		
23	*Portrait of a man with his pipe, Paris*	1931	LF	45 × 38	Linen canvas		Yes
24	*Self-portrait*	1931	LF	55 × 46	Linen canvas		Yes
25	*Self-portrait in Paris*	1931	LF	61 × 46	Linen canvas	Yes	
26	*Boats, Etretat*	1931	LF	46 × 55	Linen canvas	Yes	
27	*Still life*	1931	LF	38.5 × 46	Linen canvas		Yes
28	*Breakfast*, GI-0257 (PC)	1932	NGS	46 × 54	Linen canvas	Yes	
29	*Seafood*, 2003-03250	1932	NGS	46 × 55	Linen canvas	Yes	
30	*My landlady, Madame Normand*	1932	LF	54 × 45	Linen canvas		
31	*Street*	1932	LF	46 × 39	Linen canvas		
32	*Working at the fields*, 2003-03258	1933	NGS	49.5 × 64	Cotton canvas		
33	*Countryside in China*, 2003-03299	1933	NGS	60.5 × 72	Cotton canvas		
34	*Red and white walls*	1933	LF	55 × 45.5	Cotton canvas		
35	*Courtyard with tree*	1933	LF	55.5 × 45.5	Cotton canvas		
36	*Countryside landscape*	1933	LF	45 × 54.5	Cotton canvas		
37	*Autumn countryside*	1933	LF	45.5 × 54.5	Cotton canvas		
38	*Farmhouse and field*	1933	LF	60 × 72.5	Cotton canvas		
39	*Pagoda near Shanghai*	1933	LF	73 × 59	Cotton canvas		

40	*Courtyard, Shanghai*	1933	LF	73 × 60	Cotton canvas		
41	*Still life with green stool*	1933	LF	56 × 46	Linen canvas	Yes	
42	*Backyard*, 2003-03252	1934	NGS	59.5 × 72.5	Linen canvas	Yes	
43	*Chinese house*, 2003-03328	1934	NGS	64.5 x 50.5	Linen canvas		
44	*Nude*	1934	LF	45.5 × 55	Cotton canvas	Yes	
45	*Countryside near Shanghai*	1934	LF	46 × 54	Cotton canvas		
46	*Village lane*	1934	LF	45 × 54	Cotton canvas	Yes	
47	*Farmhouses*	1934	LF	45 × 54	Cotton canvas		
48	*Rustic landscape*	1934	LF	54 × 46	Cotton canvas	Yes	
49	*Pagoda*	1935	LF	45 × 55	Cotton canvas	Yes	
50	*Seascape near Shanghai*	1935	LF	65 × 50	Cotton canvas	Yes	
51	*Waterfall*, 2003-03247	1936	NGS	65 × 50	Linen canvas	Yes	
52	*Mount Huangshan*, 2003–03369	1936	NGS	66 × 50	Cotton canvas	Yes	
53	*Seaside*, 2003-03318	1936	NGS	45 × 54	Linen canvas	Yes	
54	*Nude*, 2003-03367	1936	NGS	46 × 54.5	Cotton canvas	Yes	
55	*House on the hill*	1936	LF	64 × 49	Linen canvas		
56	*Street market I*	1936	LF	45 × 54.5	Linen canvas	Yes	
57	*Street market II*	1936	LF	46 × 55	Cotton canvas	Yes	
58	*Seaside near Shanghai*	1936	LF	46 × 55	Linen canvas		
59	*Seascape*	1936	LF	50 × 64	Cotton canvas	Yes	
60	*Portrait of C.Y. Hwang*, P1228	1939	NGS	61 x 46.4	Hardboard		
61	*Nude*	1940	LF	38.5 × 46	Linen canvas	Yes	
62	*Malay man*, 2003-03244	1942	NGS	94 × 73	Linen canvas	Yes	
63	*Bathing in the river*, 2003-03291	1947	NGS	126.5 × 86.5	Linen canvas		
64	*Climbing the hill*, 2003-03298	1948	NGS	75 × 61	Cotton canvas	Yes	
65	*View from St John's Fort*	1948	LF	46 × 55	Linen canvas	Yes	
66	*Village*, 2003-03270	1950	NGS	99 × 131.5	Linen canvas		
67	*Kampong scene*, 2003-03245	1951	NGS	60 × 72.5	Linen canvas		
68	*Orchids*, 2003-03379	1952	NGS	50 × 40.5	Linen canvas		
69	*Government Office in Johore Bahru*, 2003-03300	1953	NGS	63.2 × 76.3	Linen canvas		
70	*Scene in Bali*, 2003-03333	1953	NGS	127 × 85.5	Linen canvas	Yes	
71	*Offerings*, 2003-03269	1953	NGS	131.5 × 98.5	Linen canvas	Yes	
72	*Outdoor painting*, 2003-03290	1954	NGS	85 × 127	Linen canvas		
73	*Painting kampong*, 2003-04149	1954	NGS	120.5 × 71	Linen canvas		
74	*Batik workers*, P-0197	1954	NGS	88.5 × 69	Linen canvas		
75	*Boats*, 2003-03275	1956	NGS	91 × 70	Linen canvas	Yes	
76	*Char Siew seller*, 2003-03311	1958	NGS	59.5 × 72.5	Linen canvas	Yes	
77	*Johor Bahru*, P-0591	1962	NGS	96.5 x 73.5	Hardboard		
78	*National day*, 2003-03280	1967	NGS	86 x 127.5	Linen canvas		
79	*Outdoor painting*, 2003-03337	1968	NGS	85 x 126.5	Linen canvas		
80	*Fruit sellers*, 2003-03295	1969	NGS	122 × 91.5	Linen canvas		
81	*Chinese bridge over river*, 2003-03386	c. 1974	NGS	71 × 91.5	Linen canvas		
82	*Mountain*, 2003-03246	1977	NGS	38 × 45.5	Hardboard	Yes	
83	*Mountain*, 2003-03313	1981	NGS	36 × 29.5	Cotton canvas	Yes	
84	*Mount Huangshan*, 2003-03304	1983	NGS	84.6 × 64.5	Hardboard	Yes	
85	*Mount Huangshan*, 2003-03327	1986	NGS	74 × 48.5	Hardboard	Yes	
86	*Mount Huangshan*, 2003-03251	1987	NGS	71 × 55.6	Hardboard	Yes	
87	*Mountains*, 2003-03306	1991	NGS	76.5 × 61	Linen canvas		
88	*Nude*, 2003-03259	1992	NGS	42 × 97	Hardboard		

89	*Mount Huangshan*, 2003-03376	1993	NGS	40.5 × 31.7	Hardboard	Yes	
90	*Mount Huangshan*, 2003-03307	1994	NGS	78.5 × 58.3	Hardboard	Yes	
91	*Mount Huangshan*, 2003-03378	1995	NGS	30.5 × 40.5	Hardboard	Yes	
92	*Mountain*, 2003-03293	1995	NGS	84.7 × 118.5	Linen canvas		
93	*Nude*, 2003-03265	1995	NGS	66 × 76	Linen canvas		
94	*Mount Huangshan*, 2003-03257	1996	NGS	64 × 49	Cotton canvas	Yes	
95	*Two nudes*	1996	LF	43 × 36	Hardboard	Yes	
96	*Beauties at rest II*, 2003-03470	1998	NGS	85 × 127	Linen canvas	Yes	
97	*In conversation*, 2003-03305	1999	NGS	61 × 76	Linen canvas	Yes	

Table S2. Overview of the composition of the ground layers.

* Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection.

Title and inventory number*	Date	Chalk	Lead white	Zinc white	Barium white	Lithopone	Titanium white	Oil	Proteins	Other materials
Nude	1927	×	×	×	×	×		×		Zn soap
St Gingolph, Lac Leman, Switzerland	1929	×	×	×	×	×		×	×	
Zuo La Lu, 1993-00998	1930	×	×	×				×	×	Zn soap
Autumn colours, GI-0255 (PC)	1930	×	×		×			×		Pb soap
Countryside in France, 2003-03365	1930	×	×							
Landscape in Switzerland, P-1229	1930		×	×	×	×		×		Pb soap
Street scene in France, 2003–03366	1930	×	×					×		
Farmers house, GI-0254-(PC)	1930	×	×	×			×	×		Zn soap
Landscape	1930	×	×	×						
French countryside	1930	×	×							
Portrait of a man with his hat, Belgium	1930	×	×	×				×		
Man in blue coat, Paris	1930	×	×	×				×	×	Zn soap
Village scene, 2003-03320	1931	×	×	×				×		
French lady, 1993-00996	1931	×	×	×				×		Pb soap
Boat near the cliff, 2003-03249	1931		×	×				×		
Winter, GI-0256	1931	×	×					×		
Still life with books, Paris	1931	×	×	×	×	×	×			
Breakfast, GI-0257 (PC)	1932		×	×	×		×	×	×	Zn soap
Seafood, 2003-03250	1932	×	×		×			×		
My landlady, Madame Normand	1932	×	×	×	×	×	×	×	×	Zn soap
Working at the fields, 2003-03258	1933	×		×	×	×	×	×	×	Zn soap
Countryside in China, 2003-03299	1933	×		×	×	×	×	×	×	
Red and white walls	1933	×	×	×	×	×	×			
Courtyard with tree	1933	×	×	×	×	×	×			
Countryside landscape	1933	×	×	×	×	×	×			
Autumn countryside	1933	×	×	×	×	×				
Farmhouse and field	1933	×		×	×	×				
Pagoda near Shanghai	1933	×		×	×	×	×			
Courtyard, Shanghai	1933	×		×	×	×	×			
Still life with green stool	1933	×	×					×		
Backyard, 2003-03252	1934	×	×	×	×	×	×	×	×	
Chinese house, 2003-03328	1934	×		×	×	×	×			
Nude	1934	×		×	×	×	×	×		
Countryside near Shanghai	1934	×		×	×	×	×			
Village lane	1934	×	×	×	×	×	×			
Farmhouses	1934	×		×	×	×				
Rustic landscape	1934	×	×	×	×	×	×	×	×	
Pagoda	1935	×		×	×	×				
Seascape near Shanghai	1935	×		×	×	×	×	×	×	
Waterfall, 2003-03247	1936	×		×	×	×	×	×	×	Zn soap

Mount Huangshan, 2003–03369	1936	×		×	×	×	×	×		Zn soap
Seaside, 2003-03318	1936	×	×	×	×	×	×	×	×	
Nude, 2003-03367	1936	×		×	×	×	×	×	×	Zn soap
House on the hill	1936	×		×	×	×				
Street market I	1936	×		×	×	×	×			
Street market II	1936	×	×	×	×	×	×			
Seaside near Shanghai	1936	×		×	×	×	×	×	×	
Seascape	1936	×	×	×	×	×		×		Zn soap
Nude	1940		×		×		×	×		
Climbing the hill, 2003-03298	1948		×	×	×	×	×			
View from St John's Fort	1948	×	×	×	×	×	×			
Village, 2003-03270	1950	×	×	×	×	×	×	×		
			×	×	×	×	×	×		
Kampong scene, 2003-03245	1951	×	×	×	×	×	×	×		
		×	×	×	×	×		×		
Orchids, 2003-03379	1952	×	×	×			×	×		Zn soap, China clay
		×	×	×			×	×		Zn soap, China clay
Government Office in Johore Bahru, 2003-03300	1953	×	×	×	×		×	×		
		×	×	×				×		Zn soap
Scene in Bali, 2003-03333	1953	×	×	×	×		×	×		Zn soap
		×	×	×	×			×		
Offerings, 2003-03269	1953	×	×		×			×	×	
Outdoor painting, 2003-03290	1954			×				×		Zn soap
Painting kampong, 2003-04149	1954			×				×		Zn soap
Boats, 2003-03275	1956	×	×	×	×		×			
		×	×	×				×		
Char Siew seller, 2003-03311	1958	×	×	×	×	×	×			
		×	×	×				×		Zn soap
		×	×	×				×		Zn soap
Johor Bahru, P-0591	1962									
National day, 2003-03280	1967	×	×	×	×	×	×	×		
		×	×	×	×	×	×	×		
Outdoor painting, 2003-03337	1968	×	×	×			×	×		
Mountain, 2003-03313	1981		×	×	×	×		×		Zn soap
Mountains, 2003-03306	1991	×	×	×	×	×	×	×		
		×	×	×	×	×	×	×		Zn soap
Mountain, 2003-03293	1995	×	×	×	×	×	×	×		
		×	×	×	×	×	×	×		
Nude, 2003-03265	1995	×	×	×	×	×	×	×		
		×	×	×	×	×	×	×		Zn soap
Mount Huangshan, 2003-03257	1996		×	×	×	×		×		Zn soap
Beauties at rest II, 2003-03470	1998	×	×	×			×	×		
In conversation, 2003-03305	1999	×	×	×	×	×	×	×		Zn soap
		×	×	×	×	×	×	×		Zn soap

Table S3. Summary of the materials found in the paint mixtures.

* Accession numbers indicate paintings from the NGS collection. Titles without the accession numbers are from Liu family collection.

Title and inventory number*	Date	Ultramarine	Prussian blue	Cobalt blue	Cerulean blue	Cobalt violet	Manganese blue	Phthalocyanine blue	Viridian	Emerald green	Phthalocyanine green	Cr-containing yellow	Cobalt yellow	Cd-containing yellow	Cd-containing orange	Hansa yellow G	Hansa yellow 10G	Fe-containing yellow earth	Umber	Fe-containing red earth	Naphthol red AS-D	Alizarin crimson	Synthetic alizarin lake	Brazilwood	Hansa red	Geranium lake	Other organic red	Cd-containing red	Chalk	Lead white	Zinc white	Barium white	Lithopone	Titanium white	Bone black	Carbon black	Starch	Zn soap	Pb soap
Nude	1927	×							×	×		×						×	×								×			×	×	×	×		×				
Zuo La Lu, 1993-00998	1930	×	×						×			×		×				×		×															×				
Autumn colours, GI-0255 (PC)	1930	×	×						×			×						×	×	×									×	×	×				×				
Countryside in France, 2003-03365	1930	×	×						×			×						×									×			×	×	×		×		×		×	
Landscape in Switzerland, P-1229	1930	×	×						×	×		×	×	×				×		×							×		×		×	×	×		×		×	×	
Village scene, 2003-03320	1931	×	×						×			×						×		×							×		×	×					×	×	×		
French lady, 1993-00996	1931	×	×	×					×	×		×						×																	×	×			×
Boat near the cliff, 2003-03249	1931	×	×	×					×			×		×				×	×							×				×	×					×			
Breakfast, GI-0257 (PC)	1932		×						×			×						×		×							×		×	×					×		×		
Seafood, 2003-03250	1932		×						×	×		×					×	×				×		×	×				×	×		×			×		×		
Working at the fields, 2003-03258	1933	×	×						×			×						×	×										×	×	×	×	×					×	
Countryside in China, 2003-03299	1933	×	×						×	×		×						×		×									×	×									
Backyard, 2003-03252	1934	×	×						×			×		×				×		×									×	×	×	×	×					×	
Chinese house, 2003-03328	1934	×	×						×			×						×	×																×			×	
Nude	1934	×							×									×											×		×	×	×	×		×		×	
Waterfall, 2003-03247	1936	×	×						×			×						×		×									×	×	×	×	×	×					
Seaside, 2003-03318	1936	×	×						×			×						×	×												×							×	
Nude, 2003-03367	1936	×	×						×			×		×				×		×							×												
Nude	1940	×	×						×			×		×	×			×	×								×		×	×	×	×	×	×	×			×	
Climbing the hill, 2003-03298	1948	×	×						×			×						×												×	×	×	×						
View from St John's Fort	1948	×	×						×			×						×												×	×	×	×						
Village, 2003-03270	1950	×	×						×	×		×		×	×			×		×			×				×		×	×	×								
Kampong scene, 2003-03245	1951	×	×						×			×		×				×	×	×			×				×								×				
Orchids, 2003-03379	1952	×	×						×	×		×		×				×	×																				

Government Office in Johore Bahru, 2003-03300	1953	×	×	×	×				×			×		×				×	×	×							×								×			×	
Scene in Bali, 2003-03333	1953	×	×				×		×			×	×	×				×									×	×		×	×	×	×						
Offerings, 2003-03269	1953	×	×						×			×		×	×			×									×	×	×	×	×	×	×	×				×	
Outdoor painting, 2003-03290	1954	×	×						×		×	×		×				×									×												
Painting kampong, 2003-04149	1954							×	×					×					×							×	×								×				
Boats, 2003-03275	1956	×	×						×			×		×				×		×						×	×	×	×	×	×	×	×	×					
Char Siew seller, 2003-03311	1958	×	×								×	×	×	×				×			×								×	×	×	×	×	×				×	
Johor Bahru, P-0591	1962	×							×			×		×				×									×												
National day, 2003-03280	1967	×	×								×			×					×	×								×											
Outdoor painting, 2003-03337	1968	×	×			×			×					×				×																					
Mountain, 2003-03246	1977	×	×						×			×								×	×						×				×	×	×	×				×	
Mountain, 2003-03313	1981	×							×					×		×		×													×	×	×	×				×	
Mount Huangshan, 2003-03304	1983	×	×								×	×						×		×	×								×		×	×	×	×				×	
Mount Huangshan, 2003-03327	1986	×	×	×				×	×		×							×	×	×							×		×		×			×				×	
Mount Huangshan, 2003-03251	1987	×	×								×							×	×										×		×			×					
Mountains, 2003-03306	1991	×									×					×		×		×									×		×	×	×	×				×	
Nude, 2003-03259	1992													×	×			×	×	×			×				×								×			×	
Mount Huangshan, 2003-03376	1993	×		×					×					×				×	×	×									×	×	×			×				×	
Mount Huangshan, 2003-03307	1994	×		×					×									×		×									×		×			×				×	
Mount Huangshan, 2003-03378	1995	×		×					×			×				×		×	×	×									×	×	×	×	×	×					
Mountain, 2003-03293	1995	×							×							×		×	×	×									×		×			×				×	
Nude, 2003-03265	1995	×		×					×			×		×				×		×	×		×				×								×			×	
Mount Huangshan, 2003-03257	1996	×	×						×			×		×		×		×			×						×			×	×	×	×	×				×	
Two nudes	1996																			×	×						×												
Beauties at rest II, 2003-03470	1998	×	×					×	×			×		×	×			×		×			×				×	×	×		×	×	×	×	×			×	
In conversation, 2003-03305	1999	×	×					×	×			×						×		×							×											×	