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Analysis of the manufacturing craft of the painted gold foils applied on the lacquerware of the Jin Yang Western Han Dynasty tomb in Taiyuan, Shanxi, China

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Abstract

Seven pieces of gold foils for surface decoration of the lacquerware were excavated in the late Western Han Dynasty tomb in the area of the Jin Yang (晋阳) Ancient City site in Taiyuan (太原), Shanxi (山西), China. These gold foils portray images of the carriage, the leopard, the tigers, the ox, and the dancer with fluttering sleeves, etc., with black lines outlining the contours and red paint depicting vivid patterns. The study used Stereo Microscopes, Metallurgical Microscopy, Environmental Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (ESEM-EDS), and Laser Raman Spectroscopy (LRS) to analyse the thickness of the gold foils, the alloy composition, the composition of the paint and other surface attachments, and investigate the manufacturing process. As the results show, the thickness of the gold foils is about 26 μm. The composition is a gold-silver alloy with about 96% Au/(Au + Ag) (surface) and 98% Au/(Au + Ag) (cross-section). The metallurgical observation shows that the gold foils underwent heating and forging. The black lines on the front side are Chinese ink lines, with cracking and peeling phenomenon, and parallel polishing lines can be seen at the peeling places, while no polishing lines are observed on the back side. Some red paint made of cinnabar is above the black lines, and the binder is organic. Some lacquer residues are found on the back. According to the results of the study, the manufacturing process of the gold foils applied on the lacquerware is as follows: the gold foils are obtained by heating and forging, the front sides of the gold foils are polished, the shapes are carved out, and the gold foils are pasted on the lacquerware when the lacquerware's surface is not yet dry. The gold foils are painted with black Chinese ink and red cinnabar pigment. The study's results offer important references for understanding the manufacturing craft of the gold foils applied on the lacquerware in the late Western Han Dynasty of China and guide the conservation of the lacquerware decorated with painted gold foils.

Keywords Gold foil, Western Han Dynasty, Gilding, Lacquerware, Manufacturing craft, Decoration technique

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Introduction

For its shining appearance and stable chemical properties, gold has been favoured by different cultures for a long time and is widely used for the decoration of artefacts, especially being processed to thin foils as surface decoration. Gold foils of cultural relics were found on the surfaces of metal [1], stone [1, 2], ceramic [1–3], glass [3], mosaic [3], wood [4, 5], paper [6], parchment [1], tiles [7], plaster [8] and so on. Those unearthed in China are on the surfaces of metals, wood, lacquerware or separately excavated [9] more frequently.

The manufacturing history of gold foils in ancient China can trace back to the Shang Dynasty (about 1600–1046 BC) [10], supported by the discovery of gold foils unearthed from the Yinxu site in Anyang, Henan [11], the tombs of upper Erligang period in Zhengzhou, Henan [12], the tombs of the Subutun site in Yidu, Shandong [13], the tombs of the Taixi site in Gaocheng, Hebei [14], the Taohuazhuang site in Shilou, Shanxi [15], the Sanxingdui site in Guanghan, Sichuan [16], etc. [17, 18]. In this period, gold foils were forged, cut into shapes and then attached to lacquer wares, bronze wares, wood coffins, cart and horse implements [18]. The surfaces of gold foils of this period are usually undecorated. In the Western Zhou Dynasty (1027–771 BC), gold foils were forged and then decorated with moulded or engraved patterns, supported by the discovery of gold foils unearthed from the Yan State Cemetery at Liulihe, Beijing [19], the Ying State Cemetery in Pingdingshan, Henan [20], NO.1 tomb of Qiangjia in Fufeng, Henan [21], M2001 tomb of Guo State at Shangcunling, Sanmenxia, Henan [22], the tomb of Qin Gong at Dabaozi Mountain, Lixian, Gansu [23], the car and horse pits of Qianzhangda Cemetery in Tengzhou, Shandong [24], the tombs of the Zhangjiapo site in Xi'an, Shaanxi [25], M114 tomb of Marquis Jin of North Zhao State at the Tianma-Qucun site, Shanxi [26], IM5 of Qunbak Cemetery, Luntai, Xinjiang [27], the Jinsha Site in Chengdu, Sichuan [28], etc. [18]. In the Spring and Autumn Period (770–476 BC) and the Warring States Period (475–221 BC), gold foils account for the largest proportion of gold objects excavated, which were encrusted or pasted onto bronze wares, lacquer wares, wood, jade, lead-tin wares and so on [18]. The previous gold foil-making technique is followed, and decorative patterns become more manifold, ranging from geometric shapes to plant shapes and animal shapes, such as dragons, lions, tigers, wolves, horses, birds, sheep, etc. [18]. Representative archaeological discovery of gold foils of this period is from the Majiayu Warring States Cemetery in Zhangjiachuan, Gansu [29], Zhaoxiang and Caojiagang Chu tombs in Dangyang, Hubei [30], Zenghouyi Tomb at Suixian, Hubei [31], the tombs of Jin Hou at Yangshe, Quwo, Shanxi [32], etc. [18]. In the Qin Dynasty (221–207 BC) and the Western Han Dynasty (202 BC–25 AD), the manufacture of gold artefacts ushered in a new epoch. Discovery of gold foils covers a wider range and the number is far more than the sum of the previous periods [18]. The fabricating craft of gold foils is forging as before. Painted decorations begin to appear on gold foils. The gold foils unearthed from the Western Han tombs of Maquan in Xianyang, Shaanxi [33], Fengpengling in Wangcheng, Hunan [34], and No. 304 Western Han tomb in Yangjiashan, Changsha, Hunan [35] are similar to the samples of the gold foils in this study: they are applied on the surfaces of lacquer wares, with black lines on the surfaces of the gold foils. However, the scientific analysis of these gold foils has not yet been reported, and gold foils decorated with not only black but also red paints as the gold foils of this study are rarely seen.

The research object of this study is the gold foils on the surface of the lacquerware excavated in the 2018TJL-STM4 Western Han Tomb at the site of Jin Yang Ancient City, Taiyuan, Shanxi, China. The gold foils portray images of the carriage, the leopard, the tigers, the ox, and the dancer with fluttering sleeves, etc., with black lines outlining the contours and red paint depicting vivid patterns. Gold foils with black and red paintings are rare among those of the Western Han Dynasty. The research on the manufacturing craft and decorative technique of gold foils with black and red paintings applied on the lacquerware is yet to be advanced. Scientific analysis of gold foils unearthed in archaeological excavations mainly uses microscope observation, composition analysis [36, 37], metallographic analysis, etc. to study the thickness [38], alloy composition, manufacturing process, and so on. The gold foils mentioned above are mostly gold-silver or gold-silver-copper alloys with high Au content. All of these are heated and forged. Decorative techniques are carving, chiselling, etc. In this study, we used stereo microscopes to observe the details of the gold foils, metallurgical microscope to analyse the manufacturing process, Environmental Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (ESEM-EDS) to measure the thickness of the gold foils and analyse the composition of the gold foils, black and red paintings, and other surface attachments, combined with Laser Raman Spectroscopy (LRS). Through the comprehensive analysis of the results of the test and simulation experiments of shearing and carving foils, we discuss the manufacturing craft and decorative technique of the gold foils and the combination method of the gold foils and the lacquerware. The study's results offer important references for understanding the manufacturing craft of the gold foils applied on the lacquerware in the Western Han Dynasty of China and guide the conservation of the lacquerware decorated with painted gold foils.

Materials and methods

Materials

Seven pieces of gold foils were unearthed on the surface of the lacquerware (Fig. 1e) from Chamber 2 (Fig. 1d) of the tomb 2018TJLSTM4 (M4 for short, Fig. 1c), which is located at the burial area of Jin Yang (晋阳) ancient city site (Fig. 1b), Taiyuan (太原) city, Shanxi (山西) Province, central China (Fig. 1a) and is thought to be from the late Western Han Dynasty according to the burial form.

The lacquerware was crushed during burial, leading to the separation of the gold foils from the lacquerware. The lacquerware is a round lacquer trousseau with silver persimmon on top of the lid, which is a popular lacquerware type in the Western Han Dynasty, according to the discovery of lacquerwares in Hebei, Henan, Shandong, Inner Mongolia, Yunnan, Guizhou, Anhui, Hubei, Hunan, Jiangsu, etc. [18].

Seven pieces of gold foils are noted as a-carriage, b-leopard, c-ox, d-black tiger, e-half tiger, f-dancer, and g-S-shaped fragment with green rust (Fig. 2). The seven gold foils were all microscopically observed; the samples used for further analysis are d-black tiger, e-half tiger, and g-S-shaped fragment with green rust.

D-black tiger is about 2 cm long and 1.5 cm high, with partially peeling black lines. There are several holes in the gold foil and grey buildups near the holes on the back.

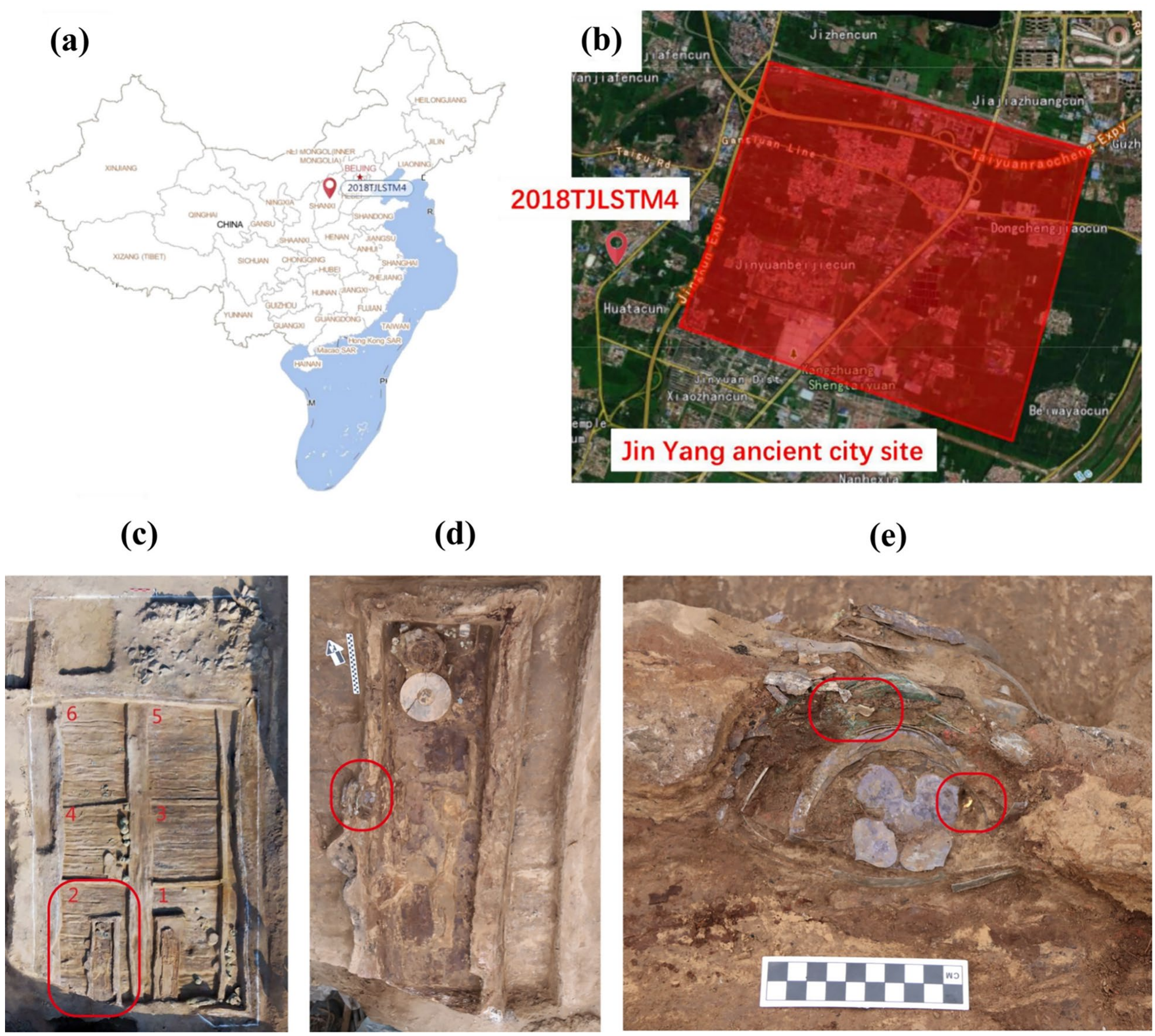

Fig. 1 **a, b** The location of tomb 2018TJLSTM4 and Jin Yang ancient city site [39]; **c** Orthophotogram of the tomb 2018TJLSTM4; **d** the lacquerware with gold foils unearthed from Chamber 2; **e** seven pieces of gold foils unearthed on the surface of the lacquerware

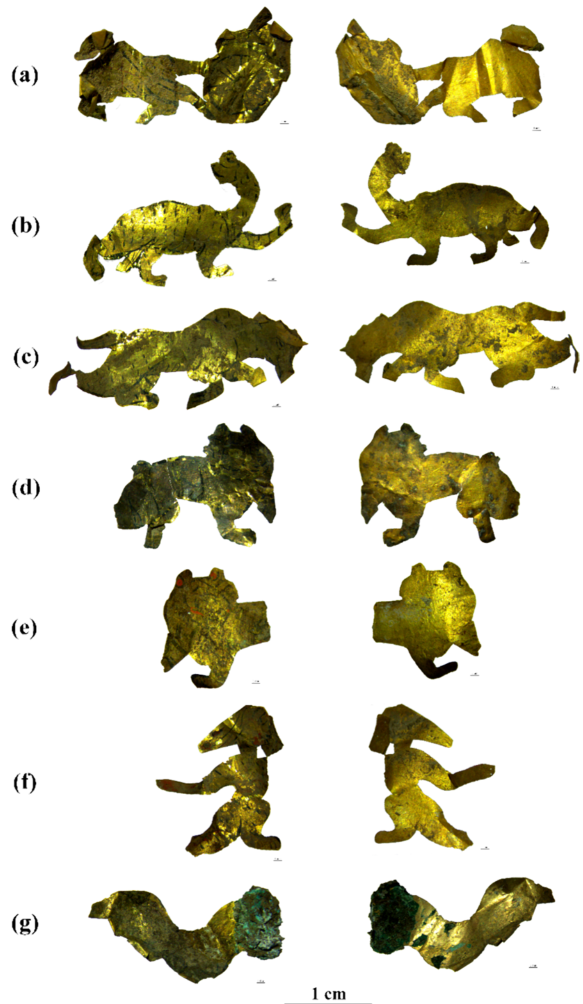

Fig. 2 Gold foils (Stereo Microscope SX-5). **a** A-carriage; **b** b-leopard; **c** c-ox; **d** d-black tiger; **e** e-half tiger; **f** f-dancer; **g** g-S-shaped fragment with green rust

E-half tiger is similar in shape to the d-black tiger, with mirror symmetry. Half of the body is missing, and the remaining part is about 1.2 cm long and 1.4 cm high, with partially peeling black lines drawing the outline and red pigments on the ears, cheek, and nose.

G-S-shaped fragment is about 2.4 cm long and 0.8 cm high, with one end adhered by green rust.

The simulation experiments of shearing and carving used 30 μm thick aluminium foils, which were performed with scissors and a utility knife to produce vertical intersections and curved edges respectively.

Stereo microscopy observation

An optical stereo microscope (SX-5, Shanghai Yongheng Optical Instrument Manufacturing Company) with a video capture device (YH-500 1 USB2.0 Camera, Shanghai Yongheng Optical Instrument Manufacturing Company) was used to observe and photograph the details of the gold foils.

An optical stereo microscope (SX-6, Shanghai Optical Instrument No.1 Factory) with a digital camera (MC170 HD, LEICA) was used to observe and photograph the details of the samples of simulation experiments.

Metallographic observation

The small unattributable fragment sample was embedded in epoxy resin, polished with sandpapers (P = 600, 1500), and finished with water-soluble diamond paste (W0.5, Naibo, Shanghai, China). The polished sample was etched with aqua regia (68% HNO_3: 36% HCl = 3:1) for 15 s, rinsed with pure water, and dried with a degreasing cotton pad.

A metallographic microscope (Eclipse LV100ND, Nikon, Tokyo, Japan) with a digital camera (DS-Ri2, Nikon, Tokyo, Japan) was used to observe and record the metallographic organization of the gold foil and the manufacturing traces on the surface of the gold foils.

Scanning electron microscopy with energy dispersive spectroscopy (SEM–EDS)

An Environmental Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (ESEM-EDS, Quanta 200FEG, FEI Company, Hillsboro, OR, USA) was used to observe the morphology and elemental distribution of the gold foils and surface attachments under an accelerating voltage of 10 kV.

The alloy composition of the cross-section of the gold foil was analysed by SEM-EDS (TM3030, HITACHI, Tokyo, Japan).

The thickness of the gold foils was measured in the SEM photos using SuperImage software.

Micro laser Raman spectroscopy (LRS)

The composition of surface attachments of the gold foils was analysed by a micro-Raman spectroscope (Thermo Scientific DXRxi, Thermo Fisher Scientific, Waltham, MA, USA) with an optical microscope (OLYMPUS BX51, Olympus Corporation, Tokyo, Japan). A 10× eyepiece, 10× objective lens, and 50× objective lens were used to locate the analysed sites. The laser wavelength is 532 nm, the grating is 1800/mm, the diaphragm is a 50 μm pinhole diaphragm, the exposure time is 0.05 s, and the number of exposures is 600. The laser power was gradually adjusted to the appropriate power starting from 0.1 mW. All spectra were calibrated using the 519.5 cm^{-1} line of a silicon wafer.

Results

Gold foil

SEM-EDS (HITACHI TM3030) map scanning of an epoxy-embedded cross-section gold foil sample shows that the average Au/(Au + Ag) wt.% of 3 randomly boxed areas is 98.03 ± 0.56% (Table 1).

ESEM-EDS (FEI Quanta 200FEG) map scanning of the back surface of the gold foil sample (e-half tiger) shows that the average Au/(Au + Ag) wt.% of 6 randomly boxed areas is 96.12 ± 0.27% (Table 2).

The average thickness of the gold foil cross-section measured at nine randomly selected locations in the SEM photograph is 26.02 ± 2.95 µm (Fig. 3).

The metallographic structure of the gold foil cross-section shows twinned and recrystallized grains, indicating that the material has been annealed (Fig. 4a). The twin lines are elongated and slightly curved, indicating that the material has been subjected to the forging process (Fig. 4b). Though the thin sample makes it hard to obtain clearer metallographic images, the current evidence can still support that the gold foil was produced by heating and forging.

Manufacturing marks

The results of the stereo microscope observation show that there are drapes and burrs at the corners of the gold foils, such as Fig. 5a the abdomen of the horse, Fig. 5b the hoof of the ox, and Fig. 5c the elbow of the tiger. Figure 5d shows the vertical intersection, where fluctuating deformation can be seen. According to the deformation of the gold foil at the crossing, the order of formation of the traces at this place is vertical first and then horizontal. Figure 5e shows small burrs near the intersection on the back of b-leopard. Figure 6 ESEM observation shows that the edge of the gold foil curls toward the back.

To compare the detailed features of the foil edges obtained by carving and shearing, simulation experiments were conducted using 30 µm thick aluminium foils. Figure 7a–d shows the front and back sides of the aluminium foils after carving or shearing vertically, and the order of trace formation can be judged based on the deformation at the intersections. The front and back edges of the sheared traces are similar in shape, both of which are thinning toward the edges; the edges of the carved traces are curling toward the back, which is similar to that of the traces in Fig. 6. Figure 7e–h shows the curved shape of carving and shearing, both of which show drapes and small burrs.

Based on the results of stereo microscopes (Fig. 5), ESEM (Fig. 6), and simulation experiments (Fig. 7), as well as the hollowed-out triangular pattern shown in Fig. 5a, it is more likely that the shapes of the gold foils were carved out with a knife rather than scissors.

Surface decorations and attachments

The decorations on the front of the gold foils are mainly black lines and red paintings. The black lines outline the shapes, and there exists the phenomenon of cracking and peeling, where the gold surface is particularly bright. The red paintings are usually lines, circles, and spots, used to depict the images. The red paintings are on top of black lines (Fig. 5f), so the drawing sequence is to use the black lines to outline

Table 1 SEM-EDS (HITACHI TM3030) map scanning results of the gold foil (cross-section)

Weight %	Au %	Ag %	O %	C %	Au/(Au + Ag) %
1	71.82	1.64	5.87	20.68	97.77
2	72.41	1.86	6.33	19.40	97.50
3	71.59	0.86	3.50	24.04	98.81
Average	71.94	1.45	5.23	21.37	98.03

Table 2 ESEM-EDS (FEI Quanta 200FEG) map scanning results of the gold foil (e-half tiger, back)

Weight %	Au %	Ag %	O %	C %	Au/(Au + Ag) %
1	81.93	3.60	3.27	11.19	95.79
2	81.28	3.74	4.63	10.35	95.60
3	82.01	3.15	8.54	6.30	96.30
4	90.10	3.40	2.70	3.80	96.36
5	79.66	3.28	3.54	13.52	96.05
6	87.38	3.40	2.49	6.73	96.25
Average	83.73	3.43	4.20	8.65	96.12

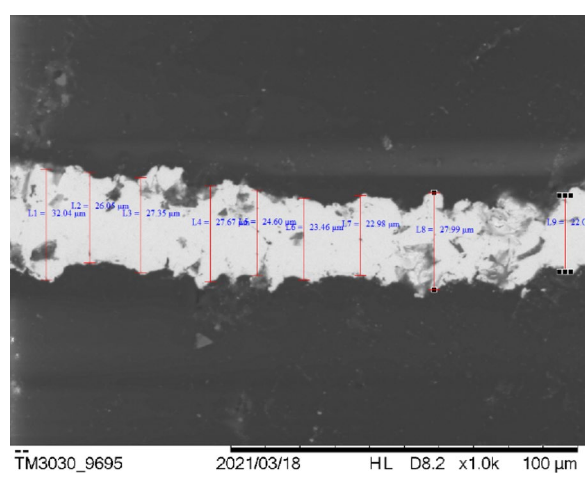

Fig. 3 A SEM photograph with an illustration of gold foil thickness measurement (HITACHI TM3030)

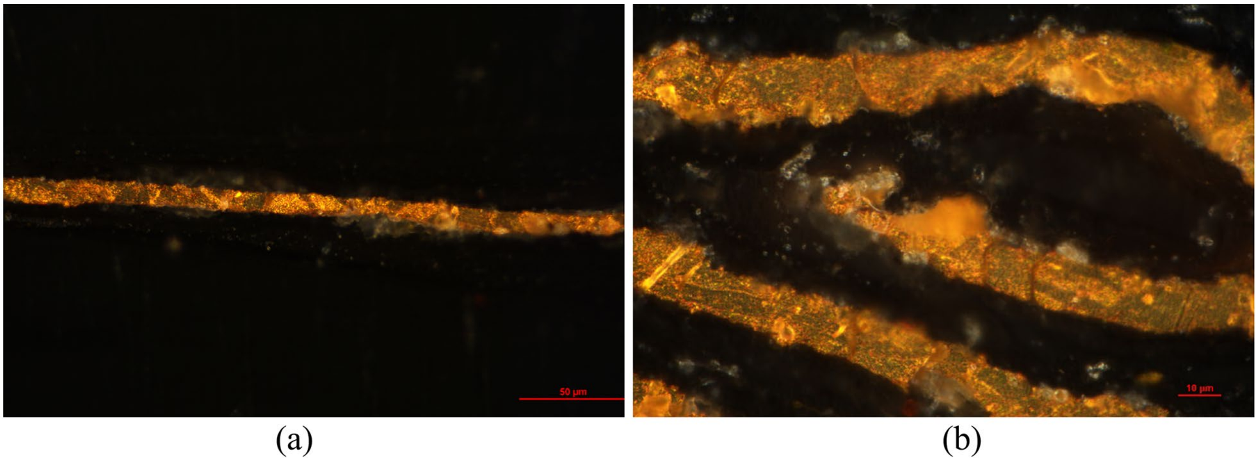

Fig. 4 Metallographic micrographs of the gold foil cross-section. **a** Twinned and recrystallized grains. **b** Elongated and slightly curved twin lines

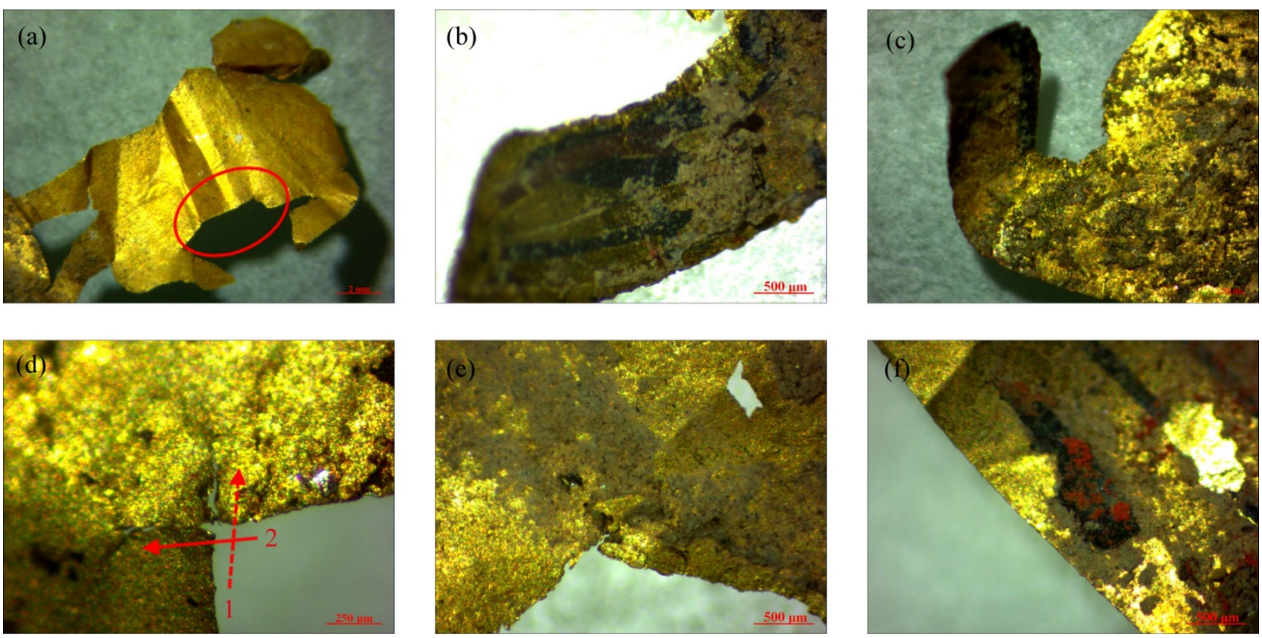

Fig. 5 Stereo microscope (SX-5) photographs. **a** A-carriage (back), drapes shown in a red circle; **b** c-ox (front), drapes; **c** e-half tiger (front), corner drapes and small burrs; **d** e-half tiger (back), the vertical intersection; **e** b-leopard (back), small burrs; **f** f-dancer (front), the flat edge and the red pigment overlaying on the black line

the pattern first, then use the red colour to draw. There is a dark red gelatinous substance, suspected to be lacquer, attaching to the back of the gold foils.

To observe the details of the surface decorations of the gold foils, stereo microscope, metallurgical microscope, and ESEM were used. To determine the chemical composition of the decorations, ESEM-EDS and LRS were performed.

Black lines

The black lines on the surface of the gold foils are dark in colour and resemble ink lines, with the phenomenon of cracking and peeling off in some places (Fig. 8a). Where the black lines peeled off, the surface of the gold foil is bright gold, and fine parallel polishing marks are visible (Fig. 8b).

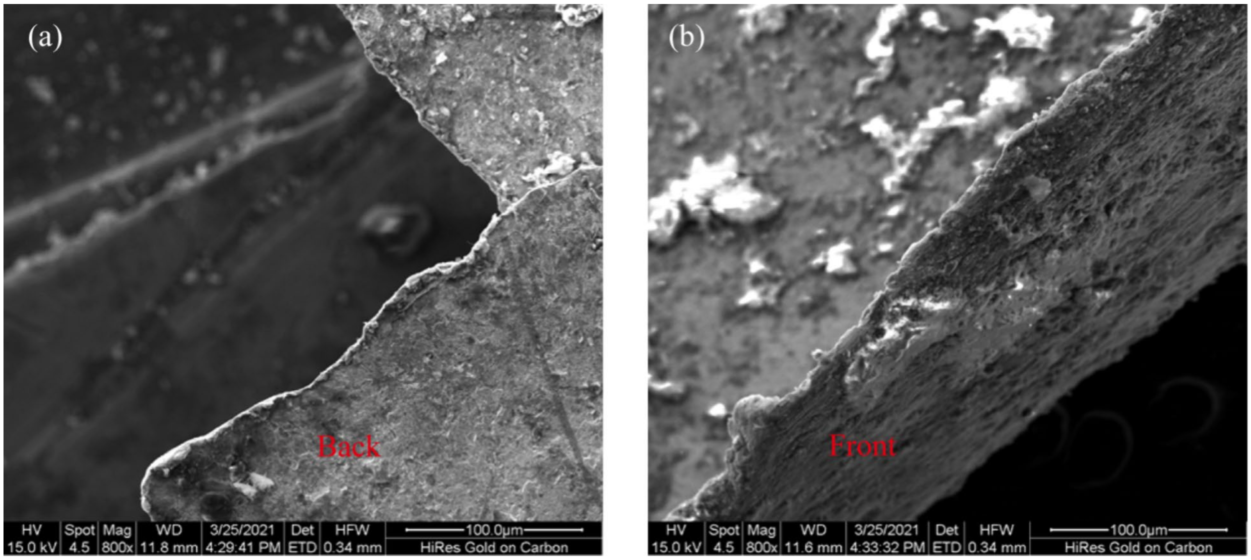

Fig. 6 ESEM photographs. **a** D-black tiger (back); **b** d-black tiger (edge)

The mapping scans of ESEM-EDS show high C and O contents at the black line; the results of the point scans show 62.71 wt.% of C and 17.84 wt.% of O at the black line (Fig. 9 and Table 3). LRS showed that the Raman shift peaks at 1599 cm^{-1} and 1338 cm^{-1} are consistent with the characteristic peak positions of the G-band 1500–1600 cm^{-1} and D-band 1345 cm^{-1} of the amorphous carbon sp^2 (Fig. 10) [40].

According to the results of microscopic observation, ESEM-EDS, and LRS, the main elements at the black line are C and O, and the main component is amorphous carbon. The Chinese ink used in the Western Han Dynasty is mainly pine soot ink, and its main raw materials are pine soot and animal glue [41], and the main component of pine soot is amorphous carbon [42–44], which coincides with the results of LRS, so the black lines are the Chinese ink.

Red paint

The ESEM-EDS point scans show the composition of the red part in Fig. 11a is 14.65 at.% for Hg, 5.01 at.% for Au, and 18.57 at.% for S. Due to the peak positions (about 2.2 keV) of Hg, Au, and S being close, the content ratio obtained by ESEM-EDS may not be accurate. Other characteristic peaks of Au do not appear, so the Au in the detection result should actually be Hg. The sum of the atomic fractions of Au and Hg is 19.66 at.%, which is approximated to be the actual atomic fraction of Hg, and the ratio of the atoms of Hg and S is close to 1, suggesting the composition of the red paint may be cinnabar (HgS) (Table 4). The results of LRS show that Raman shifts are observed at 251 cm^{-1}, 284 cm^{-1}, and 341 cm^{-1}, which coincide with the standard peak positions of HgS [43–46] (Fig. 12). ESEM-EDS point scans show that the red paint contains C for 49.40 at.% and O for 11.83 at.% (Table 4), suggesting the existence of organic matter, which may act as a cementing agent for the pigment particles. Combined with the results of microscopic observation, ESEM-EDS, and LRS, the mineral composition of the red paint is cinnabar and the organic binder is blended with the cinnabar to make the pigment, which is used to paint on the surface of the gold foils.

Dark red gelatinous substance

A dark red gelatinous substance suspected to be lacquer is observed on the back of e-half tiger. ESEM-EDS point scans show the main elements are C for 53.97 at.%, and O for 32.70 at.%, indicating the dark red gelatinous substance is organic matter (Table 5). LRS analysis of the dark red gelatinous substance on the back of e-half tiger shows a symmetric stretching vibrational peak of COO^- at 1348 cm^{-1}, an aromatic ring stretching vibrational peak at 1589 cm^{-1}, and vibrational peaks of CH2 at 2694 cm^{-1} and 2918 cm^{-1}, which matches with the Raman spectra of the lacquer [47] (Fig. 14). Combining the results of microscopic observation, ESEM-EDS, and LRS, the composition of the dark red gelatinous substance on the back of the gold foils is lacquer.

Discussion

The manufacturing process of the gold foils applied onto the lacquerware can be divided into two parts: (1) gold foil making, and (2) decoration processes. Decoration processes can be subdivided into two parts: (1) the

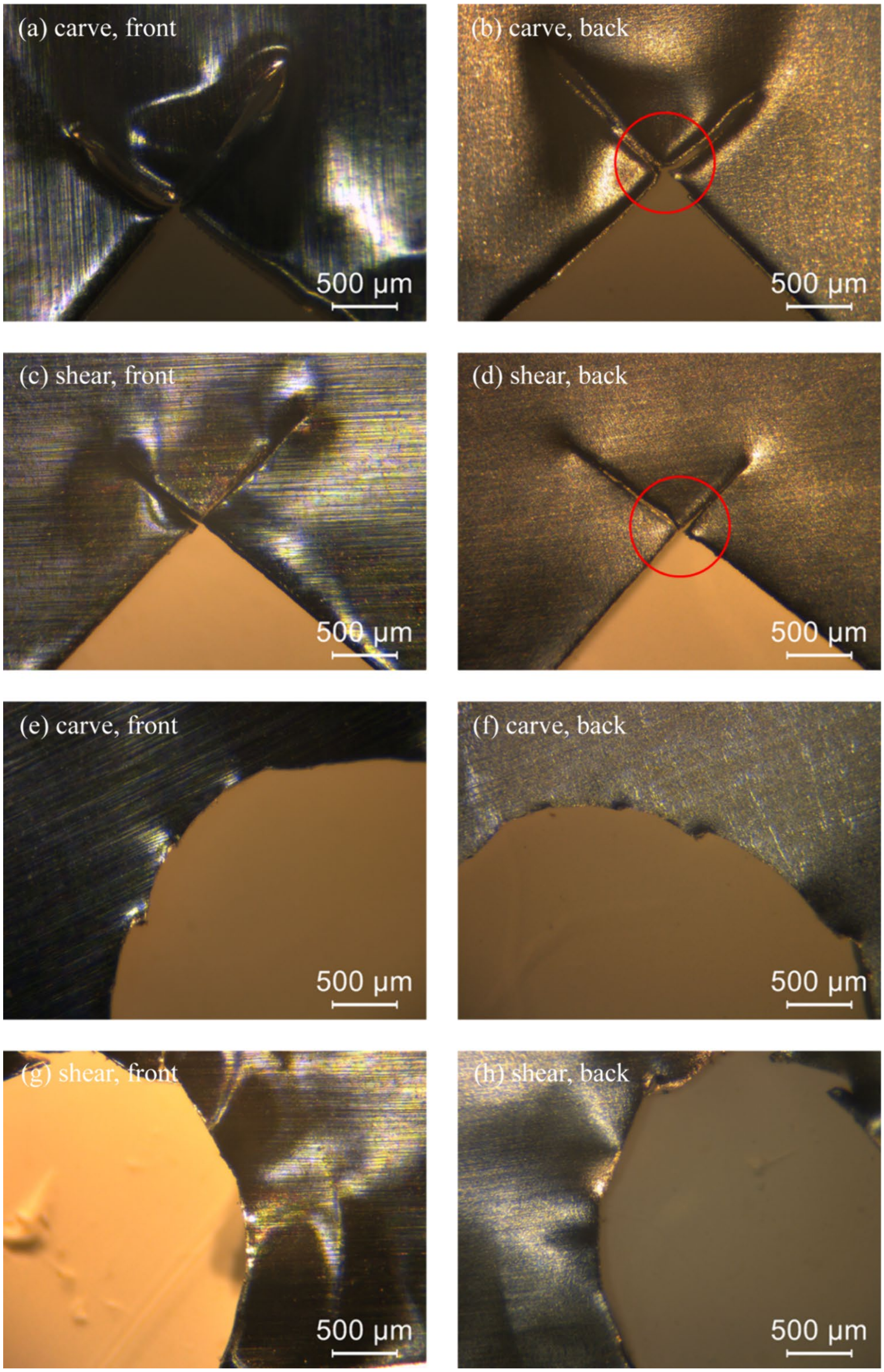

Fig. 7 The simulation experiments of carving and shearing (stereo microscope SX-6). **a** The vertical intersection carved, front; **b** the vertical intersection carved, back; **c** the vertical intersection sheared, front; **d** the vertical intersection sheared, back; **e** curve carved, front; **f** curve carved, back; **g** curve sheared, front; **h** curve sheared, back

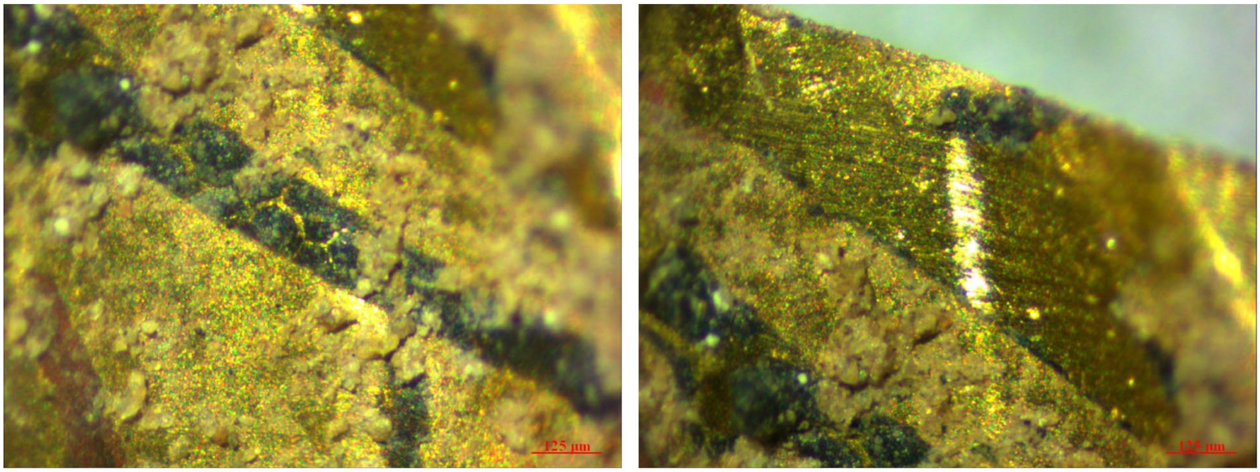

Fig. 8 Cracking and peeling phenomenon of the black lines (SX-5, sample: a-carriage). **a** Cracking phenomenon; **b** peeling phenomenon and polishing lines

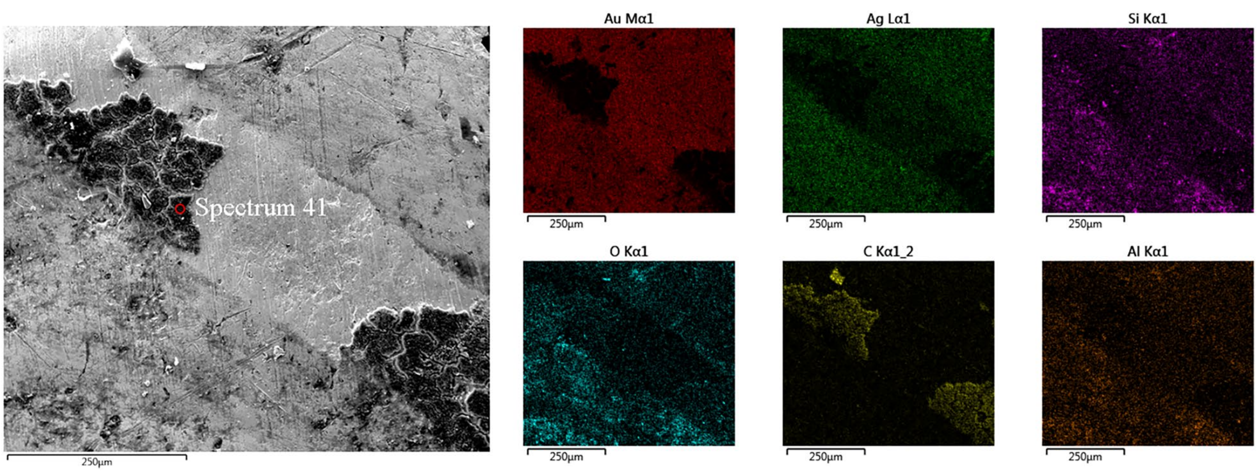

Fig. 9 ESEM-EDS mapping scan results at the black line (sample: d-black tiger)

Table 3 ESEM-EDS point scan results at the black line (sample: d-black tiger, position: Fig. 9 Spectrum 41)

Element	C	O	Ag	Ca	Au	Si	S	Cu	Al	Mg
Weight %	62.71	17.84	6.19	4.55	2.36	1.84	1.49	1.34	1.03	0.66

decoration of the gold foils, and (2) the decoration of the lacquerware using gold foils.

In each part, several key problems need to be discussed. About gold foil making, how are the gold foils made of raw materials? About the decoration of the gold foils, whether they are carved or sheared into the shapes? About the decoration of the lacquerware, what is the combination method of the gold foils and the lacquerware, pasting or flushing-exposure workmanship? These problems will be discussed in 3 parts of the following discussion: gold foil making, decoration, and adhesion.

Gold foil making

The Au content of the gold foils reveals the quality of raw materials. The gold foil analysed in this study is a gold-silver alloy with no detectable Cu element. The cross-section Au content is about 98%, which is much higher compared to gold foils excavated from other tombs, such

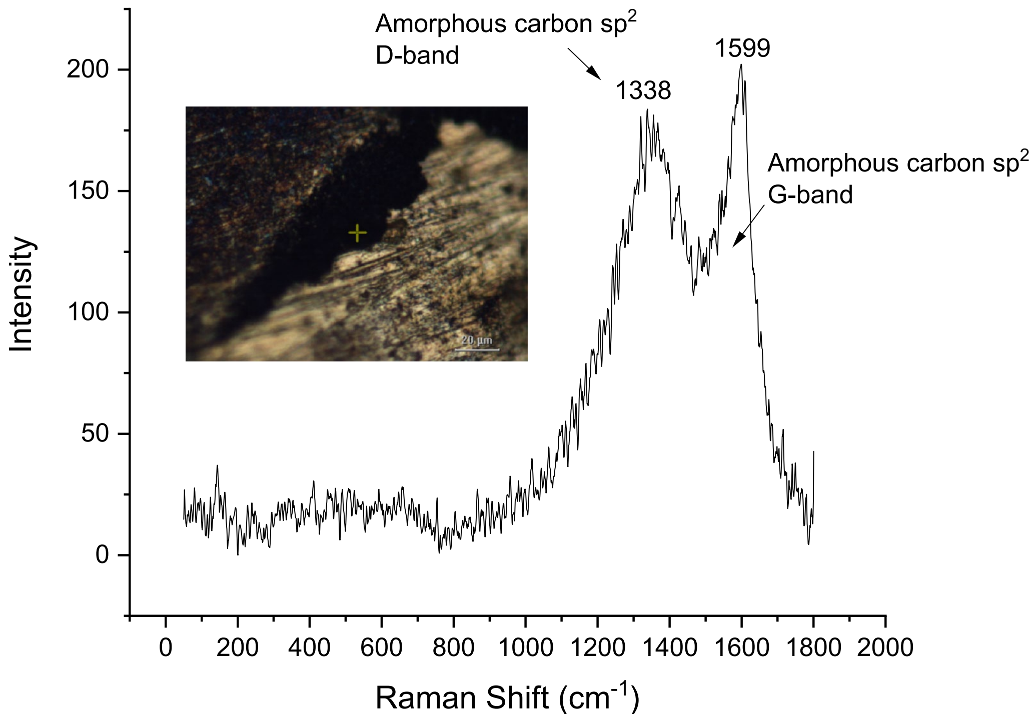

Fig. 10 LRS results at the black line (sample: d-black tiger)

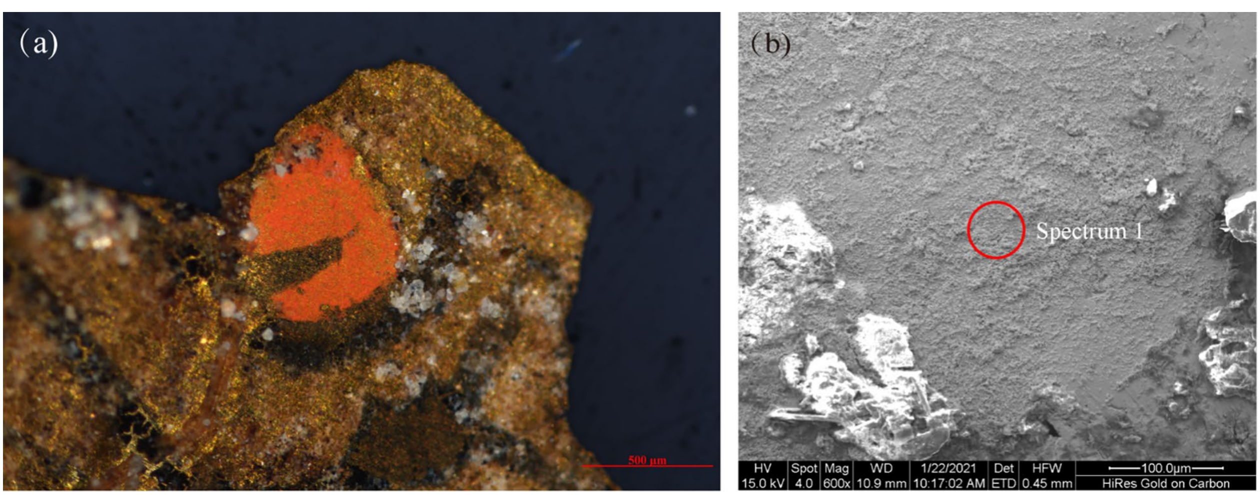

Fig. 11 The metallographic micrograph and ESEM-EDS results of the red paint (sample: e-half tiger). **a** The metallographic micrograph; **b** the ESEM photograph

Table 4 ESEM-EDS point-scan result of the red paint (sample: e-half tiger; scanning position: Fig. 11b Spectrum 1)

Element	C	Hg	S	O	Au	Al
Atomic %	49.40	14.65	18.57	11.83	5.01	0.54

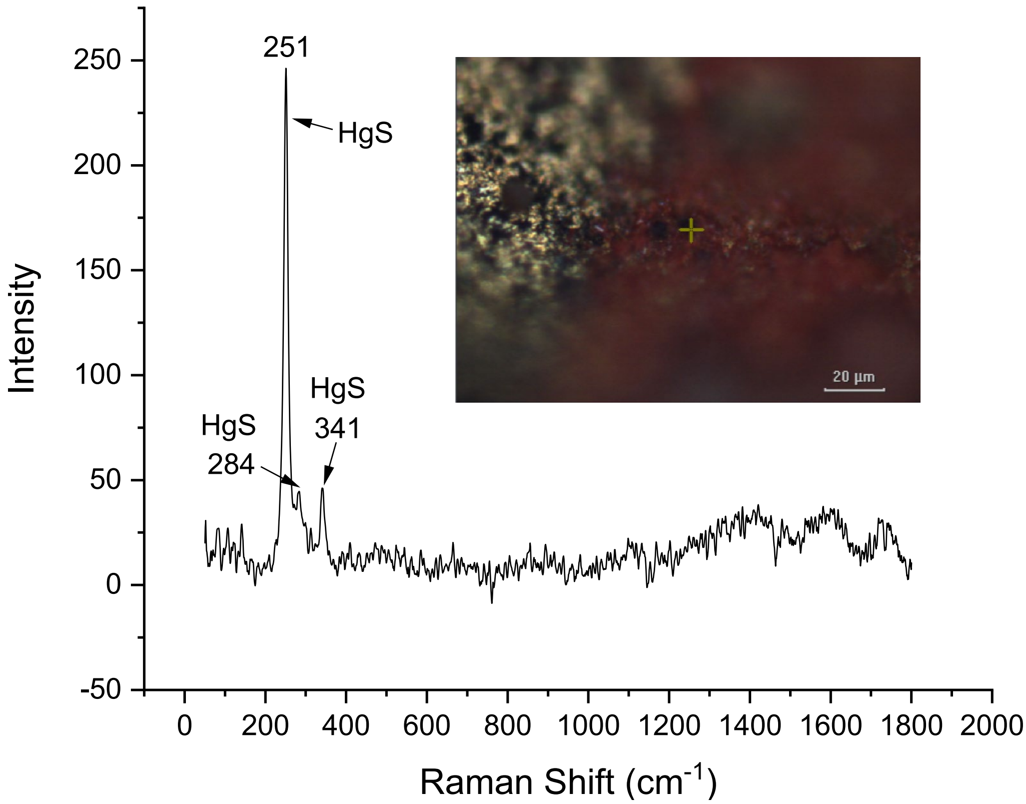

Fig. 12 LRS at the red paint (sample: e-half tiger)

Table 5 ESEM-EDS point scans of dark red gelatinous substance (sample: e-half tiger, scanning position: Fig. 13 Spectrum 33)

Element	C	O	Si	Al	Ca	Au	Fe	K	Ag
Atomic %	53.97	32.7	4.13	2.70	2.64	2.53	0.53	0.47	0.34

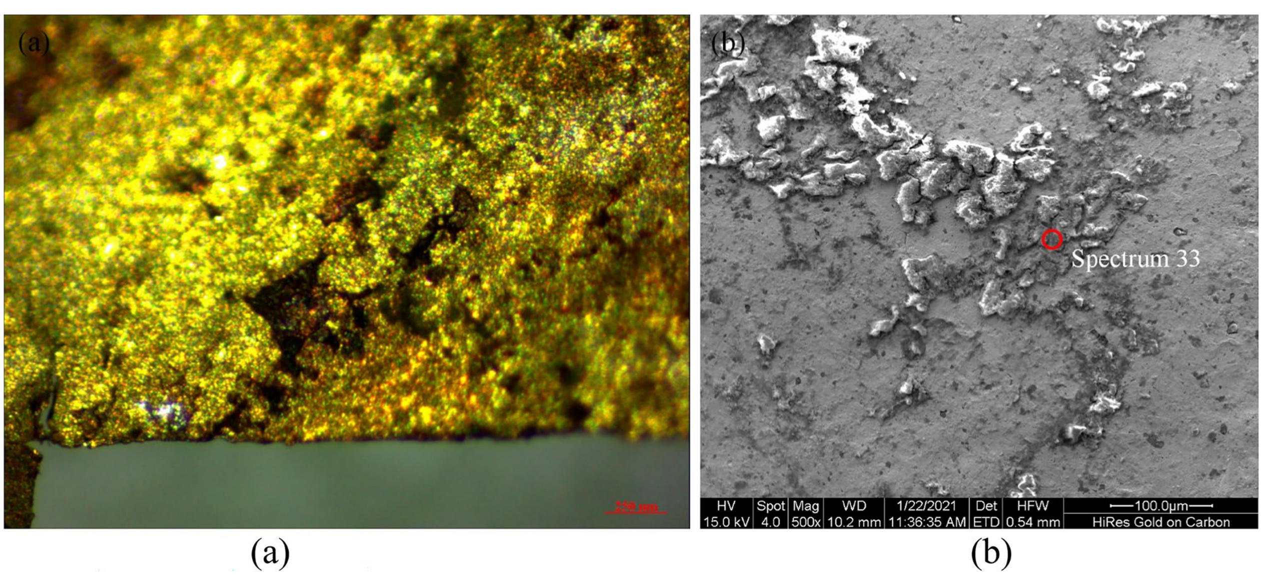

Fig. 13 Dark red gelatinous substance (sample: e-half tiger). **a** Stereo microscope, SX-5; **b** ESEM

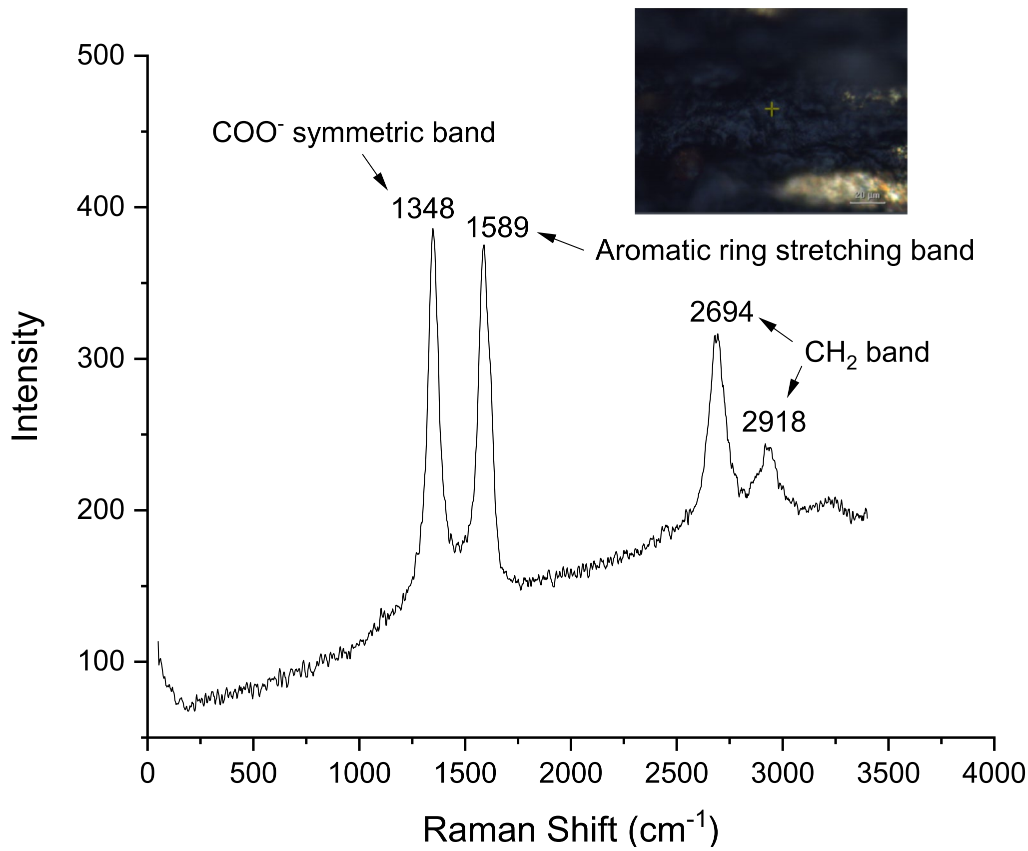

Fig. 14 LRS of dark red gelatinous substance (sample: e-half tiger)

as the gold foils from the Jinsha Site of the late Shang Dynasty and Spring and Autumn Period in Chengdu, Sichuan with Au content of 83–94% and Cu content of 0.2–1.6% [28], those from Majiayu Warring States Cemetery in Zhangjiachuan, Gansu with Au content of 79–93% [29], those from the Qin Cemetery at Dabaozishan, Lixian, Gansu with Au content of 90.6–92.1% [48], those from Hami, Xinjiang with Au content of 71–93% [49], those from M12 in Zhaoxiang and M5 in Caojiagang in Dangyang, Hubei with Au content of 82–95% [30]. Considering Au contents of other gold foils are usually surface contents, the surface Au content was also measured, with Au content of about 96%, which is still higher than most other gold foils, displaying a high level of gold refining.

The raw materials of gold are forged and heated to be foils from the very beginning of gold foil-making. Through metallographic observation of the gold foil from the Yinxu site in Anyang, Henan [11], which is the earliest gold foil ever found in China, the uneven size of grains and flat grain boundaries suggest that the annealing heat treatment process is used [50]. In the following periods, all the gold foils metallographic analysed [28–30, 48, 51] are found to be processed by hot forging. The gold foils of this study also have gone through the annealing process, indicated by twinned and recrystallized grains of the metallographic structure. The elongated and slightly curved twin lines suggest that the material has been subjected to the forging process. Thus, the gold foil-making craft is annealing and forging the same as the previous periods.

Gold foil decoration

From forged gold foil materials to decorated gold foils applied onto the lacquerware, gold foils are polished, shaped, and drawn.

According to stereo microscopy observation, the front side of the gold foil is well-polished with parallel polishing traces, while the back side has no polishing traces. The surfaces of gold ornaments excavated in Hami, Xinjiang [49] and 194 gold leaf samples from M12 in Zhaoxiang and M5 in Caojiagang in Dangyang, Hubei [30] are also polished.

From the Shang Dynasty to the Han Dynasty, called the early stage of Chinese gold production, 3 methods are probably used to create shapes of foils: carving, shearing, and chiselling [51]. Carving uses a single-edged knife. The deformation induced by the knife's motion is unidirectional in the tangent direction and downward in the normal direction concerning the plane of the gold foil (Fig. 15a). Shearing uses double-edged scissors. The deformation induced by the scissors' motion is unidirectional in the tangent direction and centreward in the normal direction (Fig. 15b). Chiselling uses the hammer and chisel, the motion of which is normal, so the deformation is only in the normal direction and downward (Fig. 15c).

Since there exists deformation in the tangent direction (Fig. 5d) and drapes (Fig. 5a–c), chiselling is first to be ruled out. Carving and shearing can both bring deformation in the tangent direction. The main difference in deformations induced by carving and shearing is in the normal direction: carving leads to downward deformation (Fig. 7b), and shearing leads to centreward deformation (Fig. 7c–d). The edge of the gold foil curls toward the back can be seen in Fig. 6 ESEM photographs, suggesting that the gold foils are more probably carved into shapes rather than sheared.

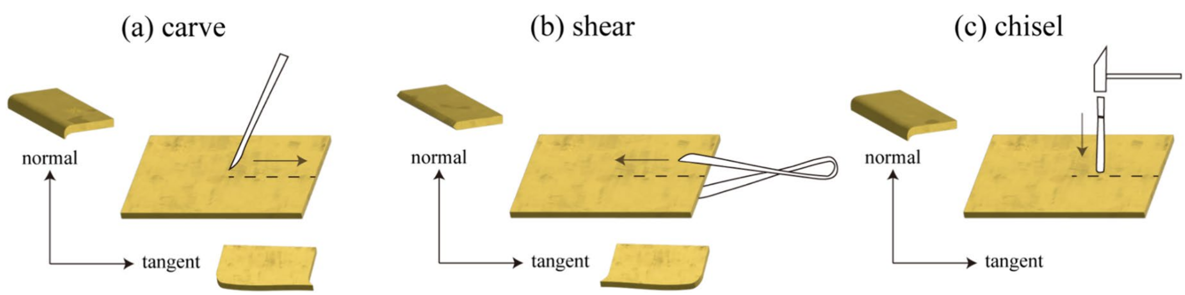

Fig. 15 Schematic of deformations in the normal and tangent directions caused by **a** carving, **b** shearing, and **c** chiselling

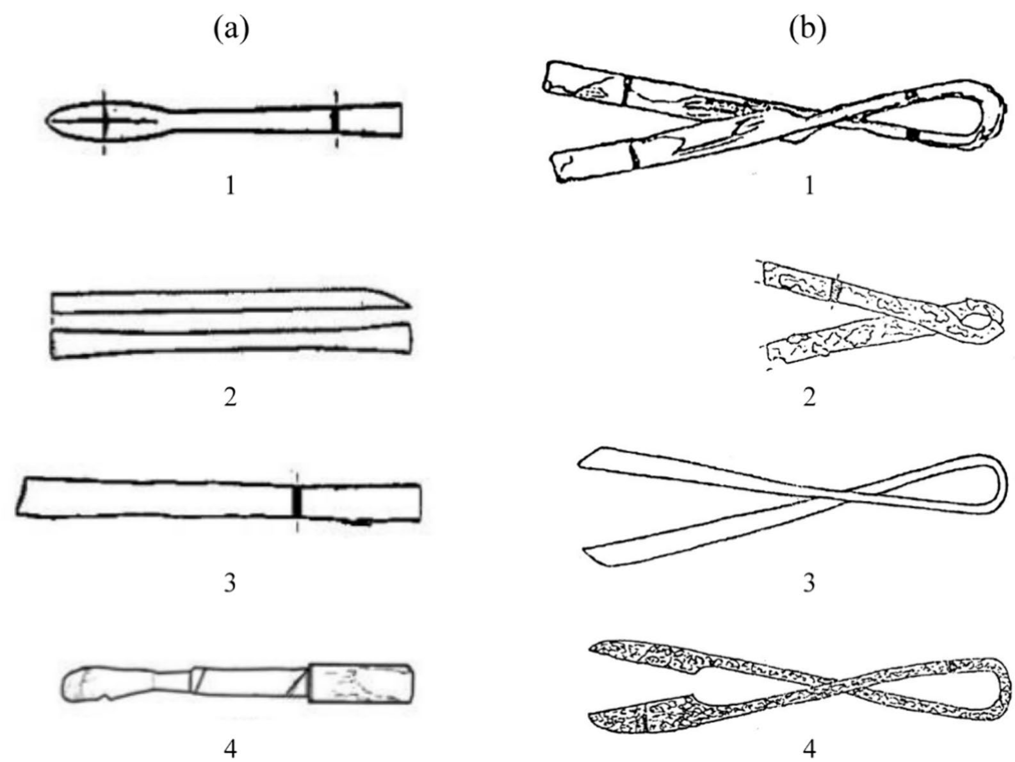

Fig. 16 Archeological discoveries of **a** carving knives [56], and **b** scissors [54]. **a** 1–4: Carving knives unearthed from the tomb of the king of South Yue (204–111 BC) in Guangzhou, Guangdong. **b** Scissors unearthed from 1: the gold pit in Guangzhou (early Western Han Dynasty) [52], 2: Duling Mausoleum Tomb in Shaanxi (early Western Han Dynasty) [57], 3: the tomb at the Yanggao Ancient Castle in Datong, Shanxi (mid-to-late Western Han Dynasty) [53], 4: Maquan, Xianyang, Shaanxi (mid-Western Han Dynasty) [55]

From the aspect of the archaeological discoveries, the earliest scissors (Fig. 16b1) were unearthed in the gold pit in Guangzhou, Guangdong (early Western Han Dynasty) [52], 12.8 cm long, forged and twisted from an iron bar, with straight edges and flat endings. The iron scissors of the mid-to-late Western Han Dynasty unearthed in the tomb at the Yanggao Ancient Castle in Datong, Shanxi [53] are 10.2 cm long, straight back, straight edges, long and slender, with slanting endings. These scissors were mainly used to cut fabric to make clothes [54]. The scissors of the mid-Western Han Dynasty unearthed in Maquan, Xianyang, Shaanxi [55] are 9.3 cm long, with exquisite carved decoration, wrapped in fabrics and placed in a lacquer box, along with tweezers, an ear spoon and a bronze mirror, supposed to be the woman's needlework tools. The scissors in the Western Han Dynasty have flat or slanting not sharp endings, which makes it hard to cut out hollow triangles as shown in Fig. 5a. While the knives unearthed from the tomb of the king of South Yue (204-111 BC) in Guangzhou, Guangdong [56] make it easier to carve out hollow triangles.

Taking the results of observations of gold foils, the simulation experiments of shearing and carving, and the archaeological discoveries of scissors and carving knives into account, the shaping craft of these gold foils is carving most likely.

There are black and red paints on the surface of gold foils. According to the results of microscopic observation, ESEM-EDS, and LRS, the black paints are Chinese ink, and the red paints are cinnabar. Since the red paints are on top of the black paints (Fig. 5f), the drawing sequence is to use the black lines to outline the pattern first, then use the red colour to depict. The gold foils decorated with both Chinese ink lines and cinnabar colouring are rarely seen. A similar phenomenon is seen on the gold foils unearthed in the Qin Cemetery at Dabaozishan, Lixian, Gansu, wrapping the wooden body of the tiger, with red parallel motifs on the surface of the gold foils [23].

ESEM-EDS results show that the C, O content is high in the red paint, indicating that the binder of the red pigment is organic. Enzyme-linked immunosorbent assay (ELISA) is used to identify gelatin (animal glue) as the binder of the cinnabar pigment of the mural [58], which offers a reference for determining the composition of the binder here. Further experimental analysis is needed to determine the type of binder used in cinnabar pigments.

Gold foil adhesion

The combination methods of gold foils and wares in ancient China are mainly 3 ways: physical covering, pasting and flushing-exposure. Physical covering craft doesn't use bonding agent, just covers gold foils to wares directly, and the edges are then pressed and hammered or riveted in place so that the gold foils do not fall off [18], mainly used on metal and wood wares. Gold foils usually cover the whole surface of the ware or stereoscopic components. Pasting craft needs the binder to apply gold foils onto wares, widely used on lacquerware in the Western Han Dynasty. Flushing-exposure craft evolves from pasting craft and is widely believed to be mature in the Tang Dynasty (618–907 AD) [59]. Gold foils are shaped and pasted onto lacquerware, and then re-varnished after drying, which is repeated several times until gold foils are shaded by lacquer. Then the surface of the lacquerware is polished repeatedly until gold foils are fully exposed again [59].

Since there exists lacquer residue on the back of the gold foils, and the gold foils are small pieces and flat, the combination method is not likely to be physical covering. Pasting and flushing-exposure both use the binder to attach gold foils and lacquerware, however, the thickness of gold foils usually used in flushing-exposure craft is about 250 μm, while about 25 μm used in pasting craft [59]. For example, the thickness of the gold foil from Yinxu, the capital of the late Shang Dynasty in Anyang, Henan is 10 μm [10]. The thickness of the gold foils from M12 in Zhaoxiang and M5 in Caojiagang in Dangyang, Hubei is 7–35 μm [30]. The thickness of the gold foils in this study is about 26 μm, which is closer to the common thickness of gold foils used in pasting craft.

Though the lacquerware was crushed during burial, leading to the separation of the gold foils and the lacquerware, complete round lacquer trousseaux decorated with gold foils from other tombs of the late Western Han Dynasty (Fig. 17) can offer a visualisation of the combination method of the gold foils and the lacquerware.

As to the binder, the materials used in the ancient Chinese gold foil pasting craft include gold glue, lacquer, lime water, plant juice, animal glue, and so on. Gold applied one-thousand-hand Buddha at Dazu Grotto, Chongqing used ripe lacquer with tung oil added as the adhesive material [60], however, this method was not widely used until the Song Dynasty (960–1279 AD) [61], which makes the use of this kind of gold glue for gold foil pasting here less possible.

The modern gold foil pasting process of lacquerware in Shanxi, China uses the same lacquer with the ware as the adhesive material, brushing a thin layer of lacquer before pasting. When the lacquer layer is 80% dry, the gold foil is pasted [62]. There is a dark red gelatinous substance remaining on the back of some gold foils, the elemental composition of which is mainly C and O. After LRS, it is determined that the composition is lacquer, so the adhesive material used for attaching is probably lacquer. The back of the gold foil has not been polished, retaining a

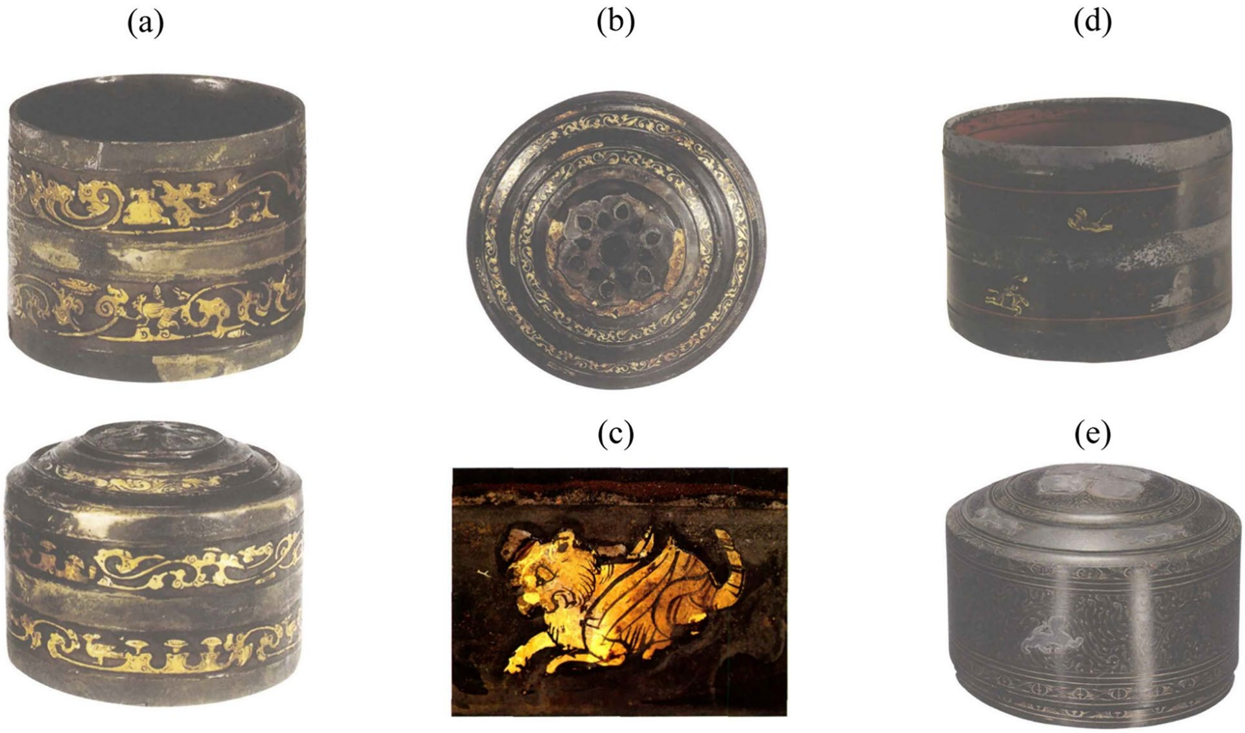

Fig. 17 Lacquerwares decorated with gold or silver foils of late Western Han Dynasty unearthed from **a** Changjie, Yangzhou, Jiangsu [35], **b** Hanjiang, Jiangsu [35], **c** Fengpengling, Wangcheng, Hunan [34], **d** M14 tomb, Huchang, Yangzhou, Jiangsu [35], **e** Xihu, Yangzhou, Jiangsu [35]

certain degree of roughness, which is conducive to the combination of the lacquerware and the gold foil surface.

Conclusion

The composition of the gold foils is a gold-silver alloy with a cross-section Au/(Au + Ag) wt.% of 98.03 ± 0.56% and a surface Au/(Au + Ag) wt.% of 96.12 ± 0.27%. Metallographic observation shows that the gold foils underwent heating and forging, with a thickness of about 26 μm, which allows the gold foils to adhere well to the lacquerware. The processing of gold foils demonstrates the high level of metalworking skills during the late Western Han Dynasty.

The gold foils are carved into shapes, the front of which is decorated with black and red paintings. The black is Chinese ink, with the phenomenon of cracking and peeling off in some places where parallel polishing marks are visible. The red is cinnabar, and the cementing material is organic. The red painting is on top of the black lines. There are no polishing traces on the back of the gold foils, retaining a certain degree of roughness, which is conducive to the combination of the lacquerware and the gold foil surface. There are lacquer residues in many places on the backside, revealing that the combination method of the gold foils and the lacquerware is pasting.

Based on the results of analysis and discussion, the manufacturing and decoration process of the gold foils applied on the lacquerware is as follows: heating and forging to obtain the gold foils, polishing the front side of the gold foils, carving into shapes, and applying them to the lacquerware when the lacquer surface is not yet dry. The gold foils used for lacquerware are decorated with black and red paints by using ink lines to outline the contour, and cinnabar pigment to draw the pattern, which is vivid and lively, displaying the ingenuity and creativity of craftsmen of the late Western Han Dynasty in China.

Abbreviations

ESEM-EDS Environmental Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy
SEM-EDS Scanning Electron Microscopy coupled with Energy-Dispersive X-ray Spectroscopy
LRS Micro Laser Raman Spectroscopy

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Author contributions

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References

1. Darque-Ceretti E, Felder E, Aucouturier M. Gilding of cultural heritage artefacts: an elaborated technology. Surf Eng. 2013;29(2):146–52. https://doi.org/10.1179/1743294412Y.0000000068.
2. Darque-Ceretti E, Aucouturier M. Dorure: décor et sublimation de la matière; Presses des MINES: Paris, 2012.
3. Darque-Ceretti E, Felder E, Aucouturier M. Foil and leaf gilding on cultural artifacts. Forming Adhesion Materia. 2011;16(1):540–59. https://doi.org/10.1590/S1517-70762011000100002.
4. MacLennan D, Llewellyn L, Delaney JK, Dooley KA, Patterson CS, Szafran Y, Trentelman K. Visualizing and measuring gold leaf in fourteenth- and fifteenth-century italian gold ground paintings using scanning macro X-ray fluorescence spectroscopy: a new tool for advancing art historical research. Herit Sci. 2019;7(1):25. https://doi.org/10.1186/s40494-019-0271-0.
5. Wu Q, Döbeli M, Lombardo T, Schmidt-Ott K, Watts B, Nolting F, Ganz D. Does substrate colour affect the visual appearance of gilded medieval sculptures? Part II: SEM–EDX observations on gold leaf samples taken from medieval wooden sculptures. Herit Sci. 2020;8(1):119. https://doi.org/10.1186/s40494-020-00456-2.
6. Vetter W, Frühmann B, Cappa F, Schreiner M. Materials and techniques used for the "Vienna Moamin": Multianalytical investigation of a book about hunting with falcons from the thirteenth century. Herit Sci. 2021;9(1):87. https://doi.org/10.1186/s40494-021-00553-w.
7. Mishmastnehi M, Holakooei P. Technological study of the gilded haft-rang tiles of the Imamzadih Ismail Mausoleum in Qazvin, Iran. Herit Sci. 2015;3(1):15. https://doi.org/10.1186/s40494-015-0044-3.
8. de la Torre-López MJ, Dominguez-Vidal A, Campos-Suñol MJ, Rubio-Domene R, Schade U, Ayora-Cañada MJ. Gold in the Alhambra: study of materials, technologies, and decay processes on decorative gilded plasterwork. J Raman Spectrosc. 2014;45(11–12):1052–8. https://doi.org/10.1002/jrs.4454.
9. Shi Y, Wen Y, Li X, Liu Z, Huang Y, He B. Transmission and innovation on gold granulation: the application of tin for soldering techniques in ancient China. Herit Sci. 2022;10(1):122. https://doi.org/10.1186/s40494-022-00753-y.
10. Yang XL. Chinese fine gold crafts and Artifacts. Beijing: Science Press; 2008.
11. Institute of Archaeology, Chinese Academy of Social Sciences. Shang Dynasty Burial at Huayuanzhuang East Ground, Yinxu, Anyang. Beijing: Science Press; 2007.
12. Henan Museum. Report on the excavation of the Shang dynasty City site in Zhengzhou cultural heritage information Series (1). Beijing: Cultural Relics Press; 1977.
13. Shandong Museum. No. 1 Slave Martyrdom Tomb in Subutun, Yidu, Shandong Province. Cultural Relics 1979(08):17-30. https://kns.cnki.net/kcms2/article/abstract?v=wYgW8A8u9voedLZHJp7bEXUCqZ28aGoSAiKISjuHAS2MzYxqZgb-madRGUbDka9Zqg5RVLsxrIEDub2clWl4bek2-lVZjmrMkdM5QEP-7DIpBcFRHm-TO985YDBEajM7DlyRXLnE-10=&uniplatform=NZKPT&language=CHS.
14. Hebei Institute of Cultural Relics. Taixi Site of the Shang Dynasty in Gaocheng. Beijing: Cultural Relics Press; 1985.
15. Lian HP. Investigation on traditional technique of making gold foil. Sci Conserv Archaeol. 2002;14:335.
16. Sichuan Cultural Relics Management Committee; Sichuan Institute of Cultural Relics and Archaeology; Guanghan County Cultural Bureau, Sichuan Province. Brief report on the excavation of Sanxingdui ruins No.1 sacrificial Pit in Guanghan, China. Cult Relics. 1987;10:1–15.
17. Qi DF. A preliminary discussion of early Chinese gold and silver crafts-manship. Herit Quarterly. 1998;2:66–72+87.
18. Jiang N. An Archaeological Study on the Early Golden and Silver Wares in China. Doctoral dissertation, Jilin University. 2015. https://kns.cnki.net/kcms2/article/abstract?v=b4E8SuETvlJcfM26JKSagM8BlGhDfNKsQKbERvplf_jDspWshweDqEXyyHaXuM-FZLzPOdXDR1J_VKjbQVLqCKz8Q2qpHLgovNY3xS1GBI2vyj3ur6Tvi1vjnBWaBpHRUN_akiwIwYEArHTCCaAaDA==&uniplatform=NZKPT&language=CHS. Accessed 28 Mar 2024.
19. Institute of Archaeology, Chinese Academy of Social Sciences; Beijing Cultural Relics Team; Liulihe Archaeological Team. Brief Report on the Excavation of the Western Zhou-Yan State Cemetery at Liulihe, 1981-1983. 1984, 5, 404: 405–416.
20. Henan Institute of Cultural Relics and Archaeology; Pingdingshan Cultural Relics Administration. Pingdingshan Ying State Cemetery. Zhengzhou: Elephant Press; 2012.
21. Zhouyuan Fufeng Cultural Administration. Western Zhou Tomb No. 1 at Qiangjia, Fufeng Shaanxi. Relics Museol. 1987;4:5–20.
22. Henan Institute of Cultural Relics and Archaeology; Sanmenxia Cultural Relics Team. Sanmenxia Guo State Tomb. Beijing: Cultural Relics Press; 1999.
23. Han W. On the gold foil ornaments of Qin state unearthed at lixian County Gansu. Cult Relics. 1995;6:4–11.
24. Shandong Task Force, Institute of Archaeology, Chinese Academy of Social Sciences. Tengzhou Qianzhaoda Shang dynasty burials. J Archaeol. 1992;3:365–92.
25. Institute of Archaeology Chinese academy of social sciences. Zhangjiapo Western Zhou Cemetery. Beijing: Encyclopedia of China Press; 1999.
26. School of Archaeology, Peking University; Shanxi Institute of Archaeology. The fifth excavation of the Tomb of the Marquis of Jin in North Zhao State Tianma-Qucun Site. Cult Relics. 1995;7:4–39.
27. Xinjiang Task Force, Institute of Archaeology, Chinese Academy of Social Sciences; Xinjiang Bayin'guoleng Mongol Autonomous Prefecture Cultural Relics Management Institute. Brief report of the second and third excavations of Qunbak Burials in Luntai County Xinjiang. Archaeology. 1991;8(736):684–703.
28. Xiao L, Yang JC, Han RB. Scientific examinations on the metal objects from Jinsha near Chengdu. Cultural Relics. 2004;4:78–89https://kns.cnki.net/kcms2/article/abstract?v=wYgW8A8u9vp22Vw1NshnzualpRbqPn-NFAl6ybo21apG0TiNZ0okH6eS8ivhWRYXdGd4Sm958ARqqW5Oet7vE54rMHOtjOLpbzgwSsrdMHMnnGOHReGRWG7jkOVgNxYE9dc1lkggqEo=&uniplatform=NZKPT&language=CHS.
29. Shao AD, Mei JJ, Chen KL, Zhou GJ, Wang H. Preliminary analysis of metal ornaments unearthed in Zhangjiachuan Majiayuan warring states cemetery. Cult Relics. 2010;10:88–96.
30. Cheng XL, Tang LR, Li M, Wu N, Yang Q, Liu W, Zhang XY, Liu M, Han Y, Zhao DD. Research on the composition and manufacturing techniques

of gold leaves of gold-covered metal ornaments excavated from Chu tombs. Sci Conserv Archaeol. 2019;31(01):10–9.
31. Museum H. Zenghouyi Tomb. Beijing: Cultural Relics Press; 1989.
32. Shanxi Provincial Institute of Archaeology; Quwo County Cultural Relics Bureau. Brief report on the excavation of the tomb of Jin Hou in Yangshe, Quwo Shanxi. Cult Relics. 2009;1(26):4–14.
33. Li YF. Western Han Tomb of Maquan, Xianyang, Shaanxi. Archaeology. 1979;2:125–35.
34. Changsha Municipal Institute of Cultural Relics and Archaeology, Wangcheng Office of Preservation of Cultural Relics. Excavation of Fengpengling tomb of Han dynasty in Wangcheng county Hunan. Cult Relics. 2007;12:21–41.
35. Fu JY. Chinese lacquerware gold and silver decoration technology: Chinese lacquerware with gold and silver decorations. Forbidden City. 2007;3:176–89.
36. Buccolieri A, Degl'Innocenti E, Cesareo R, Castellano A, Buccolieri G. Non-invasive in-situ analysis of a wreath of gold leaves from the national archaeological museum of Taranto Italy. Measurement. 2018;126:164–7. https://doi.org/10.1016/j.measurement.2018.05.063.
37. Buccolieri A, Castellano A, Degl'Innocenti E, Cesareo R, Casciaro R, Buccolieri G. EDXRF analysis of gold jewelry from the archaeological museum of Taranto Italy. X-Ray Spectrom. 2017;46(5):421–6. https://doi.org/10.1002/xrs.2761.
38. Pessanha S, Queralt I, Carvalho ML, Sampaio JM. Determination of gold leaf thickness using X-Ray fluorescence spectrometry: accuracy comparison using analytical methodology and monte carlo simulations. Appl Radiat Isot. 2019;152:6–10. https://doi.org/10.1016/j.apradiso.2019.06.014.
39. Ding L, Yang Q, Shi D, Wang Q, Pei J, Hu G. Chemical investigation of herbal wine from Jin Yang Ancient City Site during the Late Western Han Period in China. Archaeometry. 2024;66(1):204–18. https://doi.org/10.1111/arcm.12879.
40. Dychalska A, Popielarski P, Franków W, Fabisiak K, Paprocki K, Szybowicz M. Study of CVD diamond layers with amorphous carbon admixture by Raman scattering spectroscopy. Mater Sci-Poland. 2015. https://doi.org/10.1515/msp-2015-0067.
41. Cheng HS, He WQ, Yao HY, Tang JY, Yang FJ, Ma CY, Shan GL, Zhong YL, Wang WD. A study on the elemental compositions of ancient and modern Chinese inks. Sci Conserv Archaeol. 1997;9(1):16–9.
42. Swider JR, Hackley VA, Winter J. Characterization of Chinese ink in size and surface. J Cult Herit. 2003;4(3):175–86. https://doi.org/10.1016/S1296-2074(03)00044-X.
43. Song Y, Gao F, Nevin A, Guo J, Zhou X, Wei S, Li Q. A technical study of the materials and manufacturing process used in the gallery wall paintings from the Jokhang temple. Tibet Herit Sci. 2018;6(1):18. https://doi.org/10.1186/s40494-018-0182-5.
44. Tong Y, Cai Y, Wang X, Li Z, Nevin A, Ma Q. Polychrome Arhat figures dated from the song dynasty (960–1279 CE) at the Lingyan Temple, Changqing, Shandong, China. Herit Sci. 2021;9(1):117. https://doi.org/10.1186/s40494-021-00592-3.
45. Cinnabar R070532—RRUFF Database: Raman, X-ray, Infrared, and Chemistry. https://rruff.info/Cinnabar/R070532. Accessed 08 Oct 2023.
46. Li Z, Wang L, Chen H, Ma Q. Degradation of emerald green: scientific studies on multi-polychrome Vairocana statue in Dazu Rock Carvings, Chongqing, China. Herit Sci. 2020;8(1):64. https://doi.org/10.1186/s40494-020-00410-2.
47. Narita C, Yamada K. Influence of the type of Urushi and substrate on the chemical and physical properties of Urushi Films. Prog Org Coat. 2017;105:183–9. https://doi.org/10.1016/j.porgcoat.2017.01.004.
48. Shao AD, Sun SY, Mei JJ, Chen KL, Wang H. Scientific analysis and research on Metalware Unearthed from the Qin Cemetery in Dabaozishan, Lixian County Gansu. Cult Relics. 2015;10:7188–98.
49. Tan PP, Ji J, Yang JC, Wang JX, Ma J. Scientific analysis of some gold and silver artifacts unearthed from Tomb No. 1 of Barkun Xigou Site, Hami Xinjiang. Cult Relics. 2016;000(005):85–91.
50. Wang KZ. Gold foil production in ancient China. Nonferrous Metal Mater Eng. 1980. https://doi.org/10.13258/j.cnki.snm.1980.04.012.
51. Wang YC. Scientific Study on decorative Sheetmetal Artifacts unearthed in the region of the Chu culture of the eastern Zhou period. Doctoral dissertation. Beijing: University of Science and technology Beijing; 2020.
52. Guangzhou Cultural Relics Administration. Western Han tomb in Guangzhou gold pit. Acta Archaeologica Sinica. 1974;1:145.
53. Bai YX. Archaeological research on iron objects of the pre-Qin and Han dynasties. Beijing: Science Press; 2005.
54. Archaeology. Exploring the ancient and seeking the original: a collection of scholarly essays in commemoration of the 10th Anniversary of the establishment of the journal of archaeology. Science Press: Beijing. 2007.
55. Xianyang Institute of Cultural Relics and Archaeology. Brief Report on the Clean-up of Western Han Hollow Brick Tomb in Maquan Town, Xianyang, China. Relics Museol. 2000;6:10.
56. Shi XZ. Research on the Han dynasty knives in the central plains. Henan: Master of History, Henan Normal University; 2022.
57. Institute of Archaeology, Chinese academy of social sciences. Han Duling Mausoleum Site. Beijing: Science Press; 1993.
58. Chen EX, Zhang BJ, Lin YS, Meng CL. Analysis of pigments and gels in wall paintings of cultural relics in Zhejiang Province. Cult Relics East. 2018;000(003):107–13.
59. Fu JY. Chinese lacquerware gold and silver decoration technology: Chinese lacquerware with gold and silver flushing-exposure decorations. Forbidden City. 2007;3:136–43.
60. Hu DB, Xue YN, Wang JH, Zhang HY. An analytical study of gilding and adhesive materials on the one-thousand-hand buddha at Dazu Grotto, Baoding Mountain Chongqing. Sci Conserv Archaeol. 2008;20(3):44–51.
61. Wang SX. Annotation on Xiushilu (Introduction to Lacquer Painting). Beijing: Cultural Relics Publishing House; 1983.
62. Zuo LY. The investigation of shanxi traditional gilding techniques——based on the oral of gilding Craftmen. Master's thesis, Shanxi University, Shanxi. 2014.

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