Comprehensive research of the painted statues of Tutang Buddha and two attendants Buddha in Jingyin Temple, Taiyuan, China

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Research article

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Abstract

The painted statues of Tutang Buddha and two attendants Buddha in Jingyin Temple, with exquisite design and unique style, are precious cultural heritages of China. The statue of Tutang Buddha which was carved from a mound and painted by ancient craftsmen, is rarely found in ancient China. However, on account of the influence of natural factors and artificial harms, the statues were severely damaged. Obviously, it requires urgently carrying out appropriate protection and restoration of the statues. In this study, the samples taken from the statues were analysed by multiple analytical techniques, including scanning electron microscopy with energy dispersive spectrometry (SEM-EDS), Raman spectroscopy, X-ray diffraction (XRD), biological microscopy and particle size analysis. The analysis enabled us to infer the techniques used by the creators in making the statues. This research provides reliable evidence for the conservation and future protection of these and similar statues.

Introduction

Jingyin Temple, also known as the Tutang Buddha Temple, is located in Tutang Village, 20 kilometers northwest of Taiyuan in Shanxi Province. Fu Shan, an outstanding Taoist scholar and calligrapher, lived in seclusion here frequently during the Ming and Qing Dynasties [1]. Jingyin Temple, which is over 800 years old, was built during the Northern Qi dynasty and rebuilt in AD1205. The ancient stone tablets in Jingyin Temple show that the temple was rebuilt many times during the Ming dynasty, among that some of its buildings were repaired during the reigns of the Daoguang Emperor and the Guangxu Emperor of the Qing dynasty [2]. In 2006, Jingyin Temple was declared a nationally important cultural relic by the State Council. The Buddha Pavilion is the most important building in Jingyin Temple (Fig. 1(a),(b)). The pavilion which built on a cliff, is an east-facing two-story building with a double-eaved hip-and-gable roof. There are three painted sculptures in the hall of the Buddha Pavilion. The worshiped figures here are the Three Western Saints [3]: Amitabha (Fig. 1(c)), Avalokitesvara (Fig. 1(d)) and Mahasthamaprapta (Fig. 1(e)).

The statue of Amitabha sitting on a raised platform, is one of the tallest Buddha statues in China that carved from earth mound and painted with natural pigments. Since it locates in Tutang Village, the statue is also called “Tutang Buddha”. According to the earliest evidence of the origin of Tutang Buddha found in the inscriptions on the stone tablets [2], there was a hill piled with loess which suddenly collapsed into a cave. Inside the cave, a 33.3 m mound which is likely a Buddha was found. It was then sculpted into the Tutang Buddha by the local residents. The appearance of the Tutang Buddha is showing as a bare-chested Buddha wears a robe and sits on a lotus seat with his hands in his lap. The Buddha is 9.46 m in tall and the lotus pedestal is about 6m wide. The statue was decorated with gold foils while the belt was painted with exquisite blue pattern (Fig. 2(a)). The traditional LiFen technique was applied in drawing the intricate patterns at the edge of the dress (Fig. 2(b)). The LiFen technique, also called embossed painting, is a high-level painting technique, that used widely in wall painting, statue and architectural painting in ancient China. According to the technique, the rubber powder is extruded by tools to form a line with
about 0.2cm high on the surface, which highlights the three-dimensional sense of the pattern. These overall proved the precious nature of the statue. [4]

The statues of Avalokitesvara bodhisattva and Mahasthamaprapta bodhisattva stare positioned face to face in a gentle and beautiful appearance. They are both 3.7m in tall and with the pure white, broad, plump faces. They both wear necklaces and bracelets, as well as ornate clothes. A literature search [2] determined that the two statues were made by using the traditional sculpturing technology during the Ming dynasty as following[5]: the basic shape of the statue was built with wooden sticks of the mortise-tenon joint or fixed by nails; the wood skeleton was then wrapped with reed poles and fixed with hemp ropes; the coarse muds which contain soil, sands and wheat straws, etc. were used as the cover; the thin layer was made of fine muds; finally the surface was whitened and painted. The decoration techniques of gelled patterning and gilding were applied onto the two statues to obtain the exquisite patterns.

Owing to the natural and artificial deterioration, the statues were eroded severely which shown as flacking and shedding of the paint layer, salt corrosion, some damages found at the bottom of the statues, and the finger of the Avalokitesvara bodhisattva was detached and cracked. Moreover, due to the pollutions such as surface dust and lamp black the exquisite patterns became invisible. It appears necessary to urgently preserve and restore the sculptures. In this respect, analytical studies become a reliable source of information for revealing the actual use of materials and the technique, as well as offering basic information for restoration.

Though some studies on the statues from historical perspective have been conducted[1,2], there is no previous technical investigation of the materials and techniques used in making the statues in Jingyin Temple. Only few technical studies of other sculptures have been reported for the conservation. In considering all these modern methods, the combination of Environmental Scanning Electron Microscopy with Energy Dispersive X-ray analysis(ESEM/EDX), Raman spectroscopy and Polarized light microscopy(PLM) has proved to be a powerful methodology to identify the pigments[6-8]. Application of X-ray diffraction (XRD) is beneficial for accurate identification of crystalline structures in muds[9,10].Granulometric analysis is a well established and powerful technique for the analysis of the particle sizes of the caly samples[11].The combination of Herzberg stain and optical microscope is used to distinguish the fiber sources, which is useful for the analysis of paper fiber[12]. In this work, micro-Raman spectroscopy, SEM-EDS, XRD, Granulometric analysis, OM were applied to analyse the fragments containing pigments, clay and paper. Such documentation and analysis not only offer basic information for conservation and restoration, but also support art historical studies with relevant to dating, authentication, attribution, provenance of materials.
Fig.1

General view of the temple and the Statues. (a) the interior of the Jingyin Temple; (b) the interior of the Buddha Pavilion; (c) statue of Tutang Buddha; (d) statue of Avalokitesvara bodhisattva; (e) statue of Mahasthamaprapta bodhisattva

(the cross-scale was marked and the unit is mm)

Fig.2

(a) The exquisite blue pattern painting on the gold; (b) The intricate patterns at the edge of the dress

Experimental

Samples

Samples were taken from the damaged areas of the three painted sculptures, mainly the pigment, paper, and fine clay layers, following the procedures given in Principles for the Conservation of Heritage Sites in China\textsuperscript{[13]}. The Principles restrict sampling to visible surfaces; thus the coarse clay layers and wooden frames of the statues were not sampled. A small amount of undisturbed soil from the mountainside of the Juwei Mountain where Jingyin Temple is located was also taken as a sample for comparison. The sample details are given in Table 1.

Table 1. Information of Samples

| Pigment identification |
|------------------------|
| Digital microscopy     |

AM7915MZT Dino-Lite digital microscope was applied in In-situ observation of layers in the area of weak detail in order to exam the layer-structure and obtain the repainting information. The identifiable layers lay the basis for subsequent analytical studies carried out as well as explore technological details and provide useful information for screening protection and restoration methods.

| Micro Raman spectroscopy |

Micro-Raman analysis of the pigment was performed by a XploRA Raman spectrometer (purchased from Horiba Jobin–Yvon, France) coupled with a microscope. Point measurements were performed using an argon gas laser at 532 nm, 785 nm and a 50× working distance objective. The samples were measured over the spectrum range of 3000–100 cm\textsuperscript{−1}. The spot size was 1 µm. The system used an 1200 groove/mm dispersive grating.\textsuperscript{[14]}
SEM–EDS

The combination of SEM (a Quanta 650 of the FEI Company, USA) with EDS (an X-MaxN50 of the Oxford Instruments, UK.) was used for characterizing the elements of the pigment, which was an useful micro-destructive method for analysis of the samples of cultural relics. Each sample was fixed to the sample holder with conductive adhesive. Aztec software was used in the point & ID mode for micro-analysis. Samples were analyzed with 20 kV acceleration voltage and 10 mm working distance.

Clay analysis

X-ray diffractometer (XRD)

A rotating target X-ray diffractometer (Japan Makco Corporation MXPAHF 18 kW) equipped with a X-ray tube (Cu-Kα radiation: 1.541841 Å, 40 kV and 200 mA) was used to analyse the clay samples. The diffraction patterns were produced over the range of 10 to 70 degree (2θ). The scanning speed was 8°/min, and the scanning step was 0.02.

Granulometry

Particle analysis of the clay samples was conducted. Plant fiber was removed from a sample by suspension and was heated to minimize interference from fibers in the clay on particle size determination. The sample was then sonicated for 3 min to avoid sample reaggregation. The laser particle size analyser was used to measure the ratio of total particle volume to total volume of all samples in a particular size range. The BT-9300S laser granulometer was employed to measure the particle size ranging from 0.1 µm to 716 µm. The refractive index of the sample was set at 1.63.

Paper analysis

Optical microscopy (OM)

Microscopic studies of the paper samples were carried out on a Leica DM2500 biological microscope for micromorphology observation. The paper samples were immersed in water and dispersed into a single fiber. The fibers were placed on a glass slide and dyed with I₂-ZnCl₂ solution. The biological microscope was used to observe fiber morphology and to identify the specimen of the fiber.

Results And Discussion

In-situ observation

The in situ microphotographs as shown in Fig.3, reveal multiple paint layers of the statues. The results indicated that the general sequences and combinations of layers are different for the three statues. As seen from Fig.3a, at least four paint layers were found at the statue of Tutang Buddha from top to the bottom which are: black (L1)-paper-red (L2)-paper-green (L3)-paper-dark green (L4). At the bottom of the
kasaya (Fig.3(b)), the sequence of the paint layers presents as gold (L1)-paper-red (L2)-paper-red (L3)-white(L4). Also, the examination (Fig.3(c)) of the statue of Mahasthamaprapta bodhisattva demonstrated that the white pigment layer is overlapped by the green pigment layer.

The phenomenon of repainting seriously damaged statues was universal in ancient China. The ancient Chinese craftsmen usually applied mud and lime to cover the original paint layer, then repainted it. Later, mainly in the Ming and Qing Dynasties, the processes were varied slightly, the paint layer was covered with paper sequently repainted[16]. According to the in-situ observation, at least two layers of paper were found at the three statues with three or four layers of paper in some parts. Meanwhile, the inscriptions proved the results that the statues were restored repeatedly in A.D.1541 (the reign of the Jiajing Emperor in the Ming dynasty) and A.D.1739 (the reign of the Qianlong Emperor in the Qing dynasty). Multi-layers paintings were also investigated in the paintings [17] and wooden statues[18]. The result not only helps us to deepen the knowledge of the historical and cultural value but also supports the restorers to determine whether the over layers need to be removed.

Fig.3

Multiple paint layers of the statues: (a) at the lotus of the statue of Tutang Buddha; (b) at the bottom of the kasaya of the statue of Avalokitesvara bodhisattva; (c) at the bottom of the skirt of the statue of Mahasthamaprapta bodhisattva

Analysis of the pigments

The major colours of the statues in Jingyin Temple contain gold, red, blue, green, white, black and so on. Table 2 shows an overview of the pigments that were identified by SEM-EDS and Micro-Raman spectroscopy (Fig 4-1, 4-2, 5-1, 5-2).

Compositional analysis of the gilded materials of the three statues were detected by SEM-EDS. The results suggested a high level of gold (Au). Gold was frequently used as a gilding material in decorating precious painted sculpture in ancient China. In Northern China, the clay statues were decorated with gold and colors in ancient times. The technique of gilding the entire statue was widely used in Ming and Qing dynasties[19], which was also discovered in the statue of Tutang Buddha.

Three red samples were analysed by SEM-EDS and Micro-Raman spectroscopy. The elements of Hg, S and Pb were found by SEM-EDS in the Sample JYS-2-3. Different results of the Micro-Raman spectroscopy were obtained at two detection points of red Sample JYS-2-3. At one of the points we have detected the strong Raman peaks at 252,286,342 cm\(^{-1}\) which correspond well to characteristic Raman bands of cinnabar (HgS)[20-22]. Moreover, the strong Raman peaks at 160,225,313,475,546cm\(^{-1}\) are
assigned to minium (Pb$_3$O$_4$). The strong absorption at 546 cm$^{-1}$ is attributed to the stretching of the Pb-O bond$^{[14,23,24]}$. The result agrees with SEM-EDS analysis and conforms the red pigment is a mixture of cinnabar and minium. The same red pigment may also be used for the Sample JYS-2-3. Although the result of Micro-Raman spectroscopy indicated the existence of cinnabar, the elements of Hg and Pb are detected. The same analytical method is applicable to Sample JYS-1-3.

The blue pigment (JYS-2-4), which used in decorating the parts of kasaya of the statue of Avalokitesvara bodhisattva, was identified as azurite (2CuCO$_3$·Cu(OH)$_2$). All peaks between 100 and 1600 cm$^{-1}$ (137, 174, 247, 400, 543, 766, 836, 944, 1096, 1348, 1425 and 1581 cm$^{-1}$) are diagnostic Raman peaks assigned to azurite$^{[25]}$. The main element of the sample was Cu detected by SEM-EDS. It is well know that azurite was the most important blue pigment not only in European paintings throughout the Middle Ages and Renaissance$^{[26]}$ but also in Ancient China$^{[27]}$.

The skirt and streamer of the statue of Mahasthamaprapta bodhisattva were painted with green pigment and gold which forms the brilliant colors and exquisite patterns. The green pigment (JYS-3-1) was identified as atacamite (Cu$_2$Cl (OH)$_3$). SEM-EDS analysis reports relatively high level of Cu. Micro-Raman study of the sample exhibited peaks at 360, 514, 825, 915, 981 cm$^{-1}$, which are assigned to atacamite$^{[28,29]}$.

SEM-EDS analysis indicates the main element of the lime layer fragment is Ca. The Raman peaks at 152, 278, 1087 cm$^{-1}$ are assigned to Calcium carbonate (CaCO$_3$)$^{[30]}$. Calcium carbonate has been used to paint white for quite a long time and was reported to be used in of art and archaeological objects, such as the mural painting$^{[31,32]}$, architecture, et al. More interestingly, the main chemical constituent of the white pigments of JYS2-1 and JYS-2-4 is Pb. The Raman band registered at 1051 cm$^{-1}$ is attributed to lead white (2PbCO$_3$·Pb(OH)$_2$)$^{[33]}$. The result indicated that the statue of Avalokitesvara bodhisattva was decorated by the white pigment of lead white.

Unfortunately due to the poor conservation of the black pigments (JYS1-6, JYS3-3) or other reasons, the information of the black pigments were not obtained. Further analytical methods will be used to detect the black pigments in subsequent studies.

Table 2. The analysis results of major color pigments of the statues
Fig. 4-1
SEM/EDS results of the samples: (a) JYS-1-1; (b) JYS-1-2; (c) JYS-1-3; (d) JYS-1-4; (e) JYS-2-1; (f) JYS-2-2.

Fig. 4-2
SEM/EDS results of the samples: (g) JYS-2-3; (h) JYS-2-4; (i) JYS-2-5; (j) JYS-3-1; (k) JYS-3-2; (l) JYS-3-3.

Fig. 5-1
Raman spectrum of samples: (a) JYS-1-2; (b) JYS-1-4; (c) JYS-2-1; (d) JYS-2-3-1.

Fig. 5-2
Raman spectrum of samples: (e) JYS-2-3-2; (f) JYS-2-4; (g) JYS-2-5; (h) JYS-3-1.

**Paper analysis**

Herzberg stain is usually used to distinguish fiber sources, because different fibers of different plant sources are dyed in different colors by the iodide/iodine mixed with zinc chloride solution\(^{[34]}\). Fig. 6 (a), (b), (c) show the three paper samples with reddish brown color. The thickness of the fibers are different, in the range of 12-60 \(\mu m\). There are numerous longitudinal stripes and transversal striations on the fiber walls. By comparing stained fibers with those most commonly used in Oriental papermaking, such as bast fibers (hemp, flex, ramie, paper mulberry, etc.), bamboos, and grass fibers (wheat and rice straws), we could deduce that the fiber sources of the three samples are ramie\(^{[35]}\). It is well known that China is the origin of ramie. Documental evidences show Tsai-lun invented a new process of paper-making, and remie was used as one of the materials in Eastern Han Dynasty\(^{[15]}\). Remie paper has been used so far.

**Fig. 6**

Morphology of paper fibers: (a) JYS-1-1; (b) JYS-2-4; (c) JYS-3-1.

**Analysis of the clay fragments**

Only samples of fine clay layer were taken for testing because of technical restrictions on historical artifacts sampling. XRD patterns shown in Fig. 7 suggested that quartz (SiO\(_2\))\(^{[36]}\) and calcite (CaCO\(_3\))\(^{[37]}\) be the primary crystalline phases in the fine clay layers and the soil from the hillside close to Jingyin.
Temple. XRD analysis show the presence of albite (Na(AlSi$_3$O$_8$)) and gypsum(Ca(SO$_4$)(H$_2$O)$_2$) as minor ones of both JYS2-6 and JYS3-5 which were the same dynasty. XRD analyses revealed albite (Na(AlSi$_3$O$_8$)) being the minor component with the JYS-1-5. The granulometric analysis of JYS-4,JYS-1-5,JYS-2-6,JYS-3-4 show that the particle sizes are mainly in the range of 0.0002–0.20mm. The component particles of the samples are predominantly between 0.075mm and 0.01mm, with the content of coarse powder particle over 50%. It is also found that the proportion of the fine powder particle is close to the proportion of the clay particles. Refer to the relevant studies, it is suggested that the craftsmen made clay statues by collecting the raw materials from local area$^{[38,39]}$. The results analysis helped us to investigate the sources of the materials, which were important for working out the restoration scheme.

Fig.7

XRD Results

Table 3. Particle size distribution of the fine clay layer.

Conclusion

These excellent painted statues in Jingyin Temple are with high standard and exquisite craft. Unfortunately, owing to the deterioration factors, the statues were damaged severely. Therefore, these cultural relics need to be urgently protected and restored.

However, the materials and crafts used in making the statues in Jingyin Temple were barely studied so far. To fill the gap, in this study, several scientific techniques were used to investigate the technology and materials of the statues making, and some very interesting and unique results were revealed, such as: a mixture of cinnabar and minium, chlorite, azurite, calcium carbonate were identified as red pigments, green pigment, blue pigment, white pigment, respectively; gold foils were used to paint the outer surfaces of the statues; the statues were redrew for several times and ramie papers were covered on the paint layers when redrawing; the clays mainly obtained locally.

The results provided scientific evidence in establishing the applicable conservation schemes and selecting the applicable restoration materials. Furthermore, suggestions on the preservation of these cultural relics were discussed in this research.

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.
References

1. Shikang Fang. Cultural Resources in Taiyuan. Taiyuan: Shanxi People's Publishing House; 2009.p.68-70. (in Chinese)

2. Zeming Liu. Compiling Record of Stone Carvings in Shanxi Province Jiancaoping District. Taiyuan: Sanjin Press; 2012. p.35-36. (in Chinese)

3. Dunhuang Academy. Dunhuang grottoes art. Shanghai:Tongji University Press;2016.p.48-51. (in Chinese)

4. Chunping Cao. Traditional Architecture of South Area of Fujian Province. Xiamen: Xiamen University Press; 2006.p.240. (in Chinese)

5. Lisha Li, Jianguo Du, Hongli Liu, et al. Dynamic characteristics and seismic responses of painted sculptures of Dunhuang Mogao Grottoes. Journal of Cultural Heritage. 2016;22:1040-1048. https://doi.org/10.1016/j.culher.2016.07.003.

6. Ellen Egel, Stefan Simon. Investigation of the painting materials in Zhongshan Grottoes (Shaanxi, China).Heritage Science.2013;1(1). https://doi.org/1186/2050-7445-1-29

7. Yanying Ma, Jianhua Zhang, Dongbo Hu. Scientific analysis of a Ming Dynasty polychrome star sculpture from Shanxi Art Museum, Taiyuan, China .Sciences of Conservation and Archaeology.2015;27(4):50-60. (in Chinese)

8. Antonio Hernanz, Mercedes Iriarte, Primitiva Bueno-Ramirez. Raman Microscopy of Prehistoric Paintings in French Megalithic Monuments. Journal of Raman Spectroscopy. 2016;47(5):571-578. https://doi.org/10.1002/jrs.4852.

9. Yuxuan Gong, Chengquan Qiao, Bochao Zhong, et al. Analysis and Characterization of Materials used in Heritage Theatrical Figurines. Heritage Science.2020;8(1):1-18. https://doi.org/1186/s40494-020-0358-7.

10. Silvie Svarcova, Petr Bezdicka, David Hradil, et al. Clay pigment structure characterisation as a guide for provenance determination—a comparison between laboratory powder micro-XRD and synchrotron radiation XRD. Analytical and Bioanalytical Chemistry. 2011;399(1):331-336. https://doi.org/1007/s00216-010-4382-4.

11. Fei Huang. Research on the Conservation of Color-painted Sculptures of the Tang Dynasty of Foguang Temple in Wutai. M.A. dissertation: University of Science and Technology of China 2014. (in Chinese)

12. Tao Li, Jinxin Ji, Zhong Zhou, et al. A multi-analytical approach to investigate date-unknown paintings of Chinese Taoist priests. Archaeological and Anthropological Sciences. 2017;9(3):395-404. https://doi.org/10.1007/s12520-015-0293-9.

13. Chinese National Committee for the International Council on Monuments and Sites. Principles for the Conservation of Heritage Sites in China. Beijing: Cultural Relics Press;2015.p.10-15. (in Chinese)

14. Liu Liu, Decai Gong, Zhengquan Yao, et al. Characterization of a Mahamayuri Vidyarajni Sutra excavated in Lu’an, China. Heritage Science. 2019;7(1):1-9. https://doi.org/1186/s40494-019-0320-8.
15. Juhua Wang. Papermaking raw materials of China An atlas of micrographs and the characteristics of fibers. Beijing: China Light Industry Press; 1999. p.163-170. (in Chinese)

16. Jie Chen. The technique of making the Buddhist statues in China. Shanghai: Tongji University Press;2011.p.10-30. (in Chinese)

17. Eric J. Henderson, Kate Helwig, Stuart Read, Scoot M. Rosendahl. Infrared chemical mapping of degradation products in cross-sections from paintings and painted objects. Heritage Science. 2019;7(1). https://doi.org/10.1186/s40494-019-0313-7

18. Fermo, A. Mearini, R. Bonomi, et al. An integrated analytical approach for the characterization of repainted wooden statues dated to the fifteenth century. Microchemical Journal. 2020;157:1-13.

19. Jie Chen. The technique of making the Buddhist statues in China. Shanghai: Tongji University Press; 2011.p.10-30. (in Chinese)

20. s. Gard, D.M. Santos, M.B. Daizo, et al. Pigments analysis of an Egyptian cartonnage by means of XPS and Raman spectroscopy. Applied Physics A: Materials Science & Processing. 2020; 126(3):1-12. https://doi.org/10.1007/s00339-020-3386-y

21. Arriaza, J.P. Ogalde, M. Campos, et al. Toxic Pigment in a Capacocha Burial: Instrumental Identification of Cinnabar in Inca Human Remains from Iquique, Chile. Archaeometry.2018;60(6): 1324-1333. https://doi.org/10.1111/arcm.12392.

22. Zhengfeng Liu, Hang Zhang, Wenhua Zhou, et al. Pigment identification on an undated Chinese painting by non-destructive analysis. Vibrational Spectroscopy.2019;101:28-33. https://doi.org/1016/j.vibspec.2018.08.009.

23. Stanzani, D. Bersani, P. P. Lottici, et al. Analysis of artist’s palette on a 16th century wood panel painting by portable and laboratory Raman instruments. Vibrational Spectroscopy.2016; 85: 62–70. https://doi.org/10.1016/j.vibspec.2016.03.027.

24. Dominguez-Vidal, M. J. de la Torre-López, M. J. Campos-Suñol, et al. Decorated plasterwork in the Alhambra investigated by Raman spectroscopy: comparative field and laboratory study. Journal of Raman Spectroscopy.2014;45(1):1006-1012. https://doi.org/10.1002/jrs.4439.

25. Maja Gutman, Martina Lesar-Kikelj, Ajda Mladenovic, et al. Raman microspectroscopic analysis of pigments of the Gothic wall painting from the Dominican Monastery in Ptuj (Slovenia). Journal of Raman Spectroscopy.2014;45:1103-1109. https://doi.org/1002/jrs.4628.

26. Lluveras, S. Boularand, A. Andreotti, et al. Degradation of azurite in mural paintings: distribution of copper carbonate, chlorides and oxalates by SRFTIR. Applied Physics A: Materials Science and Processing. 2010; 99(2):363-375. https://doi.org/10.1007/s00339-010-5673-5

27. Erxin Chen, Bingjian Zhang, Fan Zhao, et al. Pigments and binding media of polychrome relics from the central hall of Longju temple in Sichuan, China. Heritage Science. 2019;7. https://doi.org/10.1186/s40494-019-0289-3

28. Parviz Holakooei, Jean-François de Lapérouse, Martina Rugiadi, et al. Early Islamic pigments at Nishapur, north-eastern Iran: studies on the painted fragments preserved at The Metropolitan Museum of Art. 2018; 10(1): 175-195. https://doi.org/10.1007/s12520-016-0347-7
29. Kejia Hu, Chongbin Bai, Linyan Ma, et al. A study on the painting techniques and materials of the murals in the Five Northern Provinces’ Assembly Hall, Ziyang, China. Heritage Science. 2013;1. https://doi.org/10.1186/2050-7445-1-18.

30. Asmaa M. Hussein, Fatma S. Madkour, Hala M. Afifi, et al. Comprehensive study of an ancient Egyptian foot case cartonnage using Raman, ESEM-EDS, XRD and FTIR. Vibrational Spectroscopy. 2020;106. https://doi.org/10.1016/j.vibspect.2019.102987.

31. Wenxia Ma, Fasi Wu, Tian Tian, et al. Fungal diversity and its contribution to the biodeterioration of mural paintings in two 1700-year-old tombs of China. International Biodeterioration & Biodegradation. 2020;152. https://doi.org/10.1016/j.ibiod.2020.104972

32. Rika Kigawaa, Chie Sanoa, Miyuki Nishijimab, et al. Investigation of acetic acid bacteria isolated from the Kitora tumulus in Japan and their involvement in the deterioration of the plaster of the mural paintings. Studies in Conservation. 2013;58(1):30-40. https://doi.org/10.2307/42751795.

33. Badillo-Sanchez D, Baumann W. Comparative palette characterization of oil-on-canvas paintings of two well-known 19th-century Colombian artists by confocal Raman spectroscopy. Journal of Raman Spectroscopy. 2016;47(12):1540-1547. https://doi.org/10.1002/jrs.5065

34. Tao Li, Jinxin Ji, Zhong Zhou, et al. A multi-analytical approach to investigate date-unknown paintings of Chinese Taoist priests. Archaeological and Anthropological Sciences. 2017;9(3):395-404. https://doi.org/10.1007/s12520-015-0293-9

35. Jilong Shi, Tao Li. Technical investigation of 15th and 19th century Chinese paper currencies: Fiber use and pigment identification. Journal of Raman Spectroscopy. 2013;44(6): 892-898. https://doi.org/10.1002/jrs.4297.

36. Kholod K. Salama, Mona F. Ali, Said M. El-Sheikh. Examination and analysis of an Egyptian Coptic Fresco from Saint Jeremiah Monastery. Journal of Science & Arts. 2019;19(1):153-162.

37. Isabel Garofano, Jose Luis Perez-Rodriguez, Maria Dolores Robador, et al. An innovative combination of non-invasive UV–Visible-FORS, XRD and XRF techniques to study Roman wall paintings from Seville, Spain. Journal of Cultural Heritage. 2016;22:1028-1039. https://doi.org/1016/j.culher.2016.07.002.

38. Fan J. The Study of the material properties and restorative material of clay sculpture at Shuiluan. Archaeol Cult Relics. 1994;6:30–41 (in Chinese).

39. Li YF, Wang XD, Zhao LY, et al. The study of the material and craft used in making painted sculpture at the Houtu Temple of Jiexiu, Shanxi. Dunhuang Res. 2007;5:54–8 (in Chinese).

**Abbreviations**

SEM-EDS: scanning electron microscopy in combination with energy dispersive X-ray analysis; XRD: X-ray diffraction; OM: optical microscopy; Raman: micro-Raman spectroscopy combined with optical microscopy.
Declarations

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Contributions

Xiaojian Bai designed the experiment; prepared the samples; performed the data analysis; wrote the manuscript. Chen Jia and Zhigen Chen provided the samples and interpreted the information of statues restoration; helped for writing and revised the article. Yuxuan Gong wrote and revised the article. Huwei Cheng provided the photographs of the sculptures; revised the article. Jiayue Wang participated in completing part of the analysis.

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Ethics declarations

Competing interests

The authors declare that they have no competing interests.

Additional information

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Tables

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General view of the temple and the Statues.(a) the interior of the Jingyin Temple;(b) the interior of the Buddha Pavilion;(c) statue of Tutang Buddha;(d) statue of Avalokitesvara bodhisattva;(e) statue of Mahasthamaprapta bodhisattva (the cross-scale was marked and the unit is mm)
Figure 2

(a) The exquisite blue pattern painting on the gold; (b) The intricate patterns at the edge of the dress
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Figure 7

XRD Results

Supplementary Files

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