PART SEVEN

Methods and Treatment

Types of Weathering of the Huashan Rock Paintings

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Abstract: *The Huashan rock art in China's Guangxi Zhuang Autonomous Region dates from 2400–1600 B.P., though some have been dated to as early as 16,000 B.P. Approximately seventy sites are known, of which Huashan is the most spectacular. The rock is limestone, and the rate of dissolution by water is in excess of 8 millimeters per 100 years. New threats to the art have emerged in recent times: pollution and tourism. While the red ocher pigment of the art is stable and resistant to weathering, it is the limestone substrate that is vulnerable. This paper describes the physical, chemical, and biological deterioration affecting the art.*

Brief Description of the Huashan Rock Paintings

The Zuo River valley in the Guangxi Zhuang Autonomous Region is well known for its rock art, which can be found at more than seventy sites. The most spectacular among them is the Huashan (Hua Mountain), within the Nonggang Nature Reserve in Yaoda district, 25 kilometers from the Ningming county seat. The mountain drops abruptly into the Ming River, a tributary of the Zuo River, with a sheer cliff 270 meters high and 350 meters wide on the western side (fig. 1). The rock paintings are located between 30 and 90 meters above the river and extend for 172 meters, occupying an area of more than 8,000 square meters.

The Huashan rock paintings comprise about 1,600 dancing figures and animals, as well as depictions of bronze drums, knives, swords, bells, and ships. Most of the human figures range in height from 60 to 150 centimeters, but one is 3 meters high. These images probably represent various kinds of worship: sun, bronze drum, river god, farming god, phallus, war and victory, sacrifice, and totem (Bao Chang 1981). They are therefore important for our understanding of the cultural life of the ancient populations in the Zuo River valley. Existing stylistic studies and carbon-14 dates place the Huashan rock paintings within a time frame of 2400 to 1600 B.P., which coincides with the Warring States period and the Qin and Han dynasties in northern China (Yuan Sixun, Chen Tiemei, and Hu Yanqui 1986; Tan Shengmin 1987: 127–45). Historical records tell us that the Zuo River valley was inhabited by the Luo Yue ethnic group during this time frame; hence the Huashan rock paintings may have been created by them (Wang Kerong, Qiu Zhonglun, and Chen Yuanzhang 1988: 202–8).

FIGURE 1 A view of the Huashan cliff.

Present Condition and Microenvironment of the Huashan Rock Paintings

Topographically, Huashan is part of a karst system. Water seepage and erosion have caused cracking, scaling, and collapse of the rock (fig. 2). They have also given rise to many stalactites and veils on the rock surface (figs. 3, 4). Some of the rock paintings were executed on these formations. According to carbon-14 dating, the earliest paintings were made about 16,000 B.P. and the most recent ones about 690 B.P. Dissolution is still occurring at the rate of 2.1 to 8.3 mm/100y. Where water seepage is severe, the rate is even greater (Chen Tiemei, Chen X., and Zhu F. 1986). Seepage and erosion are the immediate threats to the paintings.

Huashan is located in a subtropical monsoon climatic zone, characterized by high temperature and abundant rainfall. Annual average temperature is 19°C to 22°C (highest, 26–28°C; lowest, 11–14°C); the annual rainfall is 1242.2 millimeters (mainly from June to September, 63%) (Ningming County Weather Bureau).

Huashan is a remote area and has been free from industrial activities for thousands of years, which has favored the preservation of the rock art. In recent decades, however, paper making, sugar production, and coal mining have been developed at the county seat of Ningming, 25 kilometers upstream, and pollution has spread to Huashan. Moreover, the increasing number of tourists visiting the site poses a great threat to the preservation of the rock paintings.

FIGURE 3 Stalactites and curtains on the Huashan cliff.

FIGURE 4 Granular substance on the Huashan cliff.

FIGURE 2 Weathering of the rock paintings on the Huashan cliff.

Painting Materials

The Huashan rock paintings were all executed with red ocher, which was applied directly onto the rock face. The rock body is limestone, mainly calcium carbonate ($CaCO_3$), as revealed by X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses (Guo Hong et al. 2005: 10–20). Analyses of the structural features and composition of the rock show it is limestone and marl, both containing fossil fragments. The fossil remains in the limestone are mostly perfectly preserved, with a lamellar structure of 30 to 45 percent by volume (fig. 5). The cementation substances are mostly calcite and micritic carbonate, which suggests that the sedimentation environment was a calm one, containing foraminifera, marine algae, and invertebrates. The marl comprises conglomerates and granules of micritic carbonates, and the cementation substance is calcite; it also contains marine invertebrates.

In spite of weathering for centuries, the color of the red ocher pigment is bright. X-ray spectroscopic analysis shows that in addition to the predominant iron, the elements are calcium, magnesium, silicon, aluminum, sodium, potassium, zinc, vanadium, sulfur, titanium, and nickel. XRD analysis reveals that the major color-generating element is Fe_2O_3, but calcite, quartz, and kaolin are also found. The analyses indicate that the pigment was derived from natural red ocher mixed with clay. Ocher, as is generally known, has high resistance to heat and humidity and is stable chemically.

Ultraviolet and infrared spectroscopic examination shows that conifer resin was used as the binding medium. The resin is insoluble in water and undoubtedly has contributed to the preservation of the rock paintings over the centuries (Qiu Zhonglun et al. 1990).

Microscopic Examination

Examination using the optical microscope shows that microscopic weathering occurs by erosion, microorganisms, surface deposits, and microscopic cracks.

Erosion

Erosion is the most common type of weathering, creating various types of pits on the rock face (fig. 6). Pits take a number of forms, such as trough, basin, and pothole. Some basin-form pits contain residues of erosion that reflect their formation process. The residue on the bottom is loose in texture and dull in color; the bottom itself is composed of many tiny cracks filled with black carbonates and oxides. It appears that the basin developed as microscopic cracks expanded. The pothole is a baglike pit with a small mouth but a large interior. The walls of the pit are loose and porous and sometimes contain calcite and limestone particles coming from the outside. Erosion holes are on average 0.54 millimeter in diameter.

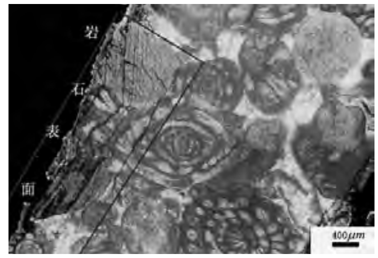

FIGURE 5 Polished, embedded thin section of Huashan rock, showing marine invertebrate fossils.

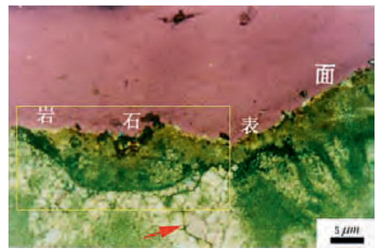

FIGURE 6 Polished, embedded thin section of Huashan rock, showing erosion pits on the surface due to weathering.

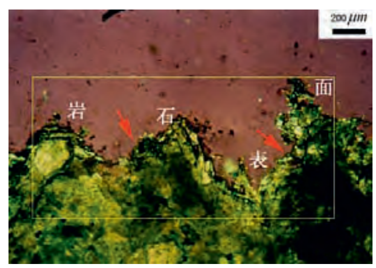

FIGURE 7 Polished, embedded thin section of Huashan rock, showing deep weathering (up to 0.8 mm) resulting from microbiological growth.

Microorganisms

As shown in figure 7, the growth of microorganisms penetrates into the rock to a depth of 0.5 to 0.8 millimeter and is less than 0.001 millimeter in diameter.

Surface Deposits

There are two types of surface deposits. One is chemically formed (e.g., a surface precipitate or veil together with granular lime), and the other is physically or biologically formed. They are different in structure, composition, and thickness.

The chemically formed deposit appears to result from the precipitation of calcite. It is characterized by a clearly visible layer structure, with light- and dark-colored layers alternating.

The light-colored layers are mainly crystalline calcite and are denser in texture than the dark-colored ones. The dark-colored layers are higly porous and composed mainly of noncrystalline calcite with organic material and other inclusions; they also contain tiny particles of quartz and feldspar.

The physical-biological mechanism deposits result from wind and water, by which particles carried to the rock surface adhere and provide a substrate for microorganisms. They are characterized by thinness and a considerable amount of clay, calcite, and quartz. Compared with the chemically formed deposit, this type is very thin and therefore also described as a deposit film. The particles of clay, calcite, or quartz are usually 0.03 to 0.06 millimeter in diameter, and the cementation substances are mainly clay and calcium carbonate. Some of the particles fill the erosion pits. Obviously, they are intrusions, accumulated by water or wind on the surface and then cemented by carbonate.

Microscopic Cracks

There are two types of microscopic cracks: those with carbonate filler (fig. 8) and those without (see fig. 7) (Yang Zhong-Tang et al. 1994). Our examination found that the fissures without fill are more developed and larger horizontally than in other directions. That they cut into rock but show no displacement indicates that they are stress relief cracks. The large number of this type of crack significantly weakens the cohesion of the rock surface and leads eventually to scaling. This type of weathering is very detrimental to the rock paintings.

Causes of Weathering

The foregoing analysis of the microscopic forms of weathering suggests three causes: chemical, physical, and biological. Chemical weathering produces pits in the rock and carbonate coverings on the surface. The subterranean water in the Huashan has a rich content of chemical substances that accounts for the above-mentioned features. Analysis of water samples from a spring and a stalactite in the Huashan and the Ming River reveals the different chemical compositions of these sources (table 1). Table 1 shows that (1) the mineralization of the river water is lower than that of the stalactite water, which is lower than that of the spring, indicating that the spring water had been in contact with the rock for less time than the stalactite water; (2) the content of Ca^{2+}, Mg^{2+}, and HCO_3^- ions of the spring and stalactite is higher than that of the river water, denoting a considerable dissolution by the subterranean water, which results in caverns, cracks, and pits, thus undermining the stability of the rock (it also reprecipitates calcium carbonate on the surface of the rock, concealing the rock paintings); (3) the content of Cl^- ion in the river water is higher than that of the spring and stalactite water, indicating that the river is slightly polluted.

Physical weathering begins with the microscopic cracks. The existence and development of these cracks change the mechanical properties of the rock, which in turn leads to loss of fragments that vary in size from one to many square centimeters, the largest being hundreds of square centimeters. These fragments are generally up to 1 to 2 centimeters thick. This type of erosion, which is determined by the structure of the rock, the development of the cracks, and the atmospheric conditions, is most hazardous to the paintings.

Biological weathering derives from microorganisms. Growth of microorganisms on the rock surface and intrusion into the rock affect both the surface and the interior. Holes inside the erosion pits, for instance, are caused by microorganisms such as lichen and algae. Deep holes that penetrate into the light- and dark-colored layers may have been produced by the decomposition of threadlike algae. Microorganisms, when combined with the other forces of erosion, may also significantly damage the rock paintings.

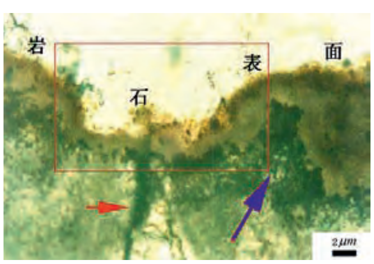

FIGURE 8 Polished thin section of Huashan rock with microscopic cracks filled with carbonate.

Pigment

The ocher pigment is rosy to dark red in color. The pigment layer is usually 0.01 to 0.03 millimeter thick but occasionally is up to 0.04 millimeter thick. Because the pigment was applied on a weathered surface, it tends to penetrate the rock. The extent of penetration depends largely on the structure of the rock and is greatest where microfissures exist. A cross section shows that the pigment penetrates deeply along the lamellar structures and turns the cement inside into a brownish yellow color (fig. 9). The pigment therefore may have helped to strengthen the weathered rock surface.

Table 1 Water Analysis

	Content (mg/l)			
Chemical Composition	**River**	**Spring**	**Stalactite (north side)**	**Stalactite (south side)**
$Na^{+}K^{+}$	14.75	13.00	19.75	15.5
Ca^{2+}	12.7	83.81	45.9	46.58
Mg^{2+}	4.81	6.93	5.94	6.45
Cl^{-}	16.31	13.47	15.6	14.18
SO_4^{2-}	15.22	9.89	31.95	31.95
HCO_3^{-}	51.26	285.57	150.11	146.45
Degree of mineralization	115.05	412.67	269.25	261.11
pH value	6.51	7.52	6.85	6.8

Source: Liu Yourong and Pan Bietong 1991.

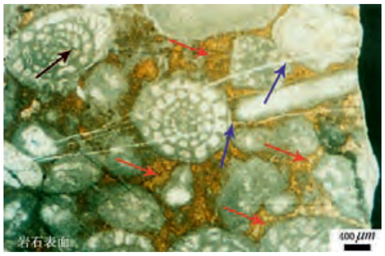

FIGURE 9 Polished thin section of Huashan rock, showing penetration of ocher into weathering microfissures that existed at the time the pigment was applied.

Conclusion

The Huashan rock paintings were created by applying red ocher directly onto the limestone rock surface. While ocher is quite stable, the rock is prone to weathering. This study has examined the microscopic forms of weathering of rock. The major form is erosion pits, but surface deposits, microscopic cracks, and holes drilled by microorganisms are also found. The underlying causes of these forms of deterioration are the chemically rich underground water acting on the limestone, development of microscopic cracks, and the growth of microorganisms. Located in a karst topography, the overall site is most threatened by the underground water.

References

Bao Chang. 1981. The origin of dance. *Wudao luncong = Dance Tribune* 4: 58–63.

Chen Tiemei, Chen X., and Zhu F. 1986. ^{14}C dating of rock paintings at Huashan Mountain, Guangxi. *Guangxi min zu yan jiu = Study of Nationalities in Guangxi* 2: 69–72.

Guo Hong, Han Rubin, Zhao Jing, Huang Huaiwu, Xie Riwan, and Lan Riyong. 2005. Pigment and the prevention of its fading on petroglyphs of the Flower Mountain. *Wen wu bao hu yu kao gu ke xue = Sciences of Conservation & Archaeology* 17 (4): 7–14.

Liu Yourong and Pan Bietong. 1991. Geological problems and preventive measures for the Huashan rock paintings in Guangxi. Unpublished internal report. Archived in the Cultural Property Bureau of the Provincial Cultural Administration, Guangxi Zhuang Autonomous Region.

Qiu Zhonglun, Li Qianrong, Pan Xiaomei, and Wang Changsui. 1990. A preliminary study of the pigment and binding medium of the Huashan rock paintings. *Wen wu* (1959) = *Wen wu* 1: 85–87.

Tan Shengmin. 1987. *Guangxi Zuo Jiang liu yu ya bi hua kao cha yu yan jiu = Investigation and study of the rock art of the Zuojiang River valley in Guangxi.* Guangxi shao shu min zu gu ji cong shu, no. 1. Nanning Shi: Guangxi min zu chu ban she.

Wang Kerong, Qiu Zhonglun, and Chen Yuanzhang. 1988. *Guangxi Zuo Jiang yan hua.* Beijing: Wen wu chu ban she.

Yang Zhong-Tang, Zhen Guangquan, Ma Tao, and He Ling. 1994. Study of the microfeatures of the weathered stone relics in Qianling Mausoleum. *Kaogu yu wenwu = Archaeology and Cultural Relics,* no. 6: 20–25.

Yuan Sixun, Chen Tiemei, and Hu Yanqui. 1986. ^{14}C dating of rock paintings on the Huashan Mountain, Ningming County, Guangxi Zhuang Autonomous Region. *Guangxi min zu yan jiu = Study of Nationalities in Guangxi* 4: 27–33.

A Study of Support Materials for Mural Paintings in Humid Environments

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Abstract: *Microorganisms are a tremendous threat to organic materials in humid environments. This paper presents our research on the selection of support materials for mural paintings in humid areas and X-ray diffraction, Fourier transform infrared, polarized light microscope, and scanning electron microscope analysis of the texture, mechanism, and form of fixed and slaked calcareous nodules* (liaojiang) *used as the source material for mortar. We conclude that the ideal material for backing mural paintings in humid environments is the inorganic mortar made from* liaojiang.

A joint research project was carried out between 1987 and 1996 by the Gansu Provincial Museum, China, the Coating Materials Institute of the Ministry of Chemical Industries, and the Lanzhou University Department of Biology in order to find solutions to the need for reinforcement materials and techniques and the prevention of mold on mural paintings in humid environments.[1] The project succeeded in identifying the causes of such deterioration problems and effectively protecting the surface of paintings from decay.

In addition to the frequently observed damage caused by soluble salts, a further danger for mural paintings that have been lifted and detached is that stress between the painting's backing and the support wall, or the stress of the backing layer itself, may cause cracking or detachment in the painting, threatening its secure attachment to the wall. In dry environments, high-fiber materials such as straw or hemp mixed with adhesive materials are satisfactory to enhance the intensity of the clay-based layer, but for paintings in a humid environment, where spores of microorganisms develop as soon as the environment is proper for their growth, these organic materials are not appropriate. In tombs where paintings have been reattached, a typical relative humidity of 75 percent and an average temperature of 8°C to 25°C contribute to the growth of spores. Under these conditions, the development of spores weakens the organic substrate materials. In addition, metabolic substances produced by microorganisms are detrimental to the paintings (Ma Qinglin, Hu Zhide, and Li Zuixiong 1996).

In 1996 the Gansu Provincial Museum started work on a national project, Backing Materials and Protection Techniques for Mural Paintings in Humid Environments. As microorganisms had already done great damage to the paintings, special attention was paid to the choice of inorganic adhesive mortars to adhere the detached clay-based layer.

History of Inorganic Mortars

Inorganic mortars have a long history in China. In ancient construction sites unearthed in Dadiwan, Qin'an county, Gansu province, especially at Sites F901 and F405, components in the flooring were made from calcium carbonate agglomerations found in loess. These nodules, called *liaojiang,* contain 60 to 80 percent $CaCO_3$ and 2 to 40 percent clay minerals. Fired *liaojiang* is generally believed to be the oldest man-made cement in the world (Li Zuixiong 1998). On the floor of Site F411 is China's oldest-known painting, dated at five thousand years. This work, referred to as the Dadiwan floor painting, measures about 1.2 meters long and 1.1 meters wide. The backing of the painting is similar to the floor of the hall of Site F901 (Lang Shude 1999). The floor painting was transferred to the city of Lanzhou for protection, and samples from the underlying support were studied in the laboratory.

Since the relative humidity in underground tombs is greater than 75 percent year-round, inorganic support materials for murals must harden slowly in reaction with water. Hardening must be slow to allow for minor expansion, aeration, and water vapor permeability for the reinforcement layer.

The Italian technique of using volcanic ash (*pozzolana*) in the restoration of underground mural paintings is well known (Schwartzbaum et al. 1984). Volcanic ash is chemically similar to fired *liaojiang*. The Dadiwan floor painting had been buried underground for nearly five thousand years but incurred no damage and remains strong and intact. This means that the mortar used is long lasting and ideal in a stable humid environment. We thus decided to research the application of similar materials for reinforcing the backing of mural paintings in humid environments.

Liaojiang as a Hydraulic Adhesive

Composition

Liaojiang, calcareous nodules that form in loess, contains a large percentage of $CaCO_3$ and other minerals such as clay, quartz, mica, and feldspar. The nodules are white, gray, light yellow, or even red in color, and the higher the clay mineral content, the darker the color.

We used X-ray diffraction (XRD), Fourier transform infrared (FTIR), polarized light microscope (PLM), and scanning electron microscope (SEM) analysis, as well as other techniques, to examine *liaojiang* nodules obtained near the site of the Dadiwan floor painting. The results, reported in table 1, show that the nodules contain about 66 percent calcite ($CaO + CO_2$), 22 percent quartz, and some mica and feldspar. Previous research has shown that the endurance of ancient building materials derives from the low percentage of Na_2O and K_2O (3–20%) and the high CaO content (40–50%) (Yang Nanru 1996).

Analytical Methods

XRD Analysis

Unfired *liaojiang* samples were heated to a high temperature (700–1,000℃) and allowed to cool to room temperature. The samples were then ground to a fine powder, sifted, and mixed with water. The mixture was spread into 0.5-centimeter-thin analytical samples, similar to the flakes found in the clay-based layer of the wall painting, and kept in an environment of 90 to 100 percent RH for one month. The composition obtained through XRD analysis of the *liaojiang* powder before hydration and the prepared analytical samples after one month in a high relative humidity environment is presented in table 2.

The analyses show that although the unfired *liaojiang* is composed mainly of calcite and quartz, the high-temperature heating changed the composition greatly. The calcite decomposed into CaO, which was converted into reactive minerals such as $CaAl_2O_4$ ($CaO{\cdot}Al_2O_3$), $Ca_2Al_2SiO_7$ ($2CaO{\cdot}Al_2O_3{\cdot}SiO_2$), and $CaSiO_3$ ($CaO{\cdot}SiO_2$). After the powder was exposed to high relative humidity for one month, the composition of the samples changed into $Ca_{1.5}SiO_{3.5}{\cdot}xH_2O$ ($1.5CaO{\cdot}SiO_2{\cdot}xH_2O$) and $Ca(OH)_2$ and a small amount of $CaCO_3$ (since the samples were not exposed to air, little $CaCO_3$ was produced).

Table 1 Composition of *Liaojiang* Nodules[a], Red Clay, and Modern Cements (wt %)

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2	SO_2
Red clay	62.15	15.79	6.45	1.06	3.22	3.08	1.14	0.07	
Liaojiang	22.06	5.44	2.03	36.82	1.49	0.98	0.60	28.4	
Liaojiang[b]	20.62	5.02	2.03	37.60	1.38			31.56	
Liaojiang[c]	20.9	5.3	4.4	65.2	1.8				1.7
Silicon cement	21–23	5–7	3–5	64–68					
Common cement[c]	21.2	5.4	2.7	64.7	2.0				2.1

a. Samples obtained from near the Dadiwan archaeological site in Qin'an county.
b. See Chen Ruiyun 1992.
c. See K. Asaga et al. 2000.

Table 2 Composition of Powdered, Heated-Treated *Liaojiang* Samples Obtained through XRD Analysis

Heating Temperature (℃)	Before Hydration[a]	1 Month after Hydration
700	SiO_2, CaO, Al_2O_3, small amount of $CaO{\cdot}Al_2O_3$	SiO_2, $Ca_{1.5}SiO_{3.5}{\cdot}xH_2O$, $Ca(OH)_2$, small amount of $CaCO_3$
800	SiO_2CaO, $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$	SiO_2, $Ca(OH)_2$, $Ca_{1.5}SiO_{3.5}{\cdot}xH_2O$, small amount of $CaCO_3$
900	SiO_2, CaO, $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$	SiO_2, $Ca(OH)_2$, $Ca_{1.5}SiO_{3.5}{\cdot}xH_2O$, small amounts of $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$ and $CaCO_3$
1,000	SiO_2, CaO, $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$, $CaO{\cdot}SiO_2$	$Ca(OH)_2$, $Ca_{1.5}SiO_{3.5}{\cdot}xH_2O$, small amounts of $CaAl_2O_4$, $CaCO_3$, and $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$

a. Exposure to 90–100% RH.

FTIR Analysis

Samples prepared for XRD analysis were used to determine FTIR spectra. The results are shown in figures 1 through 3.

Comparison of the spectra in figures 1 and 2 shows a large phase transformation. Before hydration there is no $CaCO_3$ in the samples, but after hydration and exposure to air the $CaCO_3$ content increases in the regions 1420 cm^{-1}, 873 cm^{-1}, and 712 cm^{-1}. In the regions 3,674–3,300 cm^{-1} and 996 cm^{-1}, the change shows that hydration also occurs for other substances. The newly formed $CaCO_3$ appears in the regions 1,420 cm^{-1}, 873 cm^{-1}, and 712 cm^{-1}. Comparison of figures 2 and 3 shows that the *liaojiang* after hydration is very similar to the material from the Dadiwan floor painting substrate.

PLM Analysis

Samples of heated *liaojiang* powder and samples after hydration were examined under the polarized light microscope. Compared to the raw fired material, the *liaojiang* after hydration has formed many particles of different sizes and shapes, which indicates that after hydration the *liaojiang* has a high degree of cohesion.

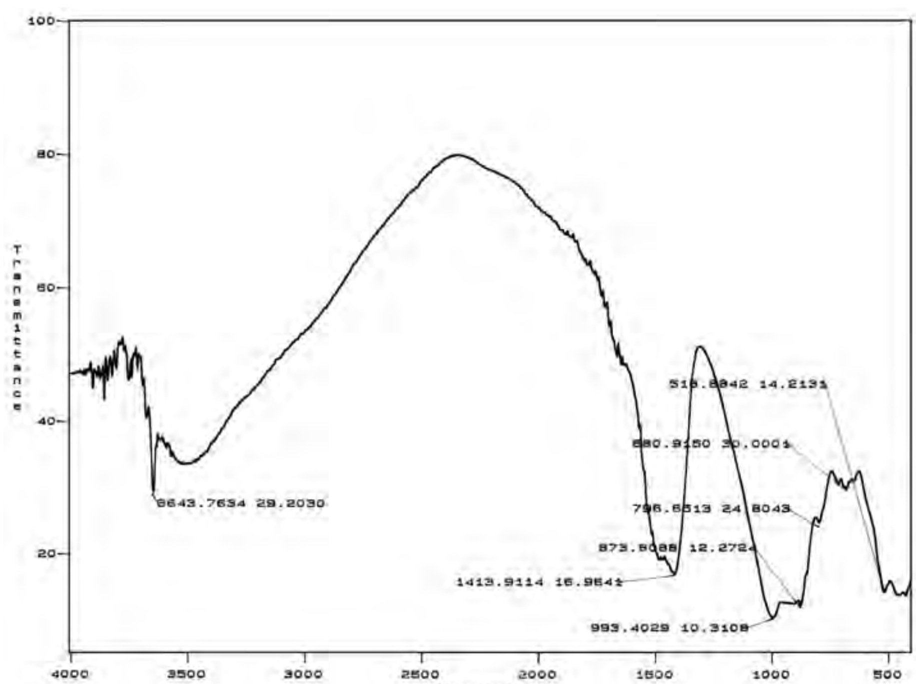


FIGURE 1 FTIR spectrum of gray *liaojiang* sample after heating for twenty-four hours at 900°C.

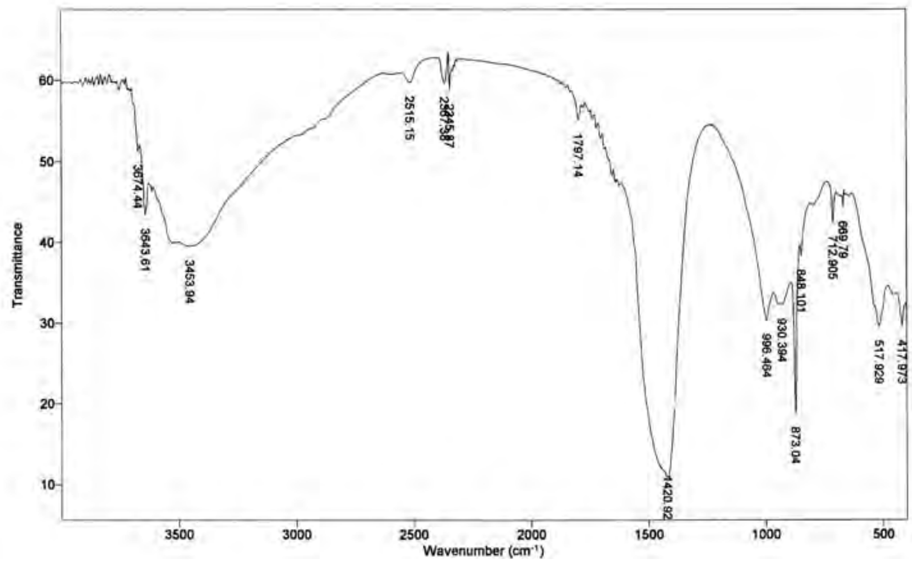


FIGURE 2 FTIR spectrum of *liaojiang* one month after hydration.

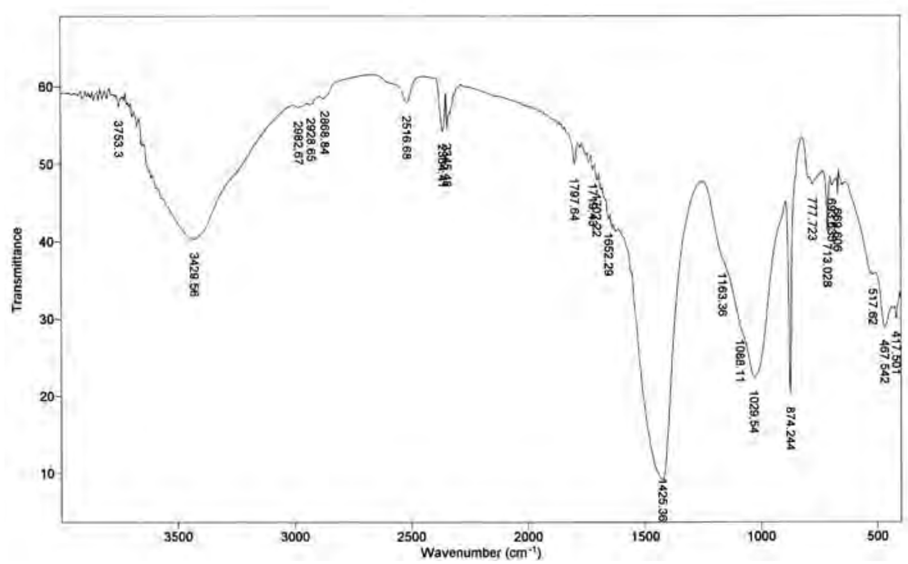
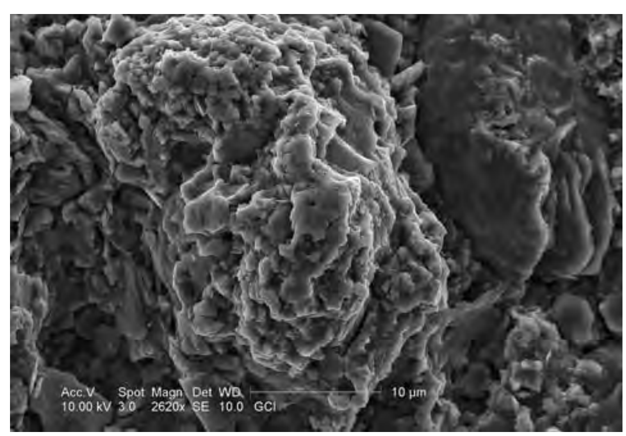


FIGURE 3 FTIR spectrum of the Dadiwan floor painting substrate.

FIGURE 4 SEM image of *liaojiang* sample one month after hydration (2620×).

SEM Analysis

Figure 4 shows a sample of *liaojiang* one month after hydration as examined by SEM. The hydrated *liaojiang* has a very high degree of cohesiveness and has formed a continuous interlinking structure; the regular pores between particles ensure aeration and permeability, thus allowing thorough carbonation over time; that is, the CaO will react with CO_2 to form $CaCO_3$. Three years after hydration the *liaojiang* sample formed well-developed calcite crystals. This means that a restored support for a painting will continue to improve its cohesiveness three years after the work is done.



Curing Process

Calculations demonstrate that the heating temperature used in the Dadiwan floor was about 950℃ (Ma Qinglin and Li Xian 1991). The following are the analyses using XRD of the *liaojiang* nodules taken from the Dadiwan site.

From a comparison of figures 5 through 8 (data for figures 7 and 8 are listed in tables 3 and 4), it is concluded that the process of heating and hardening of *liaojiang* at 900℃ is

$CaCO_3 + SiO_2$ (including mica and feldspar) → $CaO + 2CaO{\cdot}Al_2O_3{\cdot}SiO_2 + CaAl_2O_4 + 2CaO{\cdot}SiO_2$

During hydration,

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$2CaO{\cdot}SiO_2 + H_2O \rightarrow 1.5CaO{\cdot}SiO_2{\cdot}xH_2O$$
$$2CaO{\cdot}Al_2O_3{\cdot}SiO_2 + H_2O \rightarrow 1.5CaO{\cdot}SiO_2{\cdot}xH_2O + 2Al(OH)_3$$
$$CaO{\cdot}Al_2O_3 + H_2O \rightarrow Ca(OH)_2 + 2Al(OH)_3$$

Therefore, the hydrated substances contain a large amount of $1.5CaO{\cdot}SiO_2{\cdot}xH_2O$, $Ca(OH)_2$, a small amount of $Al(OH)_3$, and some unhydrated $2CaO{\cdot}Al_2O_3{\cdot}SiO_2$. Among them, $Al(OH)_3$ and $1.5CaO{\cdot}SiO_2{\cdot}xH_2O$ are effective inorganic cementing agents.

Table 3 Data Comparison of Figure 7 and Standard Materials in JCPDS[a] Files

Samples		$Ca_2Al_2SiO_7$ (35-0755)		CaO (43-1001)		$CaAl_2O_4$ (34-440)		SiO_2 (31-1233)	
dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0
4.2711	18	4.231	2					4.257	22
3.8340	6	3.842	1						
3.7201	8	3.707	15						
3.3508	72							3.342	100
3.2408	9								
3.0640	9	3.0629	21						
2.9781	10					2.97	100		
2.8554	27	2.8446	100			2.86	3		
2.7793	55			2.7777	37				
2.7560	33								
2.7121	21	2.7175	5						
2.6589	10								
2.6361	11								
2.4571	11							2.457	8
2.4062	100	2.4070	11	2.405	100	2.41	18		
2.2861	12	2.2869	11					2.282	8
2.1964	13								
2.0404	9	2.0398	9						
1.9812	8								
1.9111	8	1.9213	8			1.922	8		
1.8192	12							1.8179	14
1.7647	7								
1.7559	8	1.7542	25						
1.7014	48			1.7008	49				
1.5443	9							1.5418	9
1.4507	17			1.4504	13				

a. International Centre for Diffraction Data.

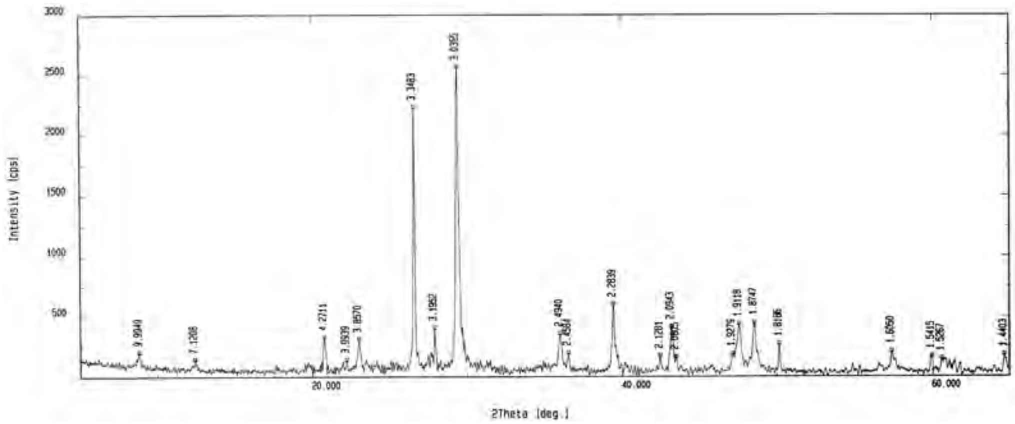


FIGURE 5 XRD analysis of the Dadiwan floor painting substrate (main components, calcite and quartz).

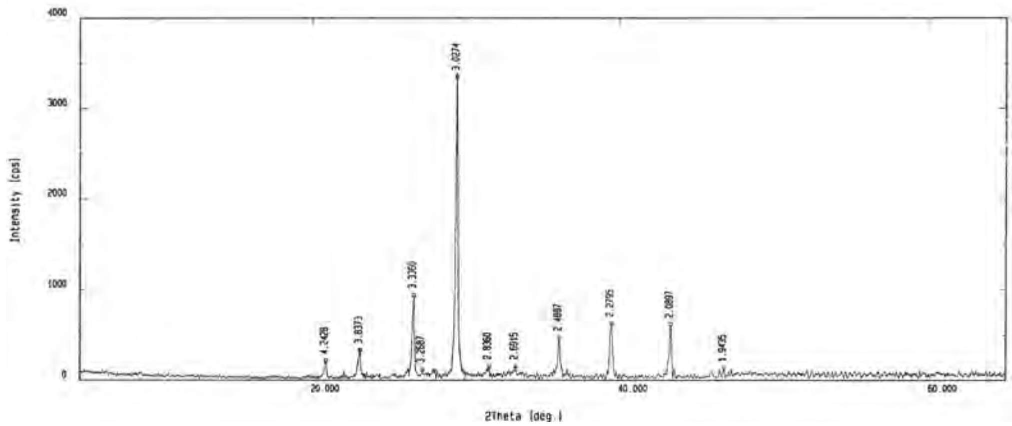


FIGURE 6 XRD analysis of *liaojiang* obtained from loess near the Dadiwan site (main components, calcite and quartz).

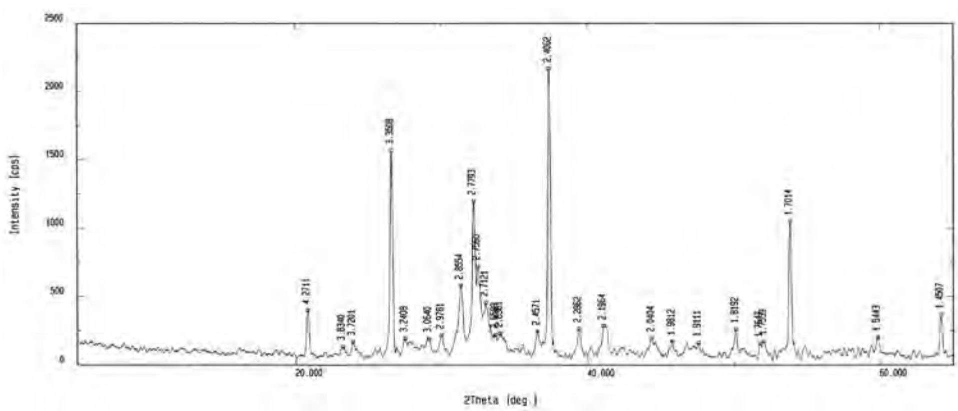


FIGURE 7 XRD analysis of *liaojiang* sample from the Dadiwan site after heating for twenty-four hours at 900°C.

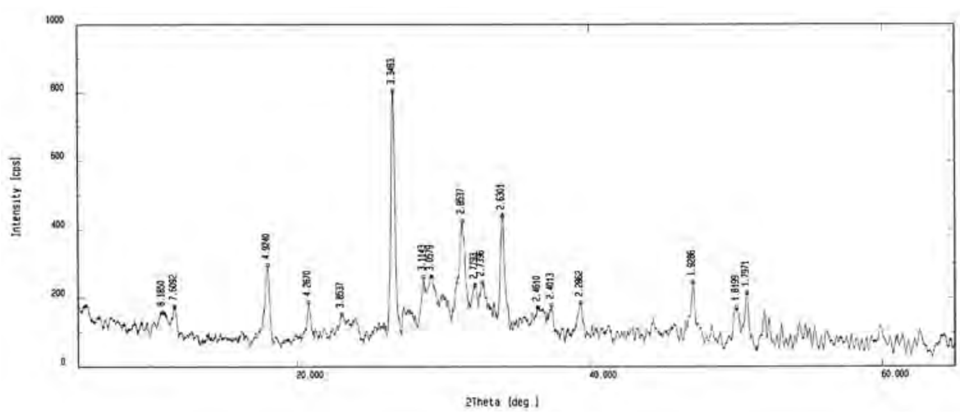


FIGURE 8 XRD analysis of Dadiwan *liaojiang* one month after hydration after heating at 900°C.

Table 4 Data Comparison of Figure 8 and Standard Materials in JCPDS[a] Files

Samples		$Ca_{1.5}SiO_{3.5}\cdot xH_2O$ (33-0306)		$Ca(OH)_2$ (4-0733)		$Ca_2Al_2SiO_7$ (35-0755)		$CaCO_3$ (5-0586)		CaO (43-1001)		SiO_2 (31-1233)	
dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0	dA°	I/I_0
8.1850	20												
7.6092	22												
4.9240	37			4.90	74								
4.2670	23											4.257	22
3.8537	19							3.86	12				
3.3483	100											3.342	100
3.1143	33			3.112	23								
3.0579	32	3.04	100			3.0629	21	3.035	100				
2.8537	53					2.8446	100	2.845	3				
2.7793	30	2.79	60							2.777	37		
2.7396	31												
2.6301	54			2.628	100								
2.4610	21			2.447 3								2.457	8
2.4013	22					2.3944	12			2.405	100		
2.2862	23					2.2869	11	2.285	18				
1.9286	30			1.927	42	1.9213	8	1.927	5				
1.8199	21	1.82	60									1.8179	14
1.7971	27			1.796	36								

a. International Centre for Diffraction Data.

Two or three days after hydration, a certain degree of cohesion is achieved. At later stages, $Ca(OH)_2$ absorbs CO_2 from the air and forms $CaCO_3$ and the hardness progresses:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

In this way, the mortar calcite becomes durable. Should it decay, the calcite ($CaCO_3$) formed still retains high cohesiveness. This is the reason the Dadiwan floor painting has survived for five thousand years.

Conclusion

Analysis of the formation and production mechanism of mortar from *liaojiang* nodules indicates that heat-treated *liaojiang* is an ideal substance for use as the support material in the restoration of mural paintings in humid environments.

Acknowledgments

The authors would like to thank Neville Agnew and David A. Scott of the Getty Conservation Institute (GCI) for supporting Ma Qinglin as a visiting scientist while he conducted this research at the GCI in 2001. We also extend thanks to Su Bomin of the Dunhuang Academy, David Carson of the GCI, and Han Jianqing, Tian Xiaolong, and Xu Rui of the Gansu Provincial Museum for samples analysis and preparation.

Notes

1 In 1996 the State Administration of Cultural Heritage presented the second Award for Progress in Science and Technology to Gansu Provincial Museum, the Coating Materials Institute of the Chemical Industry Ministry, and the Biology Department of Lanzhou University for their study of the conservation of wall paintings in humid environments—Dingjianzha No. 5 Tomb, Jiuquan, Gansu.

References

Asaga, K., M. Daimon, Li Zuixiong, and K. Yokozeki. 2000. Reproduction of ancient cementitious material used in China 5,000 years ago. In *Repair, Rehabilitation, and Maintenance of Concrete Structures, and Innovations in Design and Construction: Proceedings: Fourth International Conference, Seoul, Korea, 2000,* ed. V. M. Malhotra, 123–38. Special Publication no. 193. Farmington Hills, MI: American Concrete Institute.

Chen Ruiyun. 1993. Study of floor materials in the new Stone Age at the site of Dadiwan, Qinan county, Gansu province. *Gui suan yan xue bao = Journal of the Chinese Ceramic Society* 4: 309–18.

Lang Shude. 1999. [On-the-spot report of the finding and conservation of floor paintings of Dadiwan and F901 prehistoric palace]. In *Gansu wen wu gong zuo wu shi nian,* ed. Gansu Sheng (China), 254–64. Lanzhou: Gansu wen hua chu ban she.

Li Zuixiong. 1998. The oldest concrete in the world? Restudy of the architectural material of the Yangshao period in China. *Kao gu = Kaogu* 8: 751–57.

Ma Qinglin, Hu Zhide, and Li Zuixiong. 1996. [Research on microbe corrosion and harm to the pigments in wall paintings.] *Dunhuang Research* 49 (3): 136–44.

Ma Qinglin, and Li Xian. 1991. [Study of ancient ceramics in Gansu]. *Kao gu = Kaogu* 3: 263–72.

Schwartzbaum, P. M., I. Massari, G. Pignatelli, and C. Giantomassi. 1984. Approaches to the conservation of mural paintings in underground structures: Case studies of recent projects by ICCROM consultants and staff. In *International Symposium on the Conservation and Restoration of Cultural Property: Conservation and Restoration of Mural Paintings (I): November 17–21, 1983, Tokyo, Japan,* ed. Y. Emoto and S. Miura, 41–58. Tokyo: Organizing Committee of the International Symposium on the Conservation and Restoration of Cultural Property.

Yang Nanru. 1996. Physical-chemistry foundation of alkali-based cementitious materials 1. *Gui suan yan xue bao = Journal of the Chinese Ceramic Society* 2: 209–15.

Study and Conservation of the Dazhao Temple Wall Painting, Inner Mongolia

Du Xiaoli
Translated by Naomi Hellmann

Abstract: *In 1986 an important sixteenth- and seventeenth-century Mongolian Yellow Sect Buddhist wall painting was removed from the Dazhao Temple and taken to Hohhot Museum. Inadequate records, excessive cutting of the wall painting to carry out removal, and the use of epoxy created serious problems for its conservation. This paper describes the technical examination, treatment testing and implementation, and storage conditions of a segment of a wall painting from the monastery complex's Sutra Hall.*

The Dazhao Temple, located in the city of Hohhot in Inner Mongolia province, China, was the first Tibetan Yellow Sect Buddhist monastery built on the Mongolian grasslands. Among the structures of the complex, the Sutra Hall is a mixture of Chinese and Tibetan styles. The Tibetan Buddhist wall paintings in the hall are a valuable legacy of early Mongolian Yellow Sect Buddhist temple wall paintings from the sixteenth and seventeenth centuries.

In 1985, when the walls of the Sutra Hall underwent repair, the Department of Cultural Heritage removed 35 square meters, or one-half, of the lower wall painting from the east and west walls in an effort to salvage it. Today the wall painting is held in the Hohhot Museum.

FIGURE 1 Detail of the wall painting from the Dazhao Temple.

A History of the Removal and Treatment of the Dazhao Temple Wall Painting

Since the removal and relocation of the Dazhao Temple wall painting eighteen years ago, it has been affected by several factors related to the materials used for conservation, the conservation technique, its storage environment, its transport from the temple, and the exhibition method (figs. 1, 2). Its condition has deteriorated noticeably, requiring additional conservation measures. For this reason, preliminary research was undertaken on the history of the removal and treatment of the wall painting. However, the principal staff members involved in the undertaking at the time left the department years ago. Individuals were interviewed, and a basic account, given below, was pieced together based on their recollections, but specific details of the materials used, removal, and treatment method are unclear. Incomplete documentation of the removal and treatment of the wall painting has added to the difficulty of undertaking further treatment.

FIGURE 2 Detail of the wall painting from the Dazhao Temple.

FIGURE 3 Part of the wall painting during reconstruction.

Problems Resulting from the Method of Removal

Excessive Incisions. The 34.96-square-meter panel was sliced into 186 irregular pieces and reconstructed into 76 individual sections after treatment (fig. 3). There are twenty-eight areas of 0.67 square meter marred by cuts and twenty areas unmarred by cuts but with relatively large cracks. The remaining sections of the mural are divided into small individual pieces. For example; sections 11–13 titled "Main Buddha" (Huabian Zhuti Fo) (dimensions 2.30 by 1.99, approx. 4.6 m^2) were removed in 24 sections and reconstructed as three individual paintings after being treated. These three paintings can be put together to form a completed Buddha figure. The wall painting (fig. 4) was removed in a crude fashion concurrent with the repair of the walls. The section removed primarily depicts images of the Buddha and human figures. Only the Buddha and human figures were retained; the background, primarily depicting nature and living creatures, was abandoned.

Minimal Consideration for the Integrity and Aesthetic of the Painting. In removing and saving parts of the wall painting, consideration was given only to the size of the segment and its appearance as a whole; the integrity of the painting itself was ignored. A transverse cut, in sections 11–55, "Avalokitesvara" (Guanyin Pusa) (dimensions 0.64 by 1.04 m^2), cut the legs of the sitting Bodhisattva (Pusa) in two, severing the painting as a whole and diminishing its artistic beauty.

Problems Resulting from the Technique Used to Treat the Painting

Materials. Highly concentrated glue (a mixture of 2 parts hide glue and 1 part alum) was used to strengthen the surface of the painting, and there are visible traces of hardened glue on the parts that were painted white. The back of the painting was treated with epoxy resin as a strengthener. The 2- to 5-centimeter-thick layer of wall removed with the painting was stripped mechanically to a thickness of 1 to 1.7 centimeters. A mixture containing acetone (to dilute the epoxy resin), 5 percent di-n-butylphthalate (DBP) plasticizer, and 10 percent ethylenediamine (EDA) hardener was brushed onto the back surface and penetrated to a depth of 0.5 centimeter. After hardening, another relatively thick layer of epoxy resin was applied to the back, which was then covered in cloth fiber and set in a wood frame. Screws were fastened to the four corners of the mounted wood frame and the wall painting was hung on display.

Epoxy resin was widely used in cultural heritage conservation during the 1980s. At that time the materials and the approach adopted to remove and conserve the Dazhao Temple wall painting were considered relatively advanced. However, epoxy resin becomes extremely hard once it sets, which is incompatible with the strength, cohesiveness, and elasticity of the much weaker "canvas" underside. More than a decade later, the adverse side effects of epoxy resin gradually appeared, creating cracks, displacement, disfiguration,

FIGURE 4 Inappropriate cutting of the wall painting.

FIGURE 5 Adverse effects due to use of epoxy resin.

partial fragmentation, and other serious damage caused by the strength, age, and contamination of the substance (fig. 5).

Technique. After the Dazhao Temple wall painting was removed, not only were different concentrations of the epoxy resin mixture applied to the underside in varying degrees of thickness, but the mixture seeped *through* the cuts and cracks in the painting, penetrating its surface and causing the pigments to harden and become rigid, which is egregious. In the course of treating the painting, rivulets and droplets of the epoxy resin mixture stuck to the painting, damaging the surface and increasing the difficulty of adopting further conservation treatment.

Assessment and Materials Analysis of the Dazhao Temple Wall Painting

Damage Assessment

A history of previous treatment of the painting had to be established so as to discern the damage and interpret the traces of evidence in each segment before a diagnosis could be made and further treatment undertaken. Thirteen kinds of damage were identified (figs. 6, 7) based on a slightly revised version of a system of classification proposed by the Dunhuang Academy, since no international or national standard criteria measuring the condition of a wall painting existed.

The following procedure was used. Each section of the painting was photographed in black-and-white, enlarged to 20 by 30 centimeters, laminated, and annotated—for serious problems a 0.2-millimeter pen was used, and for other problems a 0.13-millimeter pen was used—by comparing the photograph with the corresponding section of the painting. Then each section was outlined. Areas of minute detail were enlarged with a magnifying glass to ensure accurate recording.

Materials Analysis

Pigments. In an analysis undertaken by the National Research Institute for Cultural Properties in Nara, Japan, the pigments were primarily identified as mineral in composition (Du Xiaofan and Takayasu 2000). The analysis revealed two important findings:

- Smalt. The blue glass specks observed in the wall painting are a type of imported cobalt smalt. This is the first use of smalt discovered in a wall painting, which is significant for documenting the source and origins of pigments used in the Dazhao Temple wall painting. Cobalt, potassium carbonate, and silica are components of smalt that create blue, azure, maroon, and wisteria purple colors.

Smalt goes by various names in Chinese (see Gao Lian [Qing dynasty, n.d.]; Song Yingxing [Ming dynasty, n.d.] 1959: chap. 7). An imported blue was used in China during the Yuan dynasty to create blue-and-white (Qinghua) porcelain. A bright sheen and vivid color owing to the lower amount of manganese in imported blue results in a visible luster. The cobalt in a fragment of blue-and-white Yuan dynasty porcelain excavated from the Jining Road archaeological site in 2002 and analyzed by the Inner Mongolian Institute of Archeology is a foreign product presumed to be smalt. It easily could have been introduced into China from central Asia via commercial exchange during the Yuan dynasty. Written documents note that this type of blue was imported from the present-day Arabian Peninsula. Seven or eight types of mainly African and Arabian pigments were among the variety of goods imported into China during the fifteenth and sixteenth centuries (Fei Xin 1928). Porcelain fired during the reigns of Yongle and Xuande (in the Ming period) in official kilns is still prized.

Pigment was transported inland from northwestern China through Turpan until 1596 C.E. (Shen Fuwei 1985: 309). Dazhao Temple was constructed in 1580 as a result of the Chabu Qiale Charter meeting led by Andahan (Altan Khan) and the Third Dalai Lama, in Sonam Gyatso province, Qinghai, which adopted Buddhism and abolished Shamanism (Shen Fuwei 1985). The Dazhao Temple wall paintings were directly influenced by the artistry of the Ta'er Temple wall paintings in Qinghai.

The meaning, style, composition, layout, and color used, especially the strong red and blue of the wall painting, are full of local flavor and characteristics. Smalt found in the Dazhao Temple wall paintings is therefore closely linked with Silk Road trade over the Mongolian grasslands and with the spread of Tibetan Buddhist culture.

- Color indicators. Markings with a special function were discovered in the pigment analysis undertaken by the National Research Institute for Cultural Properties in Nara (Du Xiaofan and Takayasu 2000). In creating a sketch, the artist would annotate the color with a corresponding symbol, using a specific character for each color.

  An infrared laser was used to examine a piece of 7- by 10-centimeter wall painting. It revealed two Chinese characters written in black ink underneath red and blue pigments (fig. 8). Another nine Chinese characters were discovered later during the project. Based on these studies, some characters were used to indicate color used for painting and some to mark the object to be painted. For instance, the Chinese character *gong* was marked for red pigment; the Chinese numerical character *one* was

FIGURE 6 Powdering and loss in the wall painting.

FIGURE 7 Flaking and paint loss.

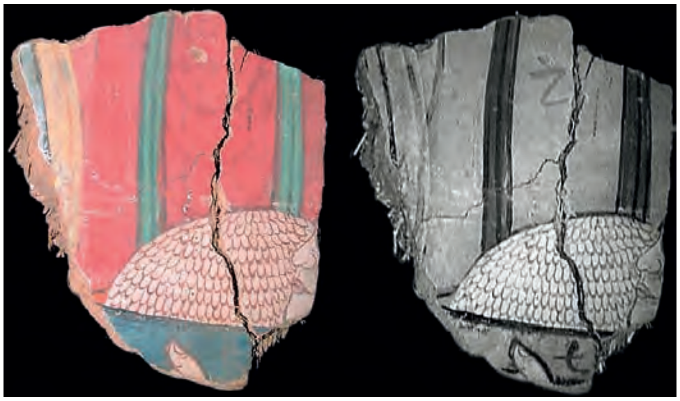


FIGURE 8 Infrared photography revealed Chinese characters specifying colors to be used (right-hand image).

marked for beige color; and the Chinese character *rice* was marked for painting grain.

According to Liu Lingcang,[1] a traditional Chinese wall painting was created in a three-step process. A charcoal sketch was outlined in ink, followed by a final indication of color for apprentices to follow. Master painters would outline in ink leaving an indication of the color. The following are examples of number characters and their color equivalent: *gong,* red; *yi,* off-white; *er,* light blue-gray; *san,* taupe; *si,* pink; *wu,* pale fuchsia; *liu,* green; *qi,* charcoal; *ba,* yellow; *jiu,* purple; and *shi,* black.

So far, all the characters discovered in the Dazhao Temple wall painting have matched up perfectly. The only exceptions are the two sashes, one uncolored and the other in green but both marked with a *liu*. It is apparent that the former was overlooked. The discovery of these characters supports previous literature describing master painters who created an ink outline using a numeric equivalent for the color to be applied by apprentices. It also explains the strong regional and ethnic character evident throughout the wall paintings, which were painted according to traditional technique but which also adopted the Mongolian and Tibetan approaches to using color.

Soil Analysis. The Dazhao Temple wall painting was painted on an earthen plaster of local origin. However, the surroundings of the temple have been changed. To learn the origin of the clay used for making plaster, three types of analyses were conducted on the original plaster and samples of local soil in order to distinguish between them and produce new plaster essentially identical to or closely resembling the wall painting's original one. Based on the pH and compositional analyses, the soil closest to the original was selected for making the new plaster.

Conservation Research

Testing to Strengthen the Surface of the Painting

Materials.

i. Solvent: distilled water
ii. Consolidating agent: gelatin, polyvinyl alcohol (PVA)
iii. Sample wall painting 1: 10 by 8.5 cm
Sample wall painting 2: 15.6 by 17.5 cm
iv. Concentrations: 0.5%, 1% 1.5%, 2%
Comparative consolidation experiments were made with the gelatin solution and PVA solution.

Procedure. Fragile areas were slowly infiltrated with the relatively weak solutions using the teat of an infant's pacifier. Following infiltration, the area was again treated, this time with a stronger solution. After saturation, a wood press and a roller were used to apply light pressure over a padding of paper-based restoration material. Finally, a metal press was used to flatten fine creases.

Results.

i. The gelatin resulted in gloss in certain areas, but dissolved easily, had good penetration, and was reversible. The pigment color was not affected.
ii. As a strong substance that hardened the layer of pigment, the poly(vinyl alcohol) solution was somewhat inferior. The color of the pigment was slightly affected: a change occurred that intensified with increased concentration; and the yellow areas faded visibly. Application was terminated.

Surface Sheen

Treating the surface with the gelatin solution produced a gloss in some areas, primarily on the white and gray and slightly on the red of the faces, hands, and sleeves of people and the clouds. The consolidant had less penetration on the smooth, nonpowdering area and nonflaking painted layer, and this resulted in surface sheen.

Remedial Measures.

i. Hot distilled water was used to clean glossy spots and reverse them to their original condition before they were treated with a dilute solution.
ii. Pigment not severely disintegrated was treated by repeated applications of a weak solution. This also prevented gloss.
iii. In areas of extreme disintegration, such as those with green and red pigments, a 2% gelatin solution was applied directly, regulating the surface area of each drop of solvent, controlling the time and amount of each interval, and carefully monitoring the penetration of the consolidant.

Surface Epoxy Resin Removal. The reagents ethanol and acetone were used. The surface of the painting was marred by dribbles and droplets of epoxy resin. A Q-tip with acetone or ethanol was gently rubbed to soften the epoxy resin. A scalpel was used to scrape away the white powder, stopping before touching the pigment. Acetone was originally used as a thinner for epoxy resin, and based on this, a slight difference was noted in the process of experimentation between the ability of acetone and ethanol to soften the resin. Acetone is slightly stronger than ethanol but leaves marks that must be treated. Neither reagent adversely affected the pigment layer. Parts of the wall painting marred by epoxy resin that penetrated the pigment layer will not be treated until the appropriate technique and materials are available.

Separating the Backing Layer of Epoxy Resin. Epoxy resin becomes extremely hard on setting, and no method currently exists to directly extract it when it has thoroughly infiltrated a porous material. A hand-operated saw was used to cut away the resin-infiltrated backing. The sliced areas typically measured 5 square centimeters. To separate the layer of epoxy resin from a segment of the wall painting only 1.59 square meters in size, the epoxy resin had to be cut into 592 pieces, which left a layer of plaster about 0.2 centimeter deep. Work was executed extremely slowly and precisely. The layer of plaster was undamaged and in present-day terms, the separation is considered a success.

Repairing Fractures in the Painting

The pieces of "canvas" plaster to be reassembled were V-shaped, inverted, and pieced together on a glass plate. The area was infused with drops of water, and rice paper was used to fill cracks. The plaster was then permeated with a 2 percent PVA solution used as a strengthening agent. Following treatment, the strengthened plaster was 1.5 to 2.0 centimeters thick.

Climate and Conditions of Storage and Restoration

Storage Climate

In Dazhao Temple, the wall painting was originally subject to significant climatic change and exposed to dust and soot. Later, in the museum, apart from periods when it was hung on display, it was always stored leaning against a wall, which exerted uneven pressure on the painting and resulted in cracking of the surface. Storage conditions have been improved: the wall painting now rests flat on a specially constructed frame, and a measure of climate control was installed in the room where it is kept. During the year, the humidity ranges between 63 and 33 percent relative humidity, and temperatures range from 25°C to −7°C. Appropriate ventilation is maintained in the summer to lower the temperature, and the humidity is adjusted during the dry months, fall and winter, increasing the air's moisture content. The painting is protected from sunlight and UV radiation. Additional improvements need to be made because northern China is subject to significant seasonal changes, with large drops in temperature at night.

Restoration Conditions

The conservation of the Dazhao Temple wall painting, which began at the Hohhot Museum in 2001 without funds, specialists, or equipment, is considered a first in Inner Mongolia. In 2002 the museum's meeting room was converted into a restoration space—a work platform, a setup for the painting, and restoration tools were constructed, and climate control was installed—but the primitive conditions still required constant maintenance and upgrading. The Hohhot Wall Painting Conservation Center, established in 2004, has since attracted seven specialized research technicians.

Based on the principles of applying as little treatment as possible and in sequence from smallest to largest size, conservation work on the Dazhao Temple wall painting sought to minimize the number of different materials used, to limit their strength, to heed their compatibility, to ensure their consistency and durability, and to regulate the work approach. Just as the work of others is critiqued, our work will also be critiqued, but conservation is hardly limited to one definitive approach. Thus it is important in practice to always be responsible, willing to learn, and innovative.

Acknowledgments

The author would like to thank the Conservation Institute of the Dunhuang Academy, the Center for Conservation at the China National Institute for Cultural Property, and the National Research Institute for Cultural Properties in Nara, Japan, for their joint support and assistance. The author would also like to thank Li Zuixiong, Masaaki Sawada, Du Xiaofan, and Koezuka Takayasu for their efforts in the pigment analysis of the Dazhao Temple wall painting; Fan Zaixuan and Chen Qing for conducting treatment and restoration tests; and the Dazhao Temple wall painting conservation project team.

Notes

1 Liu Lingchang (1907–89) was a Chinese Art Association member and a professor at the Central Art Institute. He published works on Tang dynasty portrait painting, Chinese polychrome portrait painting techniques, tools and materials for Chinese painting, and folk wall painting.

References

Du Xiaofan and K. Takayasu. 2000. Analysis of the Dazhao Temple wall painting at Hohhot Museum in Inner Mongolia Autonomous Region, China. Paper presented at the 18th General Conference of Japanese Cultural Properties, Nara, June.

Fei Xin. 1928. *Xing cha sheng lan.* Guangzhou: Guo li Zhongshan da xue yu yan li shi yan jiu suo.

Gao Lian. 1591. *Yan xian qing shang jian.* Zun sheng ba jian. [China]: Ya shang chai.

Shen Fuwei. 1985. *Zhong xi wen hua jiao liu shi.* Zhongguo wen hua shi cong shu (Shanghai, China). Shanghai: Shanghai ren min chu ban she: Xin hua dian Shanghai fa xing suo fa xing.

Song Yingxing. 1959. *Tian gong kai wu.* Zhongguo gu dai ke qi tu lu cong bian, no. 1. Shanghai: Zhonghua shu ju.

Pigment Analysis and Environmental Monitoring of Murals in the Tang Dynasty Huiling Mausoleum

Yang Mangmang and Zhang Yongjian

Abstract: *The Tang dynasty Huiling Mausoleum of Emperor Rang is located in Sanhe township, Pucheng county, in northwestern China's Shaanxi province. Rang had abdicated in favor of his brother, the emperor Xuanzong (r. 712–56). The tomb consists of a 19-meter-long inclined entrance shaft; seven vertical shafts; three compartments, each of which has two niches; a vaulted corridor that runs from under the third vertical shaft to the burial chamber; and the burial chamber. About 250 square meters of murals were discovered throughout the mausoleum.*

After the discovery of the first mural in 1999, scientific instruments were placed in the tomb to monitor temperature and humidity. Between March 2000 and January 2001 the mausoleum was excavated by a team from the Shaanxi Provincial Archaeology Research Institute. The principal excavation efforts were aimed at (1) monitoring relative humidity and temperature inside the tomb during excavation to provide a basis for the preservation and eventual removal, if necessary, of the wall paintings; (2) investigating the composition of the murals and the painting techniques used to create them to understand why some parts of the paintings were in good condition and others had deteriorated; and (3) sampling the murals for pigment analysis using X-ray fluorescence for comparison with other pigments used during the Tang dynasty.

The Tang dynasty Huiling Mausoleum of Emperor Rang (Hou Yangmin and Mu Weisheng 2000) is located in Sanhe township, Pucheng county, in northwestern China's Shaanxi province. Rang had abdicated in favor of his brother, the emperor Xuanzong, who reigned from 712 to 756.

Figure 1 shows the layout of the tomb, which is entered through a 19-meter-long inclined shaft. This passageway is decorated with wall paintings. There are also seven vertical shafts into the tomb. The tomb contains three compartments, each of which has two niches. A door sealed with bricks is located under the third vertical shaft, and a vaulted corridor runs from this door to the burial chamber. About 250 square meters of murals were discovered on the walls of the inclined entrance shaft, vertical shafts, compartments, corridor, and burial chamber.

In early October 1999 tomb robbers dug a hole, measuring about 0.7 meter in diameter and 9 meters deep, at the base of vertical shaft 6 near the burial chamber. After receiving a report of this, the Shaanxi Provincial Cultural Heritage Bureau asked the Provincial Archaeology Research Institute to take an inventory of the tomb and undertake remedial measures. Salvage excavation was conducted between March 2000 and January 2001. Scientific instruments were placed throughout the mausoleum to monitor temperature and humidity, and a simple bamboo and grass shelter was built above the tomb's entrance to reduce the potential for damage from wind, rain, and sun.

Since the founding of the People's Republic of China, about twenty tombs of princes, princesses, and royal families of the Tang dynasty have been excavated. However, this is the first emperor's tomb from the peak period of the Tang dynasty that has been excavated. Therefore, the style and layout of the tomb, burial objects, and subject of the wall paintings are highly significant and provide a great deal of information on the royal family's lifestyle and burial practices.

After completion of excavation, some of the wall paintings were detached and stored in the Shaanxi Provincial Archaeology Institute. The tomb is under the custodianship of the local government and will be used as a museum open to the general public.

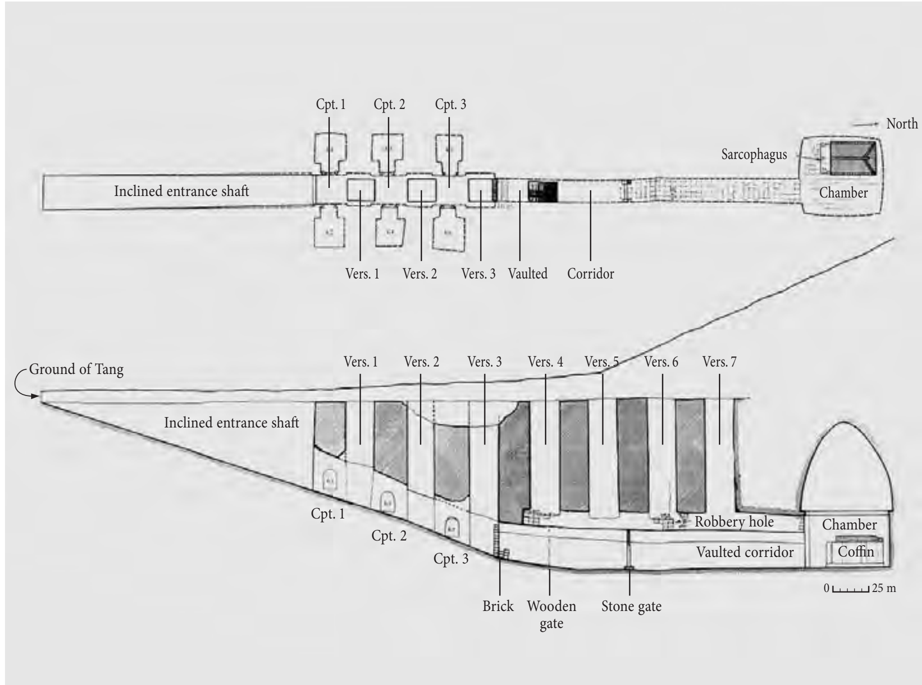


FIGURE 1 Plan view (top) and cross section (bottom) of the Huiling Mausoleum, tomb of the Tang dynasty emperor Rang. Between the entrance shaft and the vaulted corridor leading to the burial chamber there are seven vertical shafts (Vers. 1–7) and three compartments (Cpt. 1–3), each containing two niches (K1–K6).

State of Preservation of the Huiling Mausoleum Murals

The best-preserved murals are on the ceiling of the vaulted corridor, followed by those in the compartments, vertical shafts, and burial chamber. The worst-preserved murals are in the entrance shaft.

FIGURE 2 Murals on either side of a niche in the east wall of the first compartment in the Huiling Mausoleum.

Corridor Murals

The murals on the ceiling of the vaulted corridor are like new, consisting of a white plaster layer on which are painted small round yellow flowers and green leaves. A few small pieces of painted plaster had fallen from the murals, and an examination of these pieces revealed that the plaster was executed with a highly refined technique; this layer is hard and with an even thickness of between 0.6 and 0.7 centimeter.

Compartment Murals

Most of the paintings on the lower parts of the compartments are portraits and are well preserved (fig. 2), although a small area has been lost, perhaps damaged when the tomb was backfilled and sealed. The upper part of the wall paintings shows flaking, detachment, and disruption problems.

Vertical Shaft Murals

The wall paintings in the vertical shafts depict mainly human figures. Most have been relatively well preserved, with only a few areas of flaking, disruption, and detachment. However, paintings on the lower part of the shaft walls were damaged. When the tomb was sealed, backfill materials such as earth and fragments of bricks were dumped from the top of shafts, and this may have caused the damage. Figure 3 shows the painting on the west wall in the first vertical shaft.

FIGURE 3 Murals on the west wall of the first vertical shaft in the Huiling Mausoleum.

FIGURE 4 Murals on the east wall of the burial chamber in the Huiling Mausoleum.

Burial Chamber Murals

The ceiling bricks of the burial chamber are exposed, and ancient looters made a hole in the southwest corner of the ceiling. The emperor's sarcophagus was positioned in the northwest corner of the burial chamber and close to the walls, and for this reason no paintings are found on the west wall and the north wall, except for an area near the east wall.

The murals on the east wall are well preserved and depict stories from the emperor's life (fig. 4). The paintings are clear, intact, colorful, and beautiful. The plaster layer has some disruption and loss problems, and the lower part of the paintings is almost completely lost.

Entrance Shaft Murals

In this passageway a blue dragon is painted on the east wall and a white tiger on the west wall. In addition to blue and white, the colors used for these paintings include red, green, yellow, and black. The condition of the wall paintings in the entrance shaft is very poor, with disruption, detachment, and loss. The poor condition of these paintings is likely due to damage from backfill earth and brick fragments used when the tomb was intentionally sealed, as well as to the effects of farming and irrigation of the land over the shallowly buried passage. In addition, during excavation, exposure to wind and sunlight significantly affected the temperature and humidity of this part of the tomb.

Pigment Analysis

Table 1 shows the results of pigment analysis using X-ray fluorescence. The pigments used in the Huiling Mausoleum murals are the same as those normally used in Tang dynasty tombs (Zhang Qunxi 2001), grottoes, clay figures, and buildings. Because all the pigments are inorganic materials, the colors are stable.

Table 1 Results of Pigment Analysis with X-ray Fluorescence

Color	Red	Green	Black	Yellow	White
Sample Location	Neck of dragon on east wall of entrance shaft	Person's chest on north wall of burial chamber	Cloud under tiger on west wall of entrance shaft	Cloud under tiger on west wall of entrance shaft	Fallen fragment recovered from back-fill materials
Chemical Composition	HgS Vermilion	$Cu_2(OH)_2CO_3$ Malachite	PbS Lead sulfide	PbO Lead oxide	$Pb_3(CO_3)_2(OH)_2$ Lead white

Environmental Monitoring of the Huiling Mausoleum

Hair hygrographs and thermometers were placed at six locations throughout the mausoleum to monitor the humidity and temperature in the tomb during excavation. Data were collected hourly. Analysis of the monitoring data shows the following:

- The temperature inside the tomb in summer decreases gradually from the tomb entrance (40°C) to the lowest temperature in the corridor and burial chamber (about 13°C). The temperature inside the tomb in winter increases gradually from the tomb entrance (below 0°C) to the highest temperature in the corridor and burial chamber (about 13°C). The temperature in the corridor and the burial chamber is thus stable at 13°C year-round.
- Humidity inside the tomb also gradually increases from the entrance to the highest relative humidity at the burial chamber. Relative humidity in the corridor remains around 60 to 70 percent; inside the burial chamber, about 97 percent. Relative humidity in the entrance shaft, between the tomb entrance and the third compartment, is significantly influenced seasonally by outside conditions and by people walking in and out of the tomb. For instance, in this section relative humidity is higher in the summer and when it rains and lower in winter. Relative humidity varies between 60 and 97 percent.
- Temperature and relative humidity at the tomb entrance are significantly affected by outside conditions, which are both seasonal and diurnal. It will be a challenge to preserve the wall paintings under such a changeable environment.

Relationship of Environment to Mural Preservation

From the overall condition of the murals, it is apparent that an important relationship exists between the environment inside the Huiling Mausoleum and the state of preservation of the wall paintings. However, the typical relationship between environment and preservation does not hold for this tomb. Normally, lower temperature and higher humidity are considered safe for murals. If this were true in the Huiling Mausoleum, then the murals in the burial chamber would be the best preserved. This is not the case. This finding agrees with the view held by conservators at Dunhuang (Wang Jinyu 1996).

The problems seen in the wall paintings in the burial chamber might also be caused by two incidents. The first is the mechanical damage from the ancient tomb robbery; the second is rainwater, which has seeped through the ancient robbery hole, damaging the wall paintings. Several key factors explain the good preservation of the murals in the corridor:

- The murals were painted on the ceiling and were thus not affected by ground moisture.
- The backfill material was pure earth, with no brick fragments. The earth was carefully moved into the corridor and piled up manually from the inside, such that it did not cause damage to the wall painting.
- In the corridor, with only limited unfilled spaces, an oxygen-deficient environment was probably established over time, and the organic materials in the paint binding medium (and possibly the plaster too) may have survived better in the absence of an oxidizing microenvironment. The most important factor for the preservation of the murals in the corridor is its stable temperature (about 13°C) and humidity (60–70%).

As mentioned, the murals in the entrance shaft are poorly preserved, and this seems related to the type of burial fill (containing brick fragments) used. All the murals in the burial chamber have a common problem: their lower part is missing. This damage is mainly due to ground moisture.

Conclusion

Our analyses of the Huiling Mausoleum murals, along with the environmental monitoring, show that an internal temperature of about 10°C and relative humidity between 60 and 70 percent provide the best preservation environment. These results also suggest that spring and autumn are the best seasons to remove the murals, should this prove necessary.

References

Hou Yangmin and Mu Weisheng. 2000. Why was Li Xian called Emperor Rang? *Xi'an wan bao = Xi'an Evening News,* August 14.

Wang Jinyu. 1996. *Exploring the Secret of Dunhuang.* Chengdu Shi: Sichuan jiao yu chu ban she.

Zhang Qunxi. 2001. [Analysis and study on pigments of Tang tomb]. In *Tang mu bi hua yan jiu wen ji,* ed. Tianyou Zhou, Qinyan Shen, and Shanxi li shi bo wu guan, 411–19. Xi'an Shi: San qin chu ban she.

Indian Wall Paintings: Analysis of Materials and Techniques

Sekhar Chandra Set

Abstract: *In India the techniques and materials used to create wall paintings have their origins in rock paintings. This paper describes the ancient cave paintings at Ajanta, Bag, and Sittanavasal; the more recent village murals at Madhubani and wall paintings of fort palaces at Rajasthan; and the modern wall paintings found on buildings that later became Viswa Bharati University in Santiniketan. In the context of these examples, techniques and materials both in the ancient period and in the recent past are discussed.*

The principal historical source texts for Indian wall paintings date from the fifth to the sixteenth century. Although the painting methods prescribed in these texts vary, the following procedures are common to all of them: (a) preparing a fine ground for painting, (b) drawing an outline, (c) applying color with modulation, and (d) detailing. On the wall a ground consisting of two layers—rough plaster and fine plaster—is made. On the fine plaster, pigments with binding medium are applied. The description of the composition of rough plaster, pigment, and binder medium varies in the historical texts. It may be said that the texts present a reasonably accurate description of the actual painting process at some ancient Indian sites. However, a number of scholars have offered differing opinions about exact practices adopted in the ancient period. Recent wall paintings have been influenced by scientific developments. They are often painted on a surface of brick or reinforced concrete or chiseled stone tiles. Therefore, making the ground smooth by first applying a rough plaster is no longer necessary. Buon fresco *and* a secco *painting techniques have been adopted. Pigments are synthetic, and a protective coating of diluted polyvinyl acetate (PVAC) dissolved in tolune-acetone is applied to these paintings.*

The art of wall painting in India can be traced back to prehistoric times. The earliest examples of this art form can be found in caves in the hilly tracts of nine provinces of India. In particular, the Vindhya mountain range in central India provided an ideal site for prehistoric cave painting to flourish, for example, at Bhimbetka near Bhopal and at Gawalior and Adamgarh. The subject matter of these paintings included animals, birds, and human hunters, which were drawn in red ocher, with or without an outline, and painted directly on the plain rock wall. No ground was used.

Indian Wall Painting

Cave painting in India reached its height in the Buddhist religious art at the Ajanta caves, a UNESCO World Heritage Site in the state of Maharastra; in the Buddhist religious art at the Bag caves in Madhya Pradesh; and in the Jain religious art at the Sittanavasal caves in Tamil Nadu. In later periods, we find commendable development in the techniques and form of wall paintings in the fort palaces in the state of Rajasthan, in the modern building murals of Santiniketan in West Bengal, and in the mural paintings in Madhubani in Bihar. Figure 1 shows the location of these wall painting sites. This paper discusses these wall paintings to throw light on the various painting materials and techniques adopted in the Indian context.

Origin of Painting Techniques

Wall painting techniques had their origin in the so-called *Shilpa* texts, which deal with the forms of Indian art, methods of execution, and preservation. *Shilpa* texts include *Vishnu*

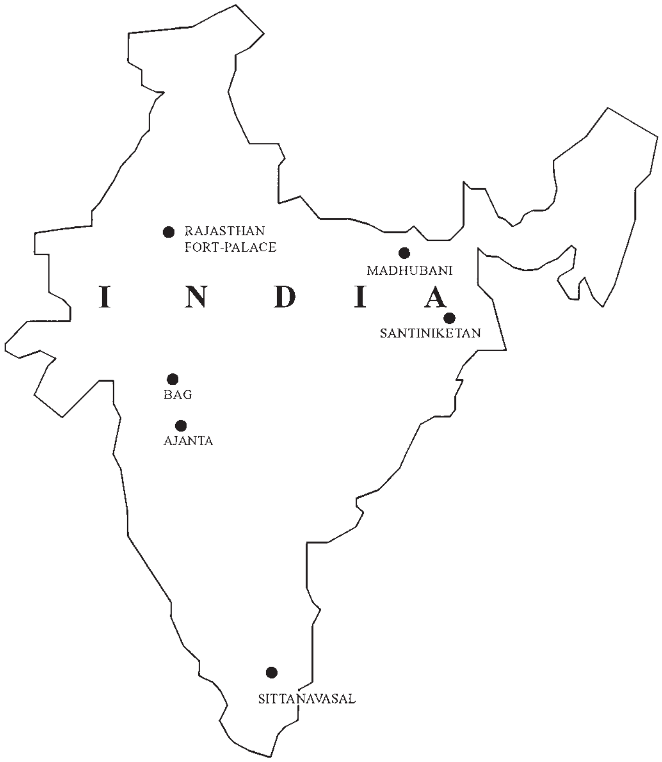


FIGURE 1 Wall painting sites in India.

Dharmottara Purana (fifth century C.E.), *Abhilashitartha Chintamani* (twelfth century), *Shilparatna* (sixteenth century), and other celebrated treatises on Indian art and related subjects. In his excellent treatise in French on the technique of Indian painting, Siri Gunasinghe (1957) dated the three texts. The question may arise about how the techniques employed in the ancient wall paintings of the Ajanta Caves (second century B.C.E.–sixth century C.E.) were inspired by *Shilpa* texts. In early times knowledge was handed down orally; it was codified in the form of *Shilpa* texts much later. Although the prescribed methods vary (variation having been advocated by the texts), the following procedures are common to all: (a) preparing a fine ground for painting, (b) drawing an outline, (c) applying color with modulation, and (d) detailing.

Components of Wall Paintings

There are five components of Indian wall paintings: carrier, ground, binder, pigments, and medium. The carrier is the support on which the ground is applied in preparation for painting. In a cave painting, the rock wall is the carrier. In fort palace (i.e., royal palace within fortifications) mural paintings, the masonry is the carrier, and so on. Let us examine what the *Shilpa* texts say about the other components.

Ground (rough and fine plaster layers). For rough plaster, the *Vishnu Dharmottara Purana* suggests the constitutents brick powder, clay, caustic lime, sesame oil, gum, and resin. The *Abhilashitartha Chintamani* advocates that rough plaster be made of a mixture of clay and animal glue. The *Shilparatna* prefers for rough plaster a mixture of limestone, shells, extracts from barks, curd, milk, and molasses. The ingredients for rough plaster were to be held together by organic materials such as gum, glue, and extracts from barks, which acted as an adhesive/binder.

The fine plaster, on which pigments are to be applied, required careful preparation. The *Vishnu Dharmottara Purana* suggests a mixture of clay, resin, and sesame oil. The *Abhilashitartha Chintamani* recommends a mixture of "naga" (most likely kaolin) and glue. The *Shilparatna* calls for a mixture of conch, oyster shells, or white clay with gum from the neem tree, or one of slaked lime and coconut water. Inorganic material such as lime or clay is the main ingredient of the fine plaster; the organic material is the adhesive/binder.

Binder. Organic material such as gum and glue extracts of bark as described above.

Pigments. The *Vishnu Dharmottara Purana* recommends pigments such as gold, silver, copper, brass, lead, tin (as leaves or as powder), mica, ivory, lac, vermilion, indigo, orpiment, and myrobalan (from the fruit of an Indian tree). The *Abhilashitartha Chintamani* prescribes conch, cinnabar, lac, red ocher, orpiment, lamp black, indigo, lapis lazuli, and gold powder. The *Shilparatna* advocates yellow ocher, orpiment, red ocher, red lead, lamp black, gold, and lac.

Medium. The *Vishnu Dharmottara Purana* and *Shilparatna* suggest that pigments be mixed with a gum solution. The *Abhilashitartha Chintamani* advocates an animal glue solution for mixing pigments.

Adherence to the *Shilpa* Texts

Let us see the extent to which the *Shilpa* texts were followed in the categories of wall paintings under discussion here.

Ajanta, Bag, and Sittanavasal Cave Paintings

The noted archaeological chemist Paramasivan analyzed samples taken from inconspicuous corners of the cave

Table 1 Wall Paintings in the Ajanta Caves (2nd century B.C.E. to 6th century C.E.)

Technique	Tempera
Carrier	Basalt cave wall
Rough Plaster	Ferruginous earth mixed with sand and organic fibers
Fine Ground	White layer of lime, kaolin, or gypsum
Pigments	White from lime, red from red ocher, yellow from yellow ocher, green from terre verte, black from lamp black
Medium	Gum or animal glue

Source: Paramasivan 1939: 25–30.

Table 2 Wall Paintings in the Bag Caves (early 7th century C.E.)

Technique	Tempera
Carrier	Wall of lime and sand composition
Rough Plaster	Red ferruginous earth
Fine Ground	Lime layer
Pigments	Yellow from yellow ocher, red from red ocher, green from terre verte, black from carbon black, white from lime, blue from lapis lazuli
Medium	Gum or animal glue

Source: Paramasivan 1939: 85–95.

paintings at the Ajanta, Bag, and Sittanavasal sites to investigate the painting techniques. He examined cross sections of the samples to determine such characteristics as particle sizes, diffusion of materials from one layer to another, and presence of fibers. He identified the composition of the binding media and pigments through chemical analysis. On completion of his investigations, Paramasivan concluded that although the techniques enumerated in the ancient *Shilpa* texts were at variance with his scientific studies of surviving paintings, the "*Abhilasitartha Chintamoni* is a fair reflection of the actual painting process in some Indian sites" (Paramasivan 1940: 95).

Paramasivan's findings for the Ajanta caves are summarized in table 1, and an example of these paintings is shown in figure 2. The painting characteristics for the Bag caves are presented in table 2, and a sample is shown in figure 3. Since the pigments used in the Ajanta and Bag wall paintings contain an organic binding medium, the painting technique is tempera (pigments dispersed in a water-miscible vehicle) and not *buon fresco* (painting on wet lime plaster) or *a secco* (painting on dried lime plaster).

Table 3 summarizes Paramasivan's findings for the Sittanavasal cave, with a sample of the artwork shown in figure 4. The Sittanavasal paintings are *a secco,* since the pig-

FIGURE 2 Nymph from a fifth-century wall painting at Ajanta (cave 17), Maharastra.

FIGURE 3 Bodhisattva from an early-seventh-century wall painting at Bag (cave 4), Madhya Pradesh.

FIGURE 4 Lotus lake from an early-ninth-century wall painting in the Sittanavasal cave temple, Tamil Nadu.

Table 3 Wall Paintings in the Sittanavasal Cave (8th to 9th century c.e.)

Technique	*Fresco secco*
Carrier	Rough stone
Rough Plaster	Lime and sand with minor impurities, thickness 2.5 mm
Fine Ground	Lime wash (0.5 mm thick) applied while rough plaster was still wet
Pigments	White from lime, black from wood charcoal or lamp black, yellow from yellow ocher, red from red ocher, blue from ultramarine/lapis lazuli, green from terre verte
Medium	Lime water

Source: Paramasivan 1939: 82–89.

Table 4 Rajasthan Fort Palace Painting: Bikaner Fort, Jodhpur Fort, Udaypur Fort, Amber Fort (Jaipur) (12th to mid-19th century c.e.)

Technique	Rajasthan *fresco buono*
Carrier	Stone/brick wall
Rough Plaster	Lime and sand (sand added to prevent formation of cracks due to shrinkage of lime while drying)
Fine Ground	Two layers of fine plaster
Pigments	Red from cinnabar/red lead/red ocher, yellow from yellow ocher, blue from ultramarine, green from a mixture of blue and yellow/terre verte, brown from Indian red, white from lime, black from carbon
Medium	None

Source: Agarawala 1977: 66–70.

ments were applied with lime water (lime painting on dry plaster). The lime water reacted with oxygen in the air and through carbonation was chemically converted into calcium carbonate, which is insoluble in water. The calcium carbonate enveloped the pigments and set them with the ground. No adhesive glue or gum was applied.

Rajasthan Fort Palace Painting

The wall painting technique used in the Rajasthan fort palaces is a type of *buon fresco* for which pigments are made to sink into wet lime plaster through the manual process of beating, burnishing, and polishing, which adds extra luster to the frescoes in Rajasthan. In addition, chemical carbonation acts to consolidate the pigments. The Rajasthan *buon fresco* technique is similar in all fort palace paintings. Figure 5 from the Amber Fort Palace (Jaipur) is representative of Rajasthan fort palace painting. Agarawala (1977: 60) wrote that the "Ajanta and Bag cave paintings are famous throughout the world and we are justly proud of this glorious tradition." Table 4 summarizes the characteristics of Rajasthan fort palace wall painting.

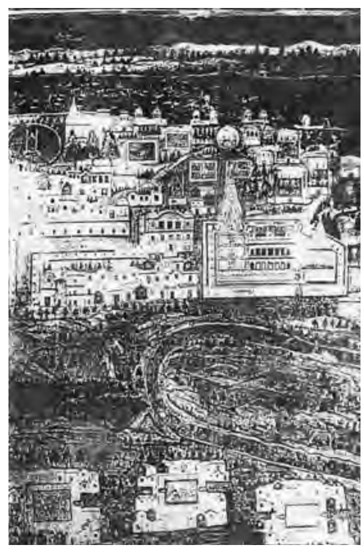


FIGURE 5 The holy city of Brindaban from an early-nineteenth-century wall painting at Amber Fort Palace, Jaipur, Rajasthan.

Santiniketan Mural Paintings

Modern wall paintings adorn the buildings at Santiniketan, which later became the Viswa Bharati University. Figures 6 and 7 show examples of this artwork.

In his foreword to *The Santiniketan Murals* (Chakrabarti, Siva Kumar, and Nag 1995), K. G. Subramanyan writes:

> Not so long ago a young British art critic visited Santiniketan after seeing a few black & white photographs of paintings of Benodebehari Mukherjee and Rabindranath Tagore. He found it a rewarding visit, not because everything in Santiniketan pleased him or conformed to his mental picture of the place, but because he found there what he called a living gallery of the early stages of modern Indian art. . . . When Patrick Geddes, the well-known town planner and environmentalist, visited Santiniketan at Rabindranath's invitation in 1922, he asked Nandalal [artist Nandalal Bose] why he had not thought of covering many of the bare walls of the building with murals. . . . Nandalal never forgot this advice—he refers to it two decades later in his little book 'Shilpa Katha.' One really needed very little to express

FIGURE 6 Birth of the prophet Chaitanya, depicted in a 1933 building mural in Santiniketan, West Bengal.

FIGURE 7 Medieval saints, depicted in a 1947 building mural in Santiniketan, West Bengal.

> oneself or to alter an environment. Our villagers transformed their mud huts quite radically with linear graffiti on floors and walls, using plain red and white earth, turning these modest habitations into something memorable.

In Santiniketan murals we find that the artists used the time-honored media of *buon fresco* and *a secco* on lime-surfaced walls. They also used the techniques of working on mud plaster to create wall paintings. Table 5 summarizes the characteristics of a Santiniketan mural depicting the birth of Chaitanya (a fifteenth-century prophet) painted by Nandalal Bose with the help of an elderly craftsman from Jaipur, named Narsingh Lal, and Nandalal's students (fig. 6). Table 6 summarizes the characteristics of a Santiniketan mural depicting medieval saints painted by Benodebehari (fig. 7). Bose used the Rajasthan *buon fresco* technique, and Benodebehari used Italian *buon fresco.*[1]

Madhubani Mural Paintings

This category of wall paintings is found today in village dwellings in the Madhubani district of the state of Bihar. Villagers in Madhubani have used the tempera technique for their murals, known for their exquisite simplicity and brightness (fig. 8). These murals are traditionally painted by women. Within a broad common art form, variation occurs

Table 5 Santiniketan Mural Painting by Nandalal Bose (early 20th century C.E.)

Technique	Rajasthan *fresco buono*
Carrier	Brick wall superstructure done in a mortar of lime brick dust
Rough Plaster	Lime and plaster
Fine Ground	Fine plaster
Pigments	Earth color of various shades like yellow ocher, red ocher, lime for white, lamp black, etc.
Medium	None

Source: Chakrabarti, Sivakumar, and Nag 1995: 1–3, 20.

Table 6 Santiniketan Mural Painting by Benodebehari (early 20th century C.E.)

Technique	Italian *fresco buono*
Carrier	Brick wall superstructure done in a mortar of lime brick dust
Rough Plaster	Lime and plaster
Fine Ground	Fine lime plaster covered with a thin coat of slaked lime
Pigments	Earth color of various shades, like yellow ocher, red ocher, lime for white, lamp black, etc.
Medium	None

Source: Chakrabarti, Sivakumar, and Nag 1995: 1–3, 27.

FIGURE 8 Krishna, depicted in a present-day village mural from Madhubani, Bihar.

in the treatment of details according to the caste of the artist. The murals are painted with bamboo twigs and rags during observance of religious and social rituals. The origin of this ritualistic domestic wall painting, which is still practiced, can be traced back to the thirteenth century, during the reign of the Hindu king Ramasinghadeva. Thakur (1981: 62) writes, "In fact Madhubani painting is a way of painting rather than a set of pictures." Table 7 summarizes the characteristics of Madhubani mural paintings.

Discussion

The historical source texts for Indian wall paintings present a reasonably accurate description of the actual painting process found at some ancient Indian sites. However, a number of scholars have offered differing opinions about the exact techniques adopted in the ancient period; perhaps some of them commented before actually investigating the sites.

E. B. Havell, superintendent of the Calcutta Art School in the early 1900s, referred to Sir John Marshal, director-general of the Archeological Survey of India during the same period, as saying that the Ajanta and Bag cave paintings are "tempera paintings, not *fresco buono*" (Havell 1928: 8). Havell maintains, "There cannot be any doubt, however, that the true fresco process has been practiced in India for many centuries. It was used by Akbar's painters in the decoration of Fatehpur Sikri."

Abanindranath Tagore, an eminent Indian painter of the late nineteenth century, was engaged by Havell to paint a fresco panel at the Calcutta School of Art. Havell referred to M. Victor Goloubeff, who had begun a long-awaited photographic survey of Ajanta in 1911, as saying that "the paintings are true frescoes, though some of them have been finished or retouched by a process analogous to tempera" (8). He also referred to Vincent Smith, a historian and Indian civil servant in 1871, as saying that the Ajanta-Bag painting school is "a local development of the cosmopolitan art of the contemporary Roman Empire" (8). But he declined to accept Smith's views.

Recent wall paintings tend to use synthetic pigments and the tempera technique. It is less time-consuming to work with this medium and technique, and consequently the painting takes less time to execute. *Buon fresco* and *a secco* are seldom found. Recent wall paintings are laid on the surface of brick, reinforced concrete, or chiseled stone tiles. Normally, the carrier is given two coats of plaster of paris, and when the final coat dries, the drawing scheme is stenciled or copied onto the wall with red or black crayon, after which a wide range of oil-based chemical colors are applied with a brush. On the painting, a protective coating of diluted polyvinyl acetate (PVAC) in toluene-acetone is applied.

Table 7 Madhubani Mural Painting (present day)

Technique	Tempera
Carrier	Clay wall of cottages with bamboo reinforcements. Walls are about 0.5 m thick and are made of clay mixed with straw and paddy (rice) husk.
Rough Plaster	First coat of paddy husk, second coat of clay with cow dung and molasses
Fine Ground	Fine clay with lime
Pigments	Earth colors of various shades, like red ocher, yellow ocher, indigo, Indian red, charcoal for black, lime for white, burnt barley seeds for black, lamp soot for black, yellow from turmeric, yellow from lime mixed with banyan leaf milk, orange from flower, green from leaves, black from burning straw mixed with goat milk, white from powdered rice mixed with water.
Medium	Vegetable gum or glue

Source: Thakur 1981: 63–64.

Acknowledgments

I wish to acknowledge Rabindranath Poyra, superintendent of Library Services, Central Library of Calcutta University at Calcutta, for his help in locating old journals; and Satyabrata Ghoshal, librarian of Rabindra Bharati University at Calcutta, for permitting me to conduct literature surveys there.

Notes

1 In Italian *buon fresco,* pigments are diluted in water and brushed on the wet ground of fine lime plaster, which absorbs the colors. When the lime plaster dries, calcium carbonate forms on the outer surface, enveloping the pigments and protecting them from weathering. With this technique, the colors are thin and transparent. In Rajasthan *buon fresco,* pigments are brushed on the ground and made to sink into the fine lime plaster through the manual process of beating, burnishing, and polishing. With this technique, the colors are thick and opaque. The burnishing and polishing give them extra luster.

References

Agarawala, R. A. 1977. *Marwar Murals.* Delhi: Agam Prakashan.

Chakrabarti, J., R. Sivakumar, and A. K. Nag. 1995. *The Santiniketan Murals.* Calcutta: Seagull Books.

Gunasinghe, S. 1957. *La technique de la peinture indienne d'après les textes du silpa.* Paris: Presses Universitaires de France.

Havell, E. B. 1928. Indian mural painting. In *Indian Sculpture and Painting Illustrated by Typical Masterpieces, with an Explanation of Their Motives and Ideals,* 2nd ed., 155–82. London: J. Murray.

Paramasivan, S. 1939a. The mural paintings in the cave temple at Sittannavasal: An investigation into the method. *Technical Studies in the Field of the Fine Arts* 8 (1): 82–89.

———. 1939b. Technique of the painting process in the cave temples of Ajanta. *Annual Report of the Archaeological Department of His Exalted Highness the Nizam's Dominions* (1936–37): 25–30.

———. 1939c. The wall paintings in the Bagh caves: An investigation into their methods. *Proceedings of the Indian Academy of Science, Section A* 10 (2): 85–95. www.ias.ac.in/j_archive/proca/10/vol10contents.html.

———. 1940. Indian wall paintings. *Journal of the Madras University* 12 (1): 95–128.

Thakur, U. 1981. *Madhubani Painting.* Delhi: Abhinav Publications.

Conservation of Mural Paintings Transferred from a Royal Mausoleum of the Western Han Dynasty at Shiyuan, Henan Province

Tie Fude

Abstract: *Most transferred wall paintings have shown damage. The structure of wall paintings is complicated, and the causes of damage are many and varied. So far we have not achieved a good understanding of the causes of deterioration or had examples of successful treatment. This study analyzes an early Western Han dynasty wall painting and makes a preliminary attempt to understand the causes. It investigates the materials, types of damages, preservation environment, and previous conservation treatments of the wall painting and aims to develop proper techniques and materials for preserving them. The mural painting under consideration, which depicts four deities (Blue Dragon, White Tiger, Scarlet Bird, and Black Turtle) among clouds, was found in a tomb in the mausoleum of a king of the Liang Kingdom of the early Western Han dynasty (second century B.C.E.), located at Shiyuan in Mangdang Mountain in Henan province. In 1992 it was lifted and transferred onto a poly board strengthened with cotton fiber. In 1999 deformation, warping, and cracking appeared on the surface of the painting. A conservation project was undertaken.*

Damage to a wall painting usually comes from the very act of its transfer, due to the materials of the painting itself and their incompatibility with protective materials and to an unfavorable environment. The wall painting Four Deities (5.14 by 3.27 meters) is a quintessential example. It was transferred from a tomb in the mausoleum compound of a king of the Liang Kingdom during the early Western Han dynasty (second century B.C.E.) that is located at Shiyuan, Henan province. The painting depicts deities such as Blue Dragon, White Tiger, Scarlet Bird, and Black Turtle, as well as magical herbs and flying clouds (fig. 1). This study analyzes the materials of the painting, the types of damage, the environment in which the painting is preserved, and the history of treatment. The goal was to find out the causes of the damage, in the hope of finding the proper techniques, materials, and methods for its long-term protection.

Background of and Damage to the Wall Painting

History of Interventions

Water accumulation in the tomb in which the Four Deities was originally found caused high humidity. An investigation prior to the removal of the wall painting indicated a temperature of 16°C and a relative humidity of 96 to 99 percent. The painting itself had a moisture content of 3.2 to 3.5 percent, sometimes as high as 14.8 percent. Because of these unfavorable conditions inside the tomb, the painting was removed in 1992. X-ray diffraction (XRD) analysis in the same year showed that the plaster layer was made of mixed clay and sand with a high content of calcium carbonate but without any fiber. The pigments are vermilion, mica, and malachite. Before the removal process, polyvinyl

FIGURE 1 The Four Deities wall painting.

acetate (PVAc) emulsion was used to reinforce the flaking fragments. The painting was cut into five pieces (3.27 by 1.13 meters), and the surface was reinforced with 5 percent polyvinyl butyral (PVB) solution, gauze, and glue. The cut segments were secured onto an epoxy backing strengthened with cotton gauze and the backing fixed onto a wooden frame (Chen Jinliang 2001: 317–25).

Exhibition Environment

The wall painting was displayed in the Henan Province Museum in 1998. The room temperature and humidity were 21 ± 3°C and 60 ± 5% relative humidity in summer and 23 ± 3°C and 33 ± 5% relative humidity in winter. The painting was displayed in an unsealed glass-fronted wooden case lit by lamps totaling 240 watts. The temperature inside the case was stable, but the relative humidity varied seasonally, from 26 to 65 percent.

Types of Damage

The painting was deformed and cracked and the paint layer warped. Fissures occurred in the upper left and bottom right corners. The painting surface also bent following the distortion of the wooden frame. The wooden frame and epoxy backing were severely deformed. In addition, the securing fixtures had started to loosen.

Materials and Structure of the Wall Painting

Analysis of the material and structure of a painting plays a vital role in preserving and restoring it. Samples from the painting were analyzed using SEM-EDX (Hitachi S3000N) and XRD (Rigaku Dmax/2200). The main constituents of the plaster are calcium carbonate and silica; the original reinforcing agent had not penetrated deep into the plaster, which resulted in accumulation of polyvinyl butyral on the surface (fig. 2); the polyvinyl acetate coating on the back of the painting is generally even, although the porosity is greater in some areas; the cotton fiber in the epoxy backing is not evenly distributed, although the epoxy itself is stable and well bound to the plaster layer; pores in the epoxy, which result from the evaporation of the solvent in the epoxy (fig. 3), are concentrated on the surface where the backing meets the plaster. In cross section the plaster layer is one-half the total thickness (5 mm). These data help us not only to understand the causes of the deteriorations but also to provide the foundation for the search for the right materials to use in restoring it.

3D Laser Digital Analysis of the Wall Painting

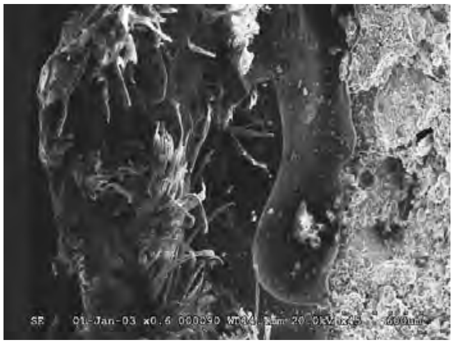
Preliminary investigations showed that the major types of damage to the wall painting were deformation caused by warping, cracking, and scaling. Because the surface of the painting had already distorted, conventional two-dimensional recording methods were not applicable (Schmid 2000: 21–28). With a 3D Minolta VIVID900 laser scanner, we documented the deformation of the painting and formulated a 3D model. The whole painting was scanned 88 times line by line horizontally and vertically, and nine key points were scanned 36 times. The scanning results were processed using the Polyworks software made by InnovMetric from Canada.

Figures 4 through 6 present the scanning results. This qualitative and quantitative mapping, recording, and analysis documents the condition of the painting and thus provides a database for future restoration work.

Mechanical Study of Deformation

Study of the deformation of the wall painting began with an analysis of the characteristics of the materials and their implications. In the past decades little research, either

FIGURE 2 Electronic SEM image of PVB.



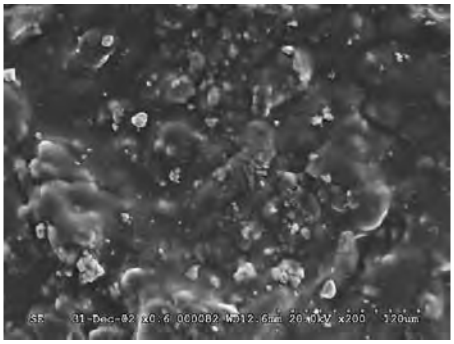


FIGURE 3 Electronic SEM image of pores in epoxy.

FIGURE 4 Deformation.

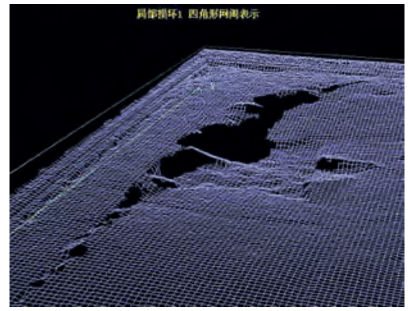


FIGURE 5 Net imaging of hole 1.

domestic or international, has been done on the materials of the backing of wall paintings, and even less research has been done on the supporting frame (Hedley 1975: 1–17; Berger 1984: 7–9; Colville, Kilpatrick, and Mecklenburg 1982: 165–70; Karpowicz 1989: 67–74). Our study is a preliminary effort in this direction. Starting with a scientific analysis of the original and present conditions of the wall painting and its materials, we analyzed the deformation using the Ansys Software in the hope of determining the causes.

Based on the original and preservation materials mentioned above and their thickness, we established a model of the materials of the painting layer, as follows:

> When the heat factor is considered, the relationship between the stress and the change caused by the stress is $[\boldsymbol{\varepsilon}_L]^{[h]} = [\mathbf{s}][\boldsymbol{\sigma}_L] + [\boldsymbol{\alpha}_L]\ \varDelta \mathbf{T}$ **(algorithm 1);**
>
> When the humidity factor is considered, the relationship between the stress and the change caused by the stress is $[\boldsymbol{\varepsilon}_L]^{[m]} = [\mathbf{s}][\boldsymbol{\sigma}_L] + [\boldsymbol{\alpha}_L]\ \varDelta \mathbf{M}$ **(algorithm 2);**
>
> When the heat and humidity and exterior load are combined, the algorithm becomes

$$\begin{Bmatrix} \varepsilon_L \\ \varepsilon_T \\ \gamma_{LT} \end{Bmatrix} - \begin{Bmatrix} S_{11} & S_{12} & 0 & \sigma_L \\ S_{21} & S_{22} & 0 & \sigma_T \\ 0 & 0 & S_{66} & L_T \end{Bmatrix} + \begin{Bmatrix} \alpha_L \\ \alpha_T \\ 0 \end{Bmatrix} \varDelta \mathbf{T} + \begin{Bmatrix} \beta_L \\ \beta_T \\ 0 \end{Bmatrix} \varDelta \mathbf{M}\ \textbf{(algorithm 3)}$$

Using Ansys Software and algorithm 3 and the aforementioned data, we calculated the bending of the wall painting. The result is that the maximum displacement of the 300-millimeter-long wooden frame is 9 millimeters; when all the factors are considered, the maximum displacement along the lines where the wall painting was cut is 15 millimeters, and the minimum displacement is 3 millimeters. This result is in general agreement with the measurements taken from the wall painting itself. The result of the calculation is shown in figure 7.

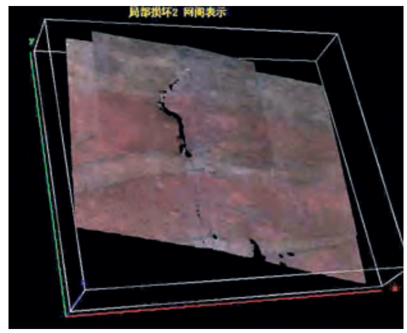


FIGURE 6 3D image of a crack.

The Ansys analysis indicates that the causes for the bending of the wall painting are as follows: (a) the materials of the painting layer and the backing are not evenly distributed and the humidity-caused swelling produces bulging in some areas of the painting layer; (b) the setting of the epoxy binding the wooden frame and the backing caused the frame to bend backward; (c) because of the epoxy layer, the front and back sides of the wooden frame expanded unevenly, which also contributed to its bending; (d) the unstable humidity of

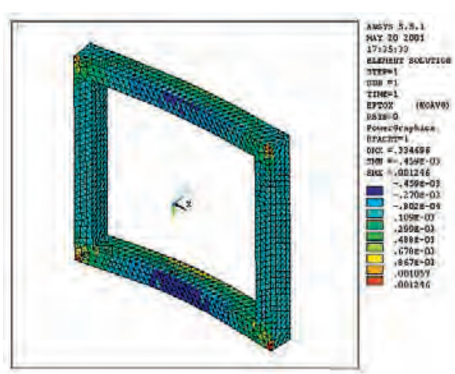


FIGURE 7 Calculated stress distribution over the frame.

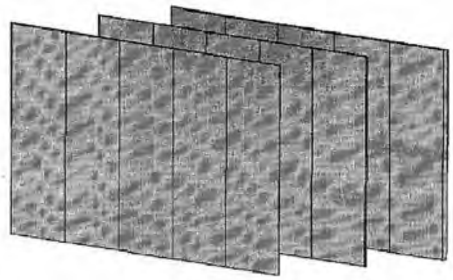


FIGURE 8 The restored frame. From left to right: painting, elastic layer, porous aluminum.

the environment in which the painting was stored gave rise to its deformation.

It follows that the wooden frame that caused the deformation of the painting needed to be removed and replaced with light and rigid materials. We chose a honeycomb aluminum board as frame and added an elastic layer to absorb remaining stress from the epoxy layer, as shown schematically in figure 8.

Preservation and Restoration of the Wall Painting

Surface Reinforcing Materials

The PVB material used for reinforcement during the transfer process was still in good condition. For the sake of consistency and compatibility, we continued to use PVB to preserve the surface of the wall painting. We used PVAc emulsion to reinforce the flaking areas. Where the plaster layer was lost, we injected a mixture of polyvinyl acohol (PVA) emulsion to stabilize the warped painting layer.

Coating

Through experiments and simulations we chose 2 percent PVA solution in water as the adhesive and two layers of Chinese rice paper (*xuanzhi*) as the coating. This choice was made in consideration of the minimum interference principle on the one hand and of the epoxy resin on the back of the painting on the other. In addition, the rice paper is easy to remove after the final treatment.

Removal of the Wooden Frame and the Epoxy Layer

After testing, we chose to use a thread saw (conventionally used in surgery) to detach the deformed wooden frame, because it causes the least impact to the painting. Sawing was conducted 2 millimeters from the back of the epoxy layer, and the remaining wood was removed manually using a carving tool. Epoxy ridges were removed by means of an electric drill.

Intermediate Layer

An intermediate layer between the backing of the painting and the honeycomb aluminum was necessary to facilitate any future restoration. This layer, if made of elastic material, helps to relieve or eliminate stress from the epoxy layer. After many experiments and evaluations, a material designated by the manufacturer QH-B6 was chosen for the intermediate layer, since it has a stress resistance of 1 megapascal (MPa) and an elasticity of about 75 percent. The mini-pores in this material are all closed and even in diameter and thickness of wall, forming a net structure. The evenness of the microscopic elements increases the stability and resistance to stress and impact.

Removable Supports

The wall painting is 17 square meters in dimension and 3.24 meters in height, which demands rigidity of the frame materials. The honeycomb aluminum panel is used in China's aviation industry and has the strength and stiffness to satisfy these requirements.

Adhesive

The adhesive used in the restoration of the painting must have good adhesion and binding to the epoxy and the aluminum. To absorb the stress from the two layers, the adhesive must have a high degree of elasticity and resiliency. During operations, we found that it took an individual segment at least one hour for the adhesive to set. Since it was difficult to secure the position of the three layers, the primary adhesive force had to have sufficient strength; the adhesive also needed sufficient solid content so as to prevent voids on setting. Based on these requirements, we tested a polyurethane adhesive, a chlorobutyl adhesive, and an acrylic acid adhesive. We found that the polyurethane adhesive, with its tensile strength of 0.5 to 0.7 MPa, was the best for the purpose.

Static Mechanical Property of the Support System

The painting layer (including plaster) is 4 millimeters thick; the epoxy layer is 1 millimeter thick, and the weight of the two layers is 12 kilograms per square meter. This weight exerts a shear force of 0.32 kilopascal (kPa) to the materials of

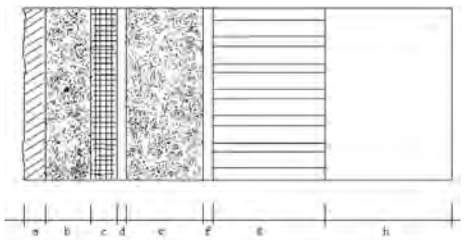


FIGURE 9 Section view of the wall painting after restoration: (a) pigment; (b) plaster; (c) epoxy; (d) adhesive; (e) intermediate layer; (f) adhesive; (g) honeycomb aluminum panel; (h) hard backing frame.

the layer underneath. The remaining stress from the back of the epoxy layer is no more than 12 kilograms per square meter of the painting layer, or 0.118 kPa (1 kg/cm^2 = 98.1 kPa). When the painting is placed vertically during exhibition, the painting and backing layers are static, without any exterior force. What they receive is the cutting shear (0.32 kPa) coming from the weight of these layers and the remaining stress of the epoxy. Both force and stress are much lower than the weight that the backing materials can hold.

Mechanical Distribution after Restoration

The wall painting after restoration is shown schematically in figure 9. The mechanical distribution of the whole is

$$\begin{aligned}\text{Stress load 0.5 kPa} &< \text{Adhesive 0.5 MPa}\\ &< \text{Intermediate layer 1 MPa}\\ &< \text{Porous aluminum 3 MPa}\\ &< \text{Aluminum frame}\end{aligned}$$

and the strength increases gradually from the painting layer toward the frame. This mechanical structure stabilizes the wall painting.

Conclusion

Based on a preliminary analysis of the causes of deterioration of the painting and the techniques and materials, we carried out a series of restoration operations, including removal of the original supporting frame and replacement with a new frame. The project was approved by the China National Cultural Heritage Bureau in 2003 and was awarded a second-grade prize for scientific innovation by the bureau.

References

Berger, G. A. 1984. The new stress tests on canvas paintings and some of their implications on the preservation of paintings. In *Preprints: ICOM Committee for Conservation, 7th Triennial Meeting, Copenhagen, 10–14 September 1984,* ed. D. de Froment, 84.2.7–84.2.9. Paris: International Council of Museums in association with the J. Paul Getty Trust.

Chen Jinliang. 2001. [Report on removing the wall painting from a Han tomb at Shiyuan]. In *Mangdang Shan Xi Han Liang wang mu di = Prince of the State of Liang's Mausoleums of the Western Han at Mount Mangdang,* ed. Yan Genqi, 317–25. Beijing: Wen wu shu ban she.

Colville, J., W. Kilpatrick, and M. M. Mecklenburg. 1982. A finite element analysis of multi-layered orthotropic membranes with application to oil paintings on fabric. In *Science and Technology in the Service of Conservation: Preprints of the Contributions to the Washington Congress, 3–9 September 1982,* ed. G. Thomson and N. S. Brommelle, 146–50. London: International Institute for Conservation of Historic and Artistic Works.

Hedley, G. A. 1975. Some empirical determinations of the strain distribution in stretched canvases. In *Preprints: ICOM Committee for Conservation, 4th Triennial Meeting, Venice, 13–16 October 1975,* 75114-1 to 75114-17. Paris: International Council of Museums.

Karpowicz, A. 1989. In-plane deformation of films of size on paintings in the plass transition region. *Studies in Conservation* 34 (2): 67–74.

Schmid, W. 2000. *GraDoc: Graphic Documentation System in Mural Painting Conservation: Research Seminar, Rome, 16–20 November 1999.* Rome: ICCROM.