陕西师范大学历史文化遗产保护教育部工程研究中心
历史文化遗产保护科学研究系列丛书
咸阳博物馆合作出版

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李玉虎 编著

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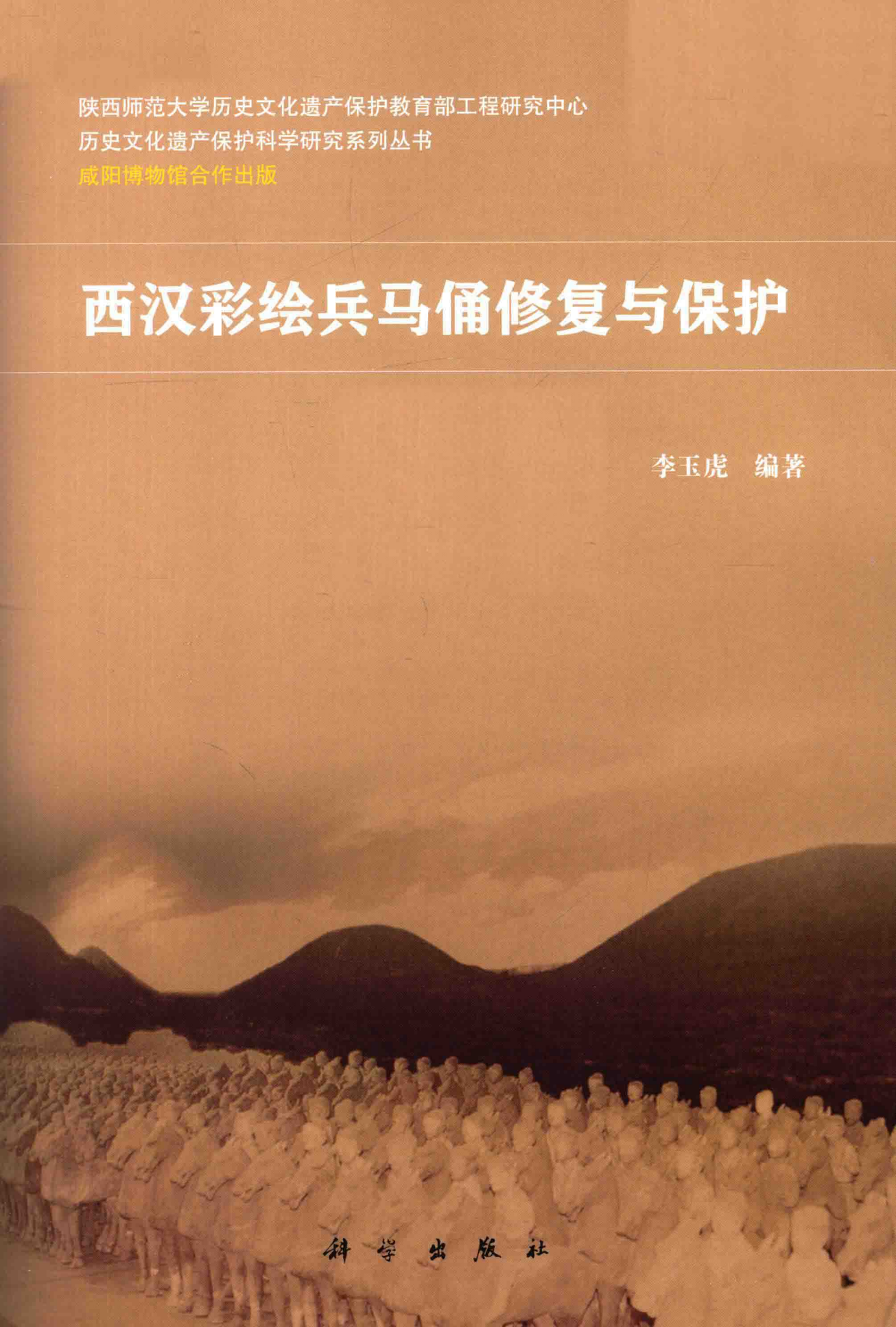

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内 容 简 介

本书是一本陶质文物彩绘修复保护专著，也是一项历时17年研究的课题。该书共包含七个方面：第一，病害成因与机理研究；第二，病害治理机理分析；第三，修复材料筛选与性能表征，对回位修复剂进行筛选以及对附着力、柔韧性的测试；第四，加速老化系统评价，包含高温高湿与低温冷冻交替、盐雾、氧化、光老化等各项进行分析测试；第五，修复工艺实践研究。如对龟裂、起翘、脱落、酥粉彩绘层的回位修复等；第六，治理效果对比，对修复前后的详细记录摄影；第七，跟踪观察档案记录。

本书适宜从事文物保护、科技考古、考古学等相关专业的研究人员及高校相关专业师生阅读、参考。

图书在版编目（CIP）数据

西汉彩绘兵马俑修复与保护 / 李玉虎编著. —北京：科学出版社，2013.12

（陕西师范大学历史文化遗产保护教育部工程研究中心历史文化遗产保护科学研究系列丛书）

ISBN 978-7-03-039402-6

Ⅰ. ①西… Ⅱ. ①李… Ⅲ. ①陶俑－器物修复－研究－中国－西汉时代②陶俑－文物保护－研究－中国－西汉时代 Ⅳ. K878.94

中国版本图书馆CIP数据核字（2013）第306754号

责任编辑：孙 莉 樊 鑫 责任校对：邹慧卿

责任印制：赵德静 版式设计：金舵手

科学出版社 出版

北京东黄城根北街16号

邮政编码：100717

http：//www.sciencep.com

文物出版社印刷厂 印刷

科学出版社发行 各地新华书店经销

*

2013年12月第 一 版 开本：787×1092 1/16

2013年12月第一次印刷 印张：10

字数：197 000

定价：168.00元

（如有印装质量问题，我社负责调换）

本书由陕西省文物局文物保护
专项资金支持出版

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序

陶质彩绘保护修复是文物保护领域的热点课题。硅酸盐陶质文物性质与彩绘层存在差异，使彩绘层的病害更为严重，相当部分已濒临自毁。彩绘的病害有龟裂、起翘、脱落、酥粉、风化褪色等，病因很复杂。有些彩陶埋藏于地下高湿缺氧的环境中上千年，出土后因环境骤变导致褪色、龟裂起翘、脱落；有些彩陶的彩绘层与陶胎中含有盐分，出土后反复溶解析出导致酥粉；也有不少彩陶长期处于不良保存环境中导致病害。这些病害多为交叉并发。保护修复研究涉及颜料与胶结物的组成与结构、颜料胶料层与陶胎表面的微观状况、盐害与颜料胶料层的作用机理等复杂情况，抢救修复难度很大。以前由于缺乏这方面的可靠性研究成果，使得许多承载有重要文化信息的彩绘永远消失，非常可惜。

近年来，我国文物保护领域在陶质彩绘文物抢救修复研究方向上取得了一批突破性的科研成果。成功抢救了一批珍贵的陶质彩绘文物。陕西师范大学历史文化遗产保护教育部工程研究中心承担的“风化褪色、龟裂起翘、胶体断裂的西汉彩绘兵马俑抢救修复”项目，就是其中的代表。

咸阳博物馆陈列展出的西汉彩绘兵马俑，是20世纪60年代我国首次发现的大型彩陶兵马俑军阵。彩绘出土时鲜艳、完整。步兵俑的服饰艳丽，盔甲鲜明，战马咆哮嘶鸣，形神兼备，是研究西汉军事、经济、民族和服饰、发饰的宝贵资料。这批兵马俑数量很多，出土后置于一般室内环境中，至今已五十余年，具有典型的多种严重病害特征，受到国内外文物保护领域的高度关注。

从2008年开始，我先后对该批兵马俑彩陶的修复保护情况进行过三次考察。项目负责人李玉虎同志向我作过多次汇报。今年4月应邀参加了国家文物局委托陕西省文物局对该项目的验收。我认为该项目取得的保护修复成果突出。它包括对风化褪色的兵马俑彩绘进行显色加固，对龟裂、起翘、脱落的彩绘层进行回贴修复，对酥粉彩绘层进行固化修复，对断裂的陶俑和陶马肢体进行粘接修复四项内容。

此项保护修复研究成果，具有以下三个特点：

一、系统、科学地研究病害成因、机理以及治理对策

治理文物病害，必须首先研究其产生的原因。该项目从文物出土前后文物环境的巨大反差入手，研究了导致其风化褪色、起翘、脱落的成因。以风化褪色为例，课题组研究了风化褪色兵马俑颜料、胶料层的微观状况与光学特性，发现存在一种微米级的“空气、空隙—粒子、间隔”界面，形成对光的散射现象，使其原貌模糊不清。彩陶出土前处于高湿缺氧的稳定环境两千余年，出土后环境温湿度显著变化，在较短时间内胶质发生收缩龟裂，连结相由水与润湿膨胀胶组成的混合体变为空气和游离粉化后的颗粒，破坏了出土前颜料胶料层对可见光的吸收与反射特性，导致其原貌严重褪色，从光学、环境学以及风化等角度诠释了陶质彩绘模糊不清的机理。

课题组为了长效保护与显现陶质彩绘的原貌，在高分子加固材料中加入适量非挥发性液态稳定剂，组成显现加固剂。稳定剂既能促进高分子加固材料的稳定性，长效保护其原貌，又能填充“空气、空隙—粒子、间隔”的界面，消除光散射现象，使用物理方法显现其原貌，具有创新性。

二、分析测试翔实、可信

为了进行加速老化系统的评价，需要制作模拟样品，它必须与兵马俑颜料胶料层的特性接近。但是，这批西汉彩绘兵马俑颜料胶料层中的胶结物历经两千余年已降解殆尽，用红外光谱等有机分析方法已不可能测出。为确定胶结物的种类，课题组以动物胶与植物胶在元素组成上含氮量的显著差异为突破口，用光电子能谱进行了比对测试，基本上确定了这批兵马俑颜料层的胶结物为动物胶。根据对比结果，课题组采用明胶与已检测证实的矿物颜料配制形成了颜料胶结层，进行老化试验。参照行业的标准，进行了柔韧性与附着力测试。通过研究分析，初步建立了对陶质彩绘颜料胶料层的系统评价体系，这同样具有创新性。显现出的色彩是否与陶质彩绘的原貌相近，是项目的关键，课题组联合中国科学院专业光学研究单位，以光谱特性曲线为客观判断标准，进行为期五年的跟踪测试，与原有色彩相比，走势非常接近，说明很有说服力。

三、进行了十五年的跟踪观察，证明自然环境时效考验的可靠性

课题组遵循文物保护修复的原则，经模拟样品试验与加速老化系统评价、保护修

复精细工艺实践等前期研究，在此基础上循序渐进地进行局部小面积修复加固，经过数年自然环境时效考验与跟踪观察证实有效后，才进行整体实施。其中有两例文物自1996年显现加固，一直跟踪观察至今，十五年来未发现变化。项目建立了完善的跟踪观察档案。这十五年的自然环境时效考验说明，是修复材料与文物本体的平衡由短期表观稳定向内在稳定的自然过渡，是与模拟老化试验评价的互相印证。这是对文物很负责任的做法，这种科学认真的精神，值得肯定与推广。

尚需注意的是，这批兵马俑相当一部分彩绘出现的酥粉现象，课题组对其成因研究分析发现是盐害所致，由于盐类的腐蚀作用，不仅彩绘，有些陶胎也明显呈酥粉现象。如何在保持原有历史痕迹不受损伤的情况下，脱去盐分并固化，保持珍贵的文物原貌，难度很大，希望继续攻关研究。

我与玉虎同志相识已有二十余年，为他锲而不舍、勇于实践、开拓创新的精神所感动。尤其在各级领导、同行的大力支持下，至今已经拥有一支多专业、中青年结合的理想团队，多个实用的实验室和试验场，从室内试验向现场试验、成品推广扩展。许多发明、专利的成果不仅应用于档案、文物保护领域，还延伸到影像资料——老化电影胶片的保护修复，并已见成效。尽管已经获得很多的荣誉和嘉奖，但他仍能谦虚、谨慎地听取不同的意见，在创新、探索的同时，不断完善改进现有的成果。祝愿他与其团队，百尺竿头，更进一步。

黄宏忠

2011年岁末于北京

Foreword

Conservation and restoration of ceramic colored drawing is a hot topic in the field of heritage conservation. The difference in nature between colored drawing layer and silicate ceramics makes the damage of the colored drawing easy. A considerable part of the painted layers borders on self-destruction. There are many diseases occurred to the colored drawing layers such as chapping, warping, shedding, crisp powder, being weathering and fading, and the causes of these diseases were complicated. It is an important factor to cause these diseases that underground colored potteries located in the humid hypoxic environment for thousands of years suddenly expose to air. Some soluble salts existed in painted layer and pottery body repeatedly dissolve and precipitate, which results in powderization of painted layer after the pottery being excavated. There are many colored potteries damaged by storage in poor preservation environment for a long time. Usually, the diseases mentioned above simultaneously happened. Conservation and restoration are complicated due to involving many factors such as composition of the pigments and binder, the micro-structure of painted layer and surface of pottery body, and action mechanism of salts and painted layer, etc. Thus the rescue and restoration of colored pottery is a tough problem. Due to lack of reliable method, much important cultural information on painted layer disappeared forever, it is exceedingly painful.

In recent years, a number of groundbreaking achievements in heritage conservation field for rescue and restoration of colored pottery relics are made in China. The project, "Rescue and Restoration of Weathered, Faded, and Cracking Terra-Cotta Warriors and Horses of the Western Han Dynasty" accomplished by the Engineering Research Center of Cultural Heritage

Conservation of Ministry of Education of Shaanxi Normal University, is a typical example.

The Color-Painted Terra-Cotta Warriors and Horses of the Western Han Dynasty exhibited in Xianyang Museum were the first large-scale pottery military array found in 1960s. At that time, the unearthed colored drawings were bright and complete. The costumes of infantry figurines with distinctive armor were colorful; the Terra-Cotta Horses were vivid. These colored potteries are valuable resource to investigate the military, economy, ethnicity, clothing and hair accessories of the Western Han Dynasty. However, these unearthed terracotta warriors and horses have been displayed in a common indoor environment for more than 50 years, resulting in serious diseases. This issue excited great attention in heritage conservation fields home and abroad.

From 2008, I have inspected the project for three times. Mr. Li Yuhu reported the project to me for many times. This year, I was invited by the State Administration of Cultural Heritage and the Cultural Relics Bureau of Shaanxi Province to evaluate and accept the project. This project included faded painting visualization, reinforcement of weathered potteries, restoration of painting layers with shedding and crack, restoration and reinforcement of the powdered painting layers, and cementation of broken potteries. In my opinion, achievement of this project is outstanding with three features as below.

(1) Systematical and scientific investigations in mechanism on formation of the diseases and coping strategy

To deal with the cultural relic diseases, one must firstly study its causes. From the dramatic difference in environment conditions between before and after unearthing cultural relics, some mechanisms on the disease formation such as shedding, weathering and fading were revealed. Taking weathered and faded relics as an example, the research group studied the relation between the surface microstructure of faded potteries and optical properties, and proposed that there

are lots of micron sized interfaces composed of air, gap, particle and interval in the surface of faded potteries, and micron sized interfaces cause light scattering to result in original color blurring.

Unearthed colored potteries located in higher humid and hypoxia environment for more than two thousand years. After being excavated, the potteries are exposed to lower humid environment, and thus they experienced a dramatic change in temperature and humidity. As a result, glue in painting layer has to shrink in a short time, and then cracks, and water in painting layer is replaced by air. Finally, optical characteristics of visible light absorption and reflection changes obviously to result in serious fading. The mechanism in terms of optics, environmentology and weathering is satisfactorily revealed the faded cause.

In order to enhance durability of the restored faded potteries, the research group added appropriate amount of non-volatile liquid stabilizer to the polymer reinforcement materials, which not only promote the stability of the polymer reinforcement materials but also eliminate the scattering interfaces. It is innovative to develop blurred color potteries by physical method.

(2) Accuracy and creditableness in analysis

To ensure creditableness of aging test, the proximity in components of painting layer between simulated sample and restored sample should be considered. However, the painting layer on the potteries made in the Western Han Dynasty have been degraded and exhausted after two thousand years, thus identification of glue used in the potteries is difficult. Based on the main component in animal glue being protein but that in vegetable glue being carbohydrate, the research group easily identified the glue used in the potteries by determining nitrogen element using XPS. Employing this method, the binder used in the terra-cotta warriors and horses is animal glue. According to this result, the simulated samples were prepared, and aging test of the corresponding

samples was carried out. Additionally, the tests of flexibility and adhesive force were conducted in the light of the industrial standard, and the basic evaluation system of painting layer on potteries was established. This investigated protocol also contains innovativeness. In this project, it is a key problem whether the color developed by the proposed method is similar to the original painted pottery. Spectroscopy determinations by Xi'an Institute of Optics and Precision Mechanics of CAS indicated that the spectral characteristics of the restored potteries are not only stable in five years but also similar to that of original potteries. The method used in this project contains innovativeness

(3) The reliability supported on the following observation in natural environment for 15 years

In light of the principles of conservation and restoration of cultural relics, and based on the simulated and accelerated aging test, as well as following observation to the preliminary local experiment for several years, the overall proposal was proposed, and the project was carried out. Two cases about the restoration and reinforcement of faded painted potteries made in 1996 have been observed for 15 years, indicating that the restored potteries unchanged. The excellent results were mutually corroborated by the aging test in the extreme conditions and the performance in natural environment. The methodology and attitude in this project, being responsible for cultural heritage, is worthy to be praised.

It is worthy of note that tackling serious powdering disease of painted potteries is a challenge subject. The research group found that the salt corrosion is the key factor in formation of the powdering disease due to the salt corrosion occurred both in painting layer and pottery body. It is difficult to remove salts and reinforce without obvious damage to the original potteries in tackling serious powdering disease. It is still needed to pay attention to this issue.

I have got acquainted with Mr. Li Yuhu for more than 20 years. I am touched by his perseverance, pioneering and innovative spirits. Under his guidance and supports

by administrative departments, the professional and vigorous team has been found, and the professional laboratories, instruments and test fields have been constructed. The investigation fields have been expanded from the archives protection to the conservation of cultural heritage relics, as well as photographic film. Although he has received many honors and awards, he is still modest, and can listen to different views so that he improves and perfects his results. I wish him and his team every success in the future.

Huang Kezhong

December, 2011

绪言

1965年8月，咸阳杨家湾发现一批阵容庞大的西汉彩绘兵马俑，这是我国首次发现的大型汉代彩绘兵马俑集群。经抢救性发掘后清理出步兵俑1965件、骑马俑583件、盾牌1170件，共计“三千人马”有余，在当时的学术界引起了很大的轰动，成为我国20世纪60年代考古界的重大发现。

该批兵马俑采用模塑窑烧的方法制作而成，本身造型生动、内涵丰富，加以彩绘后其艺术特征更加突出。时光流转荏苒千年，出土时兵俑衣饰鲜艳、图形分明：兵俑衣饰多为内衣、襦衣，白色居多，也有少数为大红、黄色等；部分外衣上披甲，甲衣分长、短两类，其上多用红色或白色细笔勾勒出鱼鳞形、方形、长方形甲片；长甲有披膊，前蔽裆胯后掩臀部，短甲无披膊，以带背挂两肩，内外层次分明。战马有大小之分，或咆哮嘶鸣、或昂首挺立，皆色彩明丽、形神兼备：大骑马俑毛色有黑、红、紫三种，骑士及马俑体格壮硕。马身彩绘络头、胸带、腿带、马镳、马鞒、辔头、节约和杏叶等，骑俑着红、白、绿、紫等服饰，有的还披黑色铠甲；小骑马俑毛色有黑、红、紫、白四种，骑士及马俑体格轻巧。此外出土的还有多种陶盾牌，按底色分为白、红、黑三种类型，盾牌脊部凸起外折，左右两面有的素面，有的彩绘有三角形、横向菱形图案，使这些模拟防御类兵器的盾牌凸显了几分威严与厚重。该批兵马俑整体来看井然有序、气势威武，细赏之下形态各异、特征分明，极富感染力。由此可见，杨家湾西汉彩绘兵马俑不但完整保存了前人的陶烧艺术精华，更是给后人呈现了一场辉煌的艺术盛宴，而彩绘赋予该批兵马俑的独特风貌与文物价值，更

是其他同时代出土文物所不具备的。

值得注意的是，该批兵马俑将步兵俑与骑马俑分别编列、独自成阵，合起来又浑然一体，成为有机配合的军制体系，观之令人震撼。除此之外还有其他形态特殊的兵俑，或指挥、或立射、或仪仗、或簿书，象征着仪仗、书记、指挥等不同的职能。这种编排形式是汉代军队的缩影，透过这些兵马俑可以基本了解汉代军队的编制、队形的编列，它是研究西汉军事制度、服饰制度、雕塑艺术的珍贵资料。近年来杨家湾西汉彩绘兵马俑已然蜚声海内外，享有“中国古代雕塑艺术杰作”的美誉。

自出土后半个世纪，杨家湾西汉彩绘兵马俑便置于一般室内环境中，与出土前的环境形成巨大差别，在本身病害不断加重之外还逐渐滋生了其他多种病害，受到国内外文物保护学界的高度关注。“风化褪色、肢体断裂的西汉彩绘兵马俑的抢救修复”是国家文物局批准实施的全国重点文物抢救修复项目，从立项至今已历时十七年。1995 年，项目组首先在模拟样品上进行加速老化系统评价。1996 年分别在一例消失殆尽的盾牌和一例步兵俑发髻上进行显现加固，清晰显现出了出土时的原貌。遵循文物不可再生的特点，对显现加固的原貌跟踪观察至今，十六年未发生变化。2000 年，项目组在对风化褪色和肢体断裂两种病害成因与机理进行诊断分析与研究的基础上，设计了“风化褪色、肢体断裂的西汉彩绘兵马俑抢救修复”方案。2003 年，咸阳博物馆、咸阳市文物局、陕西省文物局依照国家文物局对“风化褪色的古代壁画、文物彩绘、建筑彩画的显现加固”项目的鉴定结论，并根据 1996 年显现加固的两例彩绘文物七年稳定保持的跟踪观察情况，将方案上报国家文物局。2004 年获国家文物局批准，遵照国家文物局批复意见精神，对严重风化褪色的彩绘陶俑、陶马进行了显现加固。对肢体断裂、残破的陶俑、陶马进行了粘接修复。跟踪观察至今，保持稳定。

在对该批彩绘兵马俑的病害进行全面详细调研后发现，除风化褪色、肢体断裂和残破之外，相当部分彩绘层发生了起翘、脱落、龟裂和盐害酥粉两种病害，随着时间的推移，日趋严重，相当部分已完全自毁，使珍贵的原始信息永远消失。2005 年起进行了“龟裂、起翘、脱落的陶质彩绘层的回

位修复”、“酥粉彩绘层的固化修复”两项课题的研究。研究分析了龟裂、起翘、脱落和酥粉的成因，研制了龟裂、起翘、脱落彩绘层回位修复剂。研究实践了回位修复工艺；研制了酥粉彩绘层固化修复剂，研究实践了固化修复工艺。2005年，在进行模拟样品加速老化系统评价的基础上，对部分严重龟裂、起翘、脱落和酥粉彩绘层进行了回位和固化修复，跟踪观察至今，保持稳定。

《西汉彩绘兵马俑修复与保护》是在对上述抢救修复进展、科学研究、自然环境时效考验跟踪观察结果等方面进行总结的基础上整理而得的。按照科学研究与工程应用分类，则分为七个方面。第一，病害成因与机理研究。如在研究彩绘风化褪色的成因时发现，由于出土前后环境的巨大反差，使彩绘层联结相由水与润湿膨胀胶组成的混合体变为游离粉化后的颜料颗粒与空气组成的“空气、空隙—粒子、间隔”界面，对光产生散射现象，使其原貌模糊不清。第二，病害治理机理分析。如以非挥发性液态稳定剂结合，构建对风化褪色的彩绘同步进行稳定材料加固与物理显现的机制。第三，修复材料筛选与性能表征。如回位修复剂筛选时，附着力、柔韧性的测试。第四，加速老化系统评价，如高温高湿与低温冷冻交替、盐雾、氧化、光老化等。第五，修复工艺实践研究。如对龟裂、起翘、脱落、酥粉彩绘层的回位修复等。第六，治理效果对比，对修复前后的详细记录摄影。第七，跟踪观察档案记录。项目从模拟样品、文物本体小面积局部修复、整体实施的效果进行了历时十七年的全程跟踪、观察。

陕西省文物局对本项目给予了高度重视与支持。陕西省文物局鼓励、支持社会科研力量参与文物保护科学研究。2004年，陕西省文物局、陕西省档案馆、陕西师范大学联合共建了“陕西历史文化遗产保护科学研究中心”，吸引了相关教授与研究人员加盟，搭建了充满生机的历史文化遗产保护科研平台。2006年，获准建设“历史文化遗产保护教育部工程研究中心”。该项目的申请、立项、评审验收均由陕西省文物局引导。陕西省文物局局长赵荣多次赴工程现场检查并与项目负责人进行深入探讨，邀请项目负责人为全局职工做项目汇报。本书由陕西省文物局安排修复保护经费支持出版。

十七年来，《西汉彩绘兵马俑修复与保护》得到国家文物局科技专家组组长、中国文化遗产研究院院长王丹华先生，中国文化遗产研究院研究员黄克忠先生，南京博物院研究员奚三彩先生的悉心指导，他们为本书和项目付出了心血，在此敬谢！

课题组的全体人员都为本书的著者。胡道道教授主要负责显现加固机理与科学内涵的研究；邢惠萍、汪娟丽、曹明博士参与显现加固、回位修复材料研究与表征测试；王晓谋馆长负责修复效果跟踪观察与修复管理；单晓娟副研究馆员主持修复工程；陕西师范大学历史文化遗产保护教育部工程研究中心助理研究员李丽进行了照片处理与图文设计等工作；李玉虎负责项目总体设计、病害成因与机理、显现加固材料研究等。